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Comprehensive Study of the Crop Water Productivity in Bushehr Province, Iran

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ABSTRACT

Increasing population leads to intensification of water shortage problems in arid regions. Agriculture sector is the main user of water in Iran. Bushehr province with an arid and semiarid climate is located in the south of Iran. Improvement of water productivity (WP), the value or benefit derived from the use of water, is essential in the agriculture sector for achieving food security and sustainable development in the area. This study was carried out to investigate the agriculture water productivity of various crops in 161 fields with different irrigation systems. Results showed that the range of WPs in tomato, wheat, tobacco, watermelon, palm and lemon were 2.88-12.77 kg/m^3, 0.21-0.45 kg/m^3, 0.18-0.19 kg/m^3, 2.67-7.73 kg/m^3, 0.48-1.7 kg/m^3 and 1.40-1.97 kg/m^3, respectively. Use of localized irrigation systems has improved WP in most crops, especially in tomato and watermelon it has increased more than 4 times. In addition, results indicated that some crops, such as wheat, have a very low neat benefit and an economical water productivity (0-1.7 thousand Rial/m^3). Considering severe water shortage problems in the study area, promotion of irrigation systems and adopting the optimum crop patterns based on the WP should be considered.

Keywords

Bushehr, Irrigation Systems, Irrigation Efficiency, Water Productivity, Water use

1. Introduction

Iran is one of the countries with a high population growth. Based on UNESCO reports, by 2080, the population rate will be increased by about 2 to 2.99 times compared to 2000 (UNESCO, 2010). The agriculture sector must be able to produce food for this excessive population. About 90 percent of the agricultural production in Iran belongs to irrigated agriculture (ministry of agriculture, 2014), despite scarce water resources. The total renewable water in Iran is 130 billion cubic meters, more than 72 percent of which is used in agriculture, domestic and industry sectors (IWRMC, 2014). About 92 percent of Iran's water consumption (more than 85 billion cubic meters) is used in producing agricultural crops (IWRMC, 2014); therefore promotion of the agriculture water productivity is unavoidable. Improving water productivity in agriculture can reduce the pressure on the limited water resources and increase farmers' income, food security and society welfare. One of the most important factors in this case is irrigation management improvement. Technical and management solutions such as upgrading and rehabilitation of irrigation systems, adoption of new irrigation systems (Playan and Mateos, 2006; Rodrigues et al., 2010), application of deficit irrigation

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techniques (Rodrigues and Pereira, 2009), irrigation scheduling strategies (Pereira et al., 2009) and cropping pattern optimization (Vazifedoust et al., 2008) can be taken to improve WP in agriculture.

Zoebl (2002) described WP as a useful index for improvement of the water managem-ent strategies. Many studies have been conduct-ed to survey and analyze the agriculture water productivity (Playan and Mateos, 2006; Alia and Talukder, 2008; Rodrigues et al., 2010).

Water productivity in Sirsa district, India, was studied by Sing et al. (2006) and their results showed that there is a significant spatial variation in WP values. They mentioned a variable range of WP for each crop which indicated a considerable scope for improvements in WP. In a comprehensive review on crop water productivity, Zwart et al. (2004) mentioned that there are considerable opportunities for improving WP and increasing agricultural production with 20–40% less water resources. In their study, the high variability of WP has been associated to climate, irrigation water management and soil management. The most important conclusion was the fact that WP can be significantly improved if irrigation is reduced. This strategy is known as deficit irrigation (DI). Deficit irrigation, as a good strategy for improving WP, is suggested in many other studies (English, 1990; Ghinassi and Trucchi, 2001; Turner, 2004; Panda et al., 2003; Zhang et al., 2004; Ali et al., 2007). Geerts and Raes (2009) reviewed and summarized the advantages and disadvantages of deficit irrigation in improving WP. The results showed that DI is successful in increasing WP for various crops without causing severe yield reductions.

In addition, modern irrigation systems such as sprinkler and trickle systems increase WP through using less water to obtain the same yields (Kiymaz and Ertek, 2015). Ghadami et al. (2007) studied the effects of irrigation systems and plant density on the yield and water productivity. The results demonstrated that the tape irrigation system, without significant effects on the yields, would decrease 41 percent of the water usage and would increase 44 percent of the water productivity in comparison with the furrow irrigation system. In another study, Joulazadeh and Kamali (2001) reported that low pressure irrigation system (Hydroflume) increases the water usage efficiency to 70% or more.

Montazar and Kosari (2006) analyzed the crop water productivity in various regions of Iran to 2007. Their results showed that WP is variable in different crops as ranges of WP in wheat, barley, sugar beet, maize and cotton were 0.15-4 kg/m^3, 0.6-1.5 kg/m^3, 1.65-10.7 kg/m^3, 1.74-1.95 kg/m^3, and 0.17-1.35 kg/m^3, respectively. In addition, the results showed that irrigation system, irrigation scheduling and irrigation operation management play an important role in improving WP. Bushehr province is one of the most arid areas of Iran. This investigation was aimed to study the agriculture water productivity in this province. For this purpose, the levels of water use and crop yields of the main crops were studied in various districts.

2. Materials and Methods

2.1. Study area

The province of Bushehr is located in the southern area of Iran and in the north of Persian Gulf, between the northern latitudes of 27° 14' and 30° 16', and the eastern longitudes of 50° 06' and 52° 58'. The province area is 22,473 square kilometers that consists of 8 provincial towns and 22 districts. Annual precipitation of the province is 6056 million cubic meters. More than 70 percent of this precipitation is spent on evapotranspiration (Bushehr Regional Water Authority, 2010). In addition to the quantitative limits on water resources, the quality of water resources is also undesirable. Water shortage problem is the main restricting factor of sustainability in the study area.

Water restrictions have resulted in decrease of the cropped area. Although, off-season vegetable crops may lead to high income and value added in this sector. Date palm gardens have a great social and economic importance in the province. Summary of the agricultural crops data are presented in Table 1 (Agriculture Organization of Bushehr, 2012).

The total crop area is about 228493 hectare. More than 98 percent of the total production belongs to the irrigated agriculture (1265404 ton). Usually, the rainfed agriculture is not beneficial (except palm) and the rainfed crops are used as fodder. Palm, lemon, wheat, tobacco, tomato and watermelon have high economic and social importance in the area, and in this study, they have been considered for water productivity investigation. Based on the initial evaluation of the agriculture conditions in the province districts, wheat was studied in Dashti, Dashtestan and Bushehr, tobacco was studied in Tangestan and Dashti, tomato was studied in Dashti, Dayer and Kangan, watermelon was studied in Dashti and lemon and palm were studied in Tangestan, Dashtestan and Jam districts.

Table 1. Summary of the agricultural crops data in Bushehr province

Crop		Crop area (ha)			Production (ton)			Crop yield (kg/ha)	
		Irrigated area	Rainfed area	Total area	Irrigated area	Rainfed area	Total production	Irrigated	Rainfed
Wheat		17164	125544	142708	35084	7089	42173	2044	56
Barley		1374	15413	16787	2655.5	1256	3911.5	1933	81
Corn		425	0	425	2975	-	2975	7000	-
Potato		55	0	55	1025	-	1025	18636	-
Onions		698	0	698	16326	-	16326	23390	-
Tomato		16089	0	16089	732526	-	732526	45530	-
Eggplant		630	0	630	20504	-	20504	32546	-
Tobacco		2062	0	2062	2467	-	2467	1196	-
Alfalfa		510	0	510	8876	-	8876	17404	-
Maize		254	0	254	13195	-	13195	51949	-
Bean		43	0	43	68.5	-	68.5	1593	-
Watermelon		1445	0	1445	50240	-	50240	34768	-
Melon		1074	0	1074	27584.5	-	27584.5	25684	-
Cucumber		219	0	219	6238	-	6238	28484	-
Sesame		1145	0	1145	1225.3	-	1225.3	1070	-
Canola		562	0	562	165.8	-	165.8	295	-
Gardens	Palm	32030	2887	34917	162263.5	10479	172742.5	5066	3630
	Lemon	3344	0	3344	39999.6	0	39999.6	11956	0
Other		8822	48	8870	141985.3	214	142199.3	-	-
Total		84601	143892	228493	1265404	19038	1284442	-	-

2.2. Characteristics of the studied fields

Field studies were conducted between 2013 and 2014. Table 2 shows the number of studied fields in each district. The average area of the studied fields was 7.1±5.56 hectare (maximum 50 ha and minimum 1 ha). Among the studied farmers, 16.15% were illiterate, 56% had primary education and just 3% enjoyed academic education.

Table 2. Studied fields in each district of Bushehr province

District	Frequency
Bushehr	9
Kangan	11
Dayer	13
Tangestan	23
Dashtestan	31
Dashti	47
Jam	27
Total	161

The relevant irrigation systems in Bushehr province are flood irrigation, tape irrigation and trickle irrigation systems. Sprinkler irrigation is not applicable due to water salinity in this province. Mean water salinity in the districts is between 1.8 dS/m in Jam to 7.6 dS/m in Dayer and Kangan districts (Bushehr Regional Water Authority, 2010). More than 70 percent of the water demand in the agriculture sector belongs to date palm trees due to the lack of modern irrigation systems and high water requirement of palm. In this study, 40.3% of the studied systems were flood irrigation systems and 59.7% of them were localized irrigation systems (34.16% tape and 25.47% Drip).

2.3. Irrigation water measurement

Irrigation water measurement is necessary in determining WP. In this study, in pressurized water distribution systems, flow meter and in open canals, velocity meter were applied for this purpose. In the canal case, water discharge can be computed using the continuity equation:

$$Q = AV \qquad (1)$$

where Q is the water discharge, A is the flow area and V is the water velocity, which can be measured with the velocity meter.

Irrigation application efficiency was measured by inflow, outflow and infiltration (advance and recession curve) data in the surface irrigation (fig. 1) and the volumetric method in the localized irrigation.

2.4. Water productivity

Water productivity is defined as the crop yield or the crop production benefit per cubic meter of water. WP may be measured by a series of indices that describe its various aspects, e. g., physical and economic WP, irrigation WP, rainwater productivity, and ET WP. Individual indices serve for various purposes (Cai et al., 2011). ET and irrigation water productivity can be defined as follows (Kijne et al., 2003):

$$WP_{ET} = \frac{Y\,(kg\ ha^{-1})}{ET\,(m^{3}\ ha^{-1})} \qquad (2)$$

Fig. 1. Measurement of the required data for calculating application efficiency in surface irrigation (a tobacco field)

$$WP_I = \frac{Y\,(kg\ ha^{-1})}{I_g\,(m^3\ ha^{-1})} = \frac{Y\,(kg\ ha^{-1})}{\frac{I_n\,(m^3\ ha^{-1})}{E_a\,(ratio)}} \quad (3)$$

where Y is crop yield (Kg/ha), ET is evapotranspiration in the growth season (m3/ha), I is seasonal irrigation (m^3/ha), WP_{ET} is evapotranspiration water productivity, Ea is irrigation efficiency, I_n is net irrigation, I_g is gross irrigation and WP_I is irrigation water productivity.

From the irrigation point of view, Eq. (3) is more applicable and useful in evaluation of the effect of irrigation management strategies on WP (Van Halsema and Vincent, 2012). On the other hand, economic WP (WP_{eco}) may be expressed as (Alia and Talukder, 2008):

$$WP_{eco} = \frac{Total\ monetary\ value\ (\$)}{Water\ applied\ to\ the\ field\ (m^3\ ha^{-1})} \quad (4)$$

If the effectiveness of the water use is described for a single crop, Eqs. (2) or (3) will be good indicators. If the regions are compared, or the effectiveness of water use in multiple cultures or under limiting water conditions (without limiting land) (Ali et al., 2007) is studied, Eq. (4) is more appropriate.

3. Results and Discussion

3.1. Physical Productivity

Figures 2, 3 and 4 show crop yield, water uses and physical water productivity for the studied crops, respectively. Based on these figures, the results indicated that WP of tomato and watermelon can be increased between 300 to 500% with the change of irrigation system to tape irrigation system (Fig. 4). This improvement is because of a decrease in the water use, approximately 200% with respect to the flood irrigation (Fig. 3), and the yield increase (Fig. 2) due to better cropping and fertigation in the tape irrigation system (approximately 200% with respect to the flood irrigation). In recent years, application of the tap irrigation has been common for vegetables and row crops that may lead to an increase of the agriculture production.

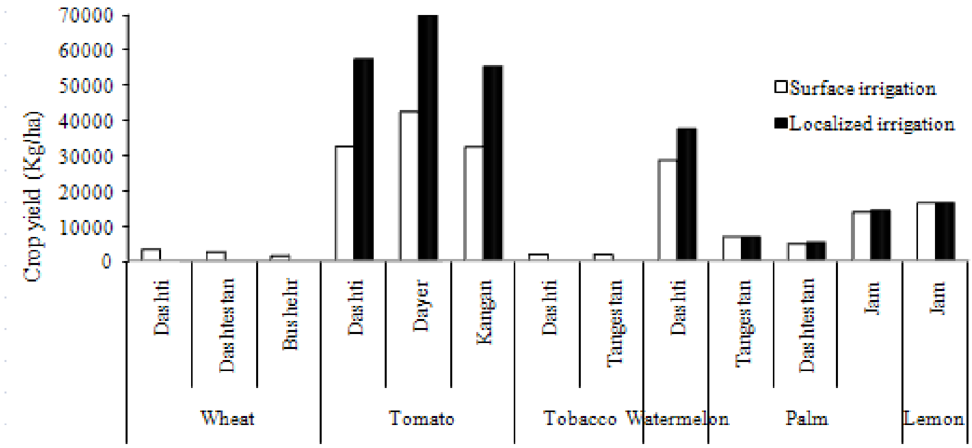

Fig. 2. Average crop yield in different districts under various irrigation systems

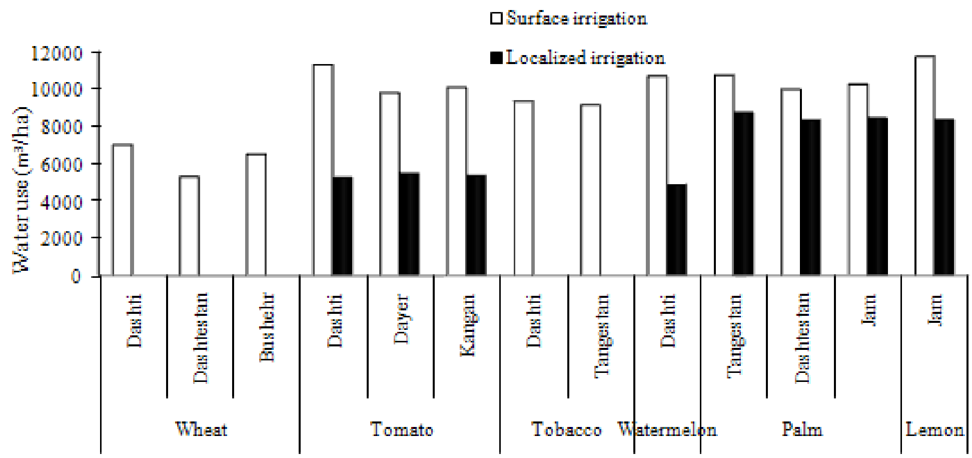

Fig. 3. Average crop water use in different districts under various irrigation systems

Wheat WP in previous studies in Helle basin (the nearest basin to the study area) has been reported about 0.6 kg/m^3 by Abgeer (2010) that is more than the obtained results in the present study. This is due to low wheat yield in Bushehr province because of various agro-climatological factors. In addition, tomato WP in this study for the surface irrigation was obtained 4.6 kg/m^3 which is in agreement with Abgeer (2010) results.

This study results indicated that tobacco WP in Tangestan is about 0.18 kg/m^3 (Fig. 4) that agrees with the results of Mokhtari et al. (2008) on tobacco in Fars province (in north of Bushehr province and near Tangestan). In addition, watermelon WP in Bushehr is higher than watermelon WP in Fars province (2 kg/m^3 based on Mokhtari et al., 2008). Rashidi and Gholami (2008) reported WP of tomato as 2.58-11.88 kg/m^3 that it is almost equal to our results (2.9–12.8 kg/m^3).

Palm WP was 0.44-1.35 kg/m^3 in flood irrigation and 0.6-1.7 kg/m^3 in drip irrigation; this result is higher than other study results (Mokhtari et al., 2008) because of higher yield production and higher adaptability. Water productivity in most of the crops, probably because of high water salinity (7.6 dS/m), was very low in Tangestan district (Fig. 4). In the same study, Al-Amoud et al. (2000) reported that the trickle irrigation system compared with the surface irrigation increases yield and water use efficiency in palm trees.

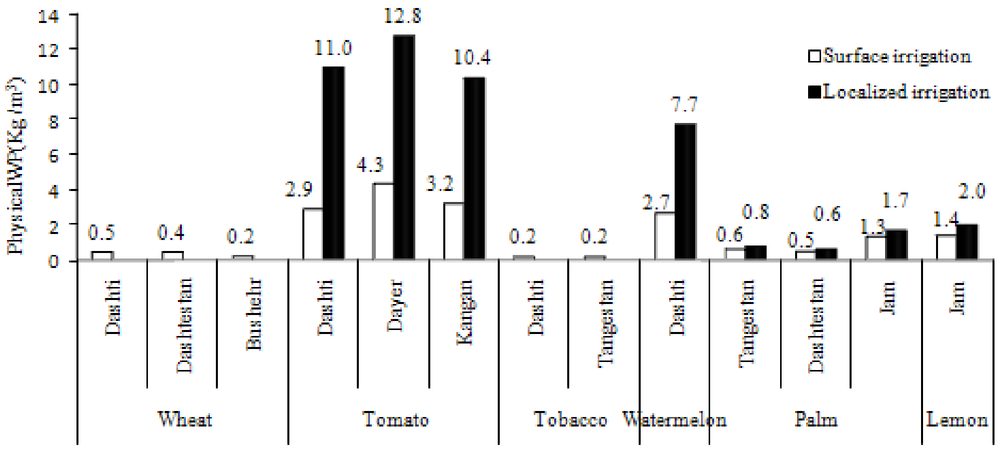

Fig. 4. Crop water productivity in the studied regions of Bushehr province

Investigation in the agriculture water productivity is one of the main techniques in optimizing agriculture production inputs. Water, as an important input in the arid areas, should be considered from the physical and economical respects. The study showed that the promotion of the irrigation systems to modern irrigation systems was more common in the case of groundwater use. In these cases, farmers are motivated more to save water and the modern irrigation system is more applicable.

In the flood irrigation systems, possibility of the precise irrigation management is very low. Traditional flood irrigation systems in the Bushehr area are associated with more water losses and more irrigation time that usually leads to a delay in the irrigation and yield and WP reduction. Farmers distinguished that the traditional systems are not efficient systems and recognized that these systems have high water losses and operating problems, but they are more confident about the crop requirement supply in these systems compared with the modern irrigation systems. Results of this study showed that WP in the tape irrigation systems are more than WP in the flood irrigation system. Water salinity is one of the main challenges of irrigation in Bushehr province. The negative effect of salinity stresses the crop growth and indicates that the yield can be decreased with the trickle irrigation system adoption due to smaller irrigation intervals. The irrigation efficiency in some fields that are irrigated with the tape system was low. Poor operation of trickle irrigation systems was the main reason of low efficiency in these systems. Water treatment process in these systems was very weak. Despite the numerous limitations, the agriculture sector in Bushehr has specific advantages including the empirical knowledge of tomato cultivation. Documentation of the agricultural practices in this area can be useful in promotion of the agricultural production.

3.2. Economical Productivity

Figure 5 shows the crop net benefit in different districts under various irrigation systems. The crop net benefit was calculated by difference gross revenues from total costs. Based on this figure, the tape irrigation system for the crops such as tomato and watermelon would lead to an increase in the net benefit, but for palm and lemon it would lead to a decrease. Regardless of the irrigation system, tomato and lemon net benefits were significantly different from other crops. In this regard, about 50% of the crop pattern in the province was allocated to tomato, vegetable and row crops.

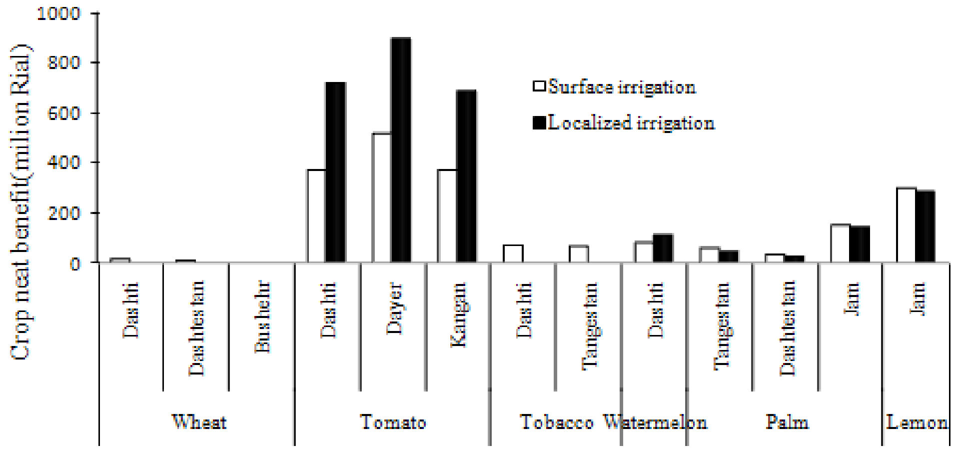

Fig. 5. Crop net benefit in different districts under various irrigation systems

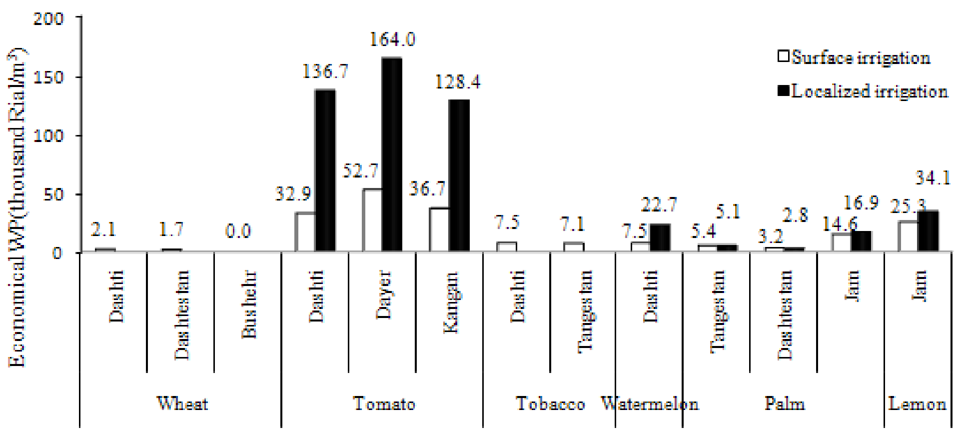

Fig. 6. Crop economical productivity in different districts under various irrigation systems

Figure 6 shows the crop economical productivity in different districts under various irrigation systems. Results indicated that the localized irrigation system in most of the cases (except palm) would lead to an increase in the economical water productivity. One of the reasons of low economical water productivity of palm is application of the drip irrigation system of the middle-aged trees. The localized irrigation system increased the economical productivity of tomatoes to 320%, tobacco to 130% and lemon to 34% (Fig. 6). In addition, results indicated that wheat water economical productivity in Bushehr province is very low because of the unsuitable calamite conditions and low knowledge of farmers. Therefore, the wheat production in the Bushehr district is uneconomic.

4. Conclusions

Increasing population leads to intensification of the water shortage problems in the arid regions. Agriculture sector is the main user of water in Iran. Bushehr province with an arid and semiarid climate is located in the south of Iran. Improvement of WP, the value or benefit derived from the use of water in the agriculture sector, is essential for achieving food security and sustainable development of the area. The main objective of this study was to evaluate WP and present solutions to improve WP in the Bushehr province. Results of this study showed that WP, because of the application of inefficient irrigation systems and use of unsuitable crop pattern, was very low in Bushehr province. Because of the high water efficiency and low water use, the localized irrigation systems in most cases led to an increase in the physical and economical water productivity. Among crops studied, tomato and wheat had the highest (2.88–12.77kg/m^3) and lowest (0.21-0.45 kg/m^3) WP, respectively. Therefore, the crop pattern and irrigation systems play an important role in WP value.

Considering severe water shortage problems in the study area, promotion of irrigation systems and utilization of the optimum crop patterns based on the WP should be developed or adopted.

In summary, based on the obtained results and field evaluations, the strategies of water productivity promotion in the region can be presented as:

1) Management strategies:
- Modifying and redesigning the crop patterns (decreasing the crop areas with low WP, such as wheat).
- Application of water reusing systems as salinity tolerant crops located in the downstream of the cycle.
- Emphasis on the virtual water trade with the neighboring provinces.

2) Technical strategies:
- Modifying the traditional irrigation systems for palm (replacement of the flood irrigation with the furrow or basin irrigation systems).
- Modifying the tape irrigation system for tomato and vegetable crops (use of mulches and application of subsurface irrigation systems).

3) Social and organizational strategies:
- Educating the farmers for better use of water and application of the modern irrigation systems.
- Development of the greenhouse culture (suitable climate conditions in Bushehr province permit constriction of inexpensive greenhouses).

4) Implementation strategies
- Development of the pressurized irrigation systems, especially drip and tape irrigation systems.
- Application of persuasive policies for crop pattern selection based on the economical water productivity.

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