Journal of the Saudi Society of Agricultural Sciences (2015) 14, 1–10

King Saud University

Journal of the Saudi Society of Agricultural Sciences

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REVIEW ARTICLE

Investigation of surface, sprinkler and drip irrigation methods based on the parametric evaluation approach in Jaizan Plain

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Received 25 September 2013; accepted 10 November 2013
Available online 15 November 2013

KEYWORDS

Surface irrigation;
Sprinkler irrigation;
Drip irrigation;
Land suitability evaluation;
Parametric method;
Soil series

Abstract The main objective of this research is to compare different irrigation methods based upon a parametric evaluation system in an area of 15,000 ha in the Jaizan Plain, Iran. Once the soil properties were analyzed and evaluated, suitability maps were generated for surface, sprinkler and drip irrigation methods using Geographic Information System (GIS). The obtained results showed that for 5275 ha (35.17%) of the study area surface irrigation method was highly recommended; whereas for 7500 ha (50%) of the study area a sprinkler irrigation method would provide to be extremely efficient and suitable; moreover, it was found that 7325 ha (48.83%) of the study area was highly suitable for drip irrigation methods. The results demonstrated that by applying sprinkler irrigation instead of surface and drip irrigation methods, the arability of 13 875 ha (92.5%) in the Jaizan Plain will improve. The comparison of the different types of irrigation techniques revealed that the sprinkler and drip irrigations methods were more effective and efficient than the surface irrigation methods for improving land productivity. It is of note however that the main limiting factor in using surface irrigation methods in this area was drainage and the main limiting factor in using sprinkler irrigation methods in this area were gravel soil texture, drainage and calcium carbonate and the main limiting factors in using drip irrigation methods were the drainage and calcium carbonate.

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Peer review under responsibility of King Saud University.

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http://dx.doi.org/10.1016/j.jssas.2013.11.001

Contents

Introduction

Food security and stability in the world greatly depends on the management of natural resources. Due to the depletion of water resources and an increase in population, the extent of irrigated area per capita is declining and irrigated lands now produce 40% of the food supply (Hargreaves and Mekley, 1998). Consequently, available water resources will not be able to meet various demands in the near future and this will inevitably result into the seeking of newer lands for irrigation in order to achieve sustainable global food security. Land suitability, by definition, is the natural capability of a given land to support a defined use. The process of land suitability classification is the appraisal and grouping of specific areas of land in terms of their suitability for a defined use.

According to FAO methodology (1976) land suitability is strongly related to ''land qualities'' including erosion resistance, water availability, and flood hazards which are in themselves immeasurable qualities. Since these qualities are derived from ''land characteristics'', such as slope angle and length, rainfall and soil texture which are measurable or estimable, it is advantageous to use the latter indicators in the land suitability studies, and then use the land parameters for determining the land suitability for irrigation purposes. Sys et al. (1991) suggested a parametric evaluation system for irrigation methods which was primarily based upon physical and chemical soil properties (Dengiz, 2006; Liu et al., 2007; Albaji, 2010) .In their proposed system, the factors affecting soil suitability for irrigation purposes can be subdivided into four groups:

- Physical properties determining the soil–water relationship in the soil such as permeability and available water content;
- Chemical properties interfering with the salinity/alkalinity status such as soluble salts and exchangeable Na;
- Drainage properties;
- Environmental factors such as slope.

Briza et al. (2001) applied a parametric system (Sys et al., 1991) to evaluate land suitability for both surface and drip irrigations in the Ben Slimane Province, Morocco, while no highly suitable areas were found in the studied area. The largest part of the agricultural areas was classified as marginally suitable, the most limiting factors being physical parameters such as slope, soil calcium carbonate, and sandy soil texture and soil depth.

Bazzani and Incerti (2002) also provided a land suitability evaluation for surface and drip irrigation systems in the province of Larche, Morocco, by using parametric evaluation systems. The results showed a large difference between applying the two different evaluations. The area not suitable for surface irrigation was 29.22% of total surface and 9% with the drip irrigation while the suitable area was 19% versus 70%. Moreover, high suitability was extended on a surface of 3.29% in the former case and it became 38.96% in the latter. The main limiting factors were physical limitations such as the slope and sandy soil texture.

Bienvenue et al. (2003) evaluated the land suitability for surface (gravity) and drip (localized) irrigation in the Thies, Senegal, by using the parametric evaluation systems. Regarding surface irrigation, there was no area classified as highly suitable (S_1). Only 20.24% of the study area proved suitable (S_2, 7.73%) or slightly suitable (S_3, 12.51%). Most of the study area (57.66%) was classified as unsuitable (N_2). The limiting factor to this kind of land use was mainly the soil drainage status and texture that was mostly sandy while surface irrigation generally requires heavier soils. For drip (localized) irrigation, a good portion (45.25%) of the area was suitable (S_2) while 25.03% was classified as highly suitable (S_1) and only a small portion was relatively suitable (N_1, 5.83%) or unsuitable (N_2, 5.83%). In the latter cases, the handicap was largely due to the shallow soil depth and incompatible texture as a result of a large amount of coarse gravel and/or poor drainage.

Mbodj et al. (2004) performed a land suitability evaluation for two types of irrigation i.e., surface irrigation and drip irrigation, in the Tunisian Oued Rmel Catchment using the suggested parametric evaluation. According to the results, the drip irrigation suitability gave more irrigable areas compared to the surface irrigation practice due to the topographic (slope), soil (depth and texture) and drainage limitations encountered within the surface irrigation suitability evaluation.

Barberis and Minelli (2005) provided land suitability classification for both surface and drip irrigation methods in Shouyang county, Shanxi province, China where the study was carried out by a modified parametric system. The results indicated that due to the unusual morphology, the area suitability for the surface irrigation (34%) is smaller than the surface used for the drip irrigation (62%). The most limiting factors were physical parameters including slope and soil depth.

Dengiz (2006) also compared different irrigation methods including surface and drip irrigation in the pilot fields of the central research institute, lkizce research farm located in southern Ankara. He concluded that the drip irrigation method increased the land suitability by 38% compared to the surface irrigation method. The most important limiting factors for surface irrigation in study area were soil salinity, drainage and soil texture, respectively whereas, the major limiting factors for drip or localized irrigation were soil salinity and drainage.

Liu et al. (2007) evaluated the land suitability for surface and drip irrigation in the Danling County, Sichuan province,

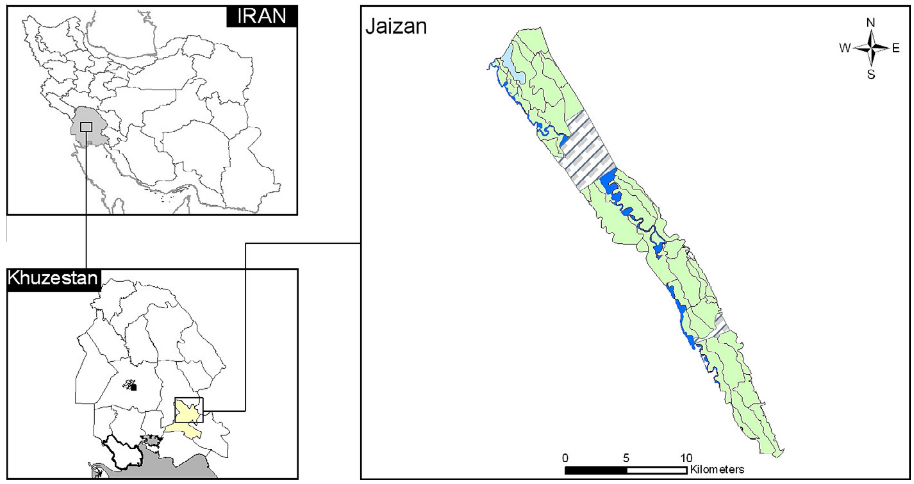

Figure 1 Location map of the study area.

Table 1 Mean Air Temperature, Relative humidity and Total Monthly Rainfall and Evaporation (1987–2010) at Ramhormoz.

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Temperature (°C)	12.7	14.7	18.7	25.2	31.8	36.1	38.2	37.8	34	28.6	20.6	14.9	26.1
Relative humidity (%)	70.8	58.4	51.2	37.6	22	17.6	19.5	21.5	21.5	29.1	45.3	67	38.4
													Total
Rainfall (mm)	99.1	55.7	36.8	19.2	2.2	0	0	0	0	6.1	22.2	74.5	315.9
Evaporation (mm)	54.7	79.5	129.2	203.1	353.4	456.1	475.1	444.5	351.2	247.6	120.2	63.8	2978.4

China, using a Sys's parametric evaluation system. For surface irrigation the most suitable areas (S_1) represented about 24% of Danling County, 33% was moderately suitable (S_2), 9% was classified as marginally suitable (S_3), 7% of the area was founded currently not suitable (N_1) and 25% was very unsuitable for surface irrigation due to their high slope gradient. Drip irrigation was everywhere more suitable than surface irrigation due to the minor environmental impact that it caused. Areas highly suitable for this practice covered 38% of Danling County; about 10% was marginally suitable (the steep dip slope and the structural rolling rises of the Jurassic period). The steeper zones of the study area (23%) were either approximately or totally unsuitable for such a practice.

Albaji et al. (2009) compared the suitability of land for surface and drip irrigation methods according to a parametric evaluation system in the plains west of the city of Shush, in southwest Iran. The results indicated that a larger amount of the land (30,100 ha – 71.8%) can be classified as more suitable for drip irrigation than surface irrigation.

The main objective of this research is to evaluate and compare land suitability for surface, sprinkler and drip irrigation methods based on the parametric evaluation systems for the Jaizan Plain, in the Khuzestan Province, Iran.

Materials and methods

The present study was conducted in an area about 15,000 hectares in the Jaizan Plain, in the Khuzestan Province, located in the southwest of Iran during 2010–2011(Fig. 1). The study area is located 40 km West of the city of Ramhormoz, 30°45′–30°58′ N and 49°45′–49°56′ E. The Average annual temperature and precipitation for the period of 1987–2010 were 26.1 °C and 316 mm, respectively. Also, the annual evaporation of the area is 2978 mm (Table 1) (KWPA, 2011). The Marun River supplies the bulk of the water demands of the region. The application of irrigated agriculture has been common in the study area. Currently, the irrigation systems used by farmlands in the region are furrow irrigation, basin irrigation and border irrigation schemes. Over much of the Jaizan Plain, the use of surface irrigation systems has been applied specifically for field crops to meet the water demand of both summer and winter crops. The major irrigated broad-acre crops grown in this area are wheat, barley, and maize, in addition to fruits, melons, watermelons and vegetables such as tomatoes and cucumbers. There are very few instances of sprinkler and drip irrigation on large area farms in the Jaizan Plain.

The area is composed of two distinct physiographic features i.e. Alluvio-Colluvial Fans and Piedmont Alluvial Plains, of which the Piedmont Alluvial Plains physiographic unit is the dominating feature. The semi-detailed soil survey report of the Jaizan Plain (KWPA, 2010) was used in order to determine the soil characteristics. Also, nine soil series and forty-three series phases were derived from the semi-detailed soil study of the area. The soil series are shown in Fig. 1 as the basis for further land evaluation practice. The soils of the area are of Aridisols and Entisols orders. Also, the soil moisture regime is Ustic while the soil temperature regime is Hyperthermic (KWPA, 2010).

The land evaluation was determined based upon topography and soil characteristics of the region. The topographic characteristics included slope and soil properties such as soil texture, depth, salinity, drainage and calcium carbonate content were taken into account. Soil properties such as cation exchange capacity (CEC), percentage of basic saturation (PBC), organic mater (OM) and pH were considered in terms of soil fertility. Sys et al. (1991) suggested that soil characteristics such as OM and PBS do not require any evaluation in arid regions whereas clay CEC rate usually exceeds the plant requirement without further limitation, thus, fertility properties can be excluded from land evaluation if it is done for the purpose of irrigation.

According to the particular semi-detailed studies of the region, samples were taken from each soil series profiles and laboratory analysis were carried out based on the conventional methods of the USDA (Page et al., 1992), and the following properties were measured by due methods: Electrical Conductivity (EC) in dS m^{-1} was calculated at 25 °C on soil water (1:5) extract; the water soluble cations were calculated using the spectrophotometer method, the Electrical Conductivity corresponds to the salinity, the soil texture was determined using the Gravimetric method (pipette). The proportional distribution of coarse sand (2.0–0.2 mm), medium sand (0.2–0.1 mm), fine sand (0.1–0.05 mm), coarse silt (0.05–0.02 mm), fine silt (0.02–0.002 mm), and clay (< 0.002 mm) was calculated and successively the soil texture was classified using the USDA Soil Textural Classification System. Lime (CaCO3) in % is expressed as calcium carbonate equivalent using gas volumetric method (Page et al., 1992).

The groups of soils that had similar properties and were located in a same physiographic unit were categorized as soil series and were taxonomied to form a soil family as per the Keys to Soil Taxonomy, (2010). Ultimately, nine soil series were selected for the surface, sprinkler and drip irrigation land suitability.

In order to obtain the average soil texture, salinity and $CaCo_3$ for the upper 150 cm of soil surface, the profile was subdivided into 6 equal sections and weighting factors of 2, 1.5, 1, 0.75, 0.50 and 0.25 were used for each section, respectively (Sys et al., 1991).

For the evaluation of land suitability for surface, sprinkler and drip irrigation, the parametric evaluation system was used (Sys et al., 1991). This method is based on morphology, physical and chemical properties of soil. In parametric method, the land is evaluated according to numerical indexes. In this classification system, firstly a degree, whose rate is from 0 to 100, is given to any land characteristic through comparing them with the tables of soil requirements. The specified degrees are used in order to measure the land index that is a multiplicative index that combines ratings assigned to soil map units and other physical conditions that affect the land use (Olsen, 1981).

The Chemical and physical soil proprieties are determined in the soil laboratory of Khuzestan Water and Power Authority using different kinds of analysis processing. The texture classification is based on the USDA triangle. This approach allows a calculation of a suitability index for irrigation considering some factors influencing the soil suitability. These factors are (Sys et al., 1991):

- Soil texture: rated taking in account the permeability and available water content, and calculated, as weighted average, for the upper 100 cm.
- Soil depth: rated with regard to the thickness and the characteristic of the soil layers (horizons).

Table 2 Rating of Textural Classes for Irrigation.

Tex*	Rating for surface irrigation					Rating for sprinkler irrigation					Rating for drip irrigation				
	Fine gravel (%)			Coarse gravel (%)		Fine gravel (%)			Coarse gravel (%)		Fine gravel (%)			Coarse gravel (%)	
	< 15	15–40	40–75	15–40	40–75	< 15	15–40	40–75	15–40	40–75	< 15	15–40	40–75	15–40	40–75
CL**	100	90	80	80	50	100	90	80	80	50	100	90	80	80	50
SiL	100	90	80	80	50	100	90	80	80	50	100	90	80	80	50
SCL	95	85	75	75	45	95	85	75	75	45	95	85	75	75	45
L	90	80	70	70	45	90	80	70	70	45	90	80	70	70	45
SiL	90	80	70	70	45	90	80	70	70	45	90	80	70	70	45
Si	90	80	70	70	45	90	80	70	70	45	90	80	70	70	45
SiC	85	95	80	80	40	85	95	80	80	40	85	95	80	80	40
C	85	95	80	80	40	85	95	80	80	40	85	95	80	80	40
SC	80	90	75	75	35	95	90	80	75	35	95	90	85	80	35
SL	75	65	60	60	35	90	75	70	70	35	95	85	80	75	35
LS	55	50	45	45	25	70	65	50	55	30	85	75	55	60	35
S	30	25	25	25	25	50	45	40	30	30	70	65	50	35	35

* Tex: Textural Classes.
** CL: Clay Loam SiL: Silty Loam SCL: Sandy Clay Loam L: Loam SiL: Silty Loam Si: Silty SiC: Silty Clay C: Clay SC: Sandy Clay SL: Sandy Loam LS: Loamy Sand S: Sandy.

Table 3 Rating of Soil Depth for Irrigation.

Soil depth (cm)	Rating for surface irrigation	Rating for sprinkler irrigation	Rating for drip irrigation
< 20	25	30	35
20–50	60	65	70
50–80	80	85	90
80–100	90	95	100
> 100	100	100	100

Table 4 Rating of $CaCo_3$ for irrigation.

$CaCo_3$ (%)	Rating for surface irrigation	Rating for sprinkler irrigation	Rating for drip irrigation
< 0.3	90	90	90
0.3–10	95	95	95
10–25	100	100	95
25–50	90	90	80
> 50	80	80	70

– Calcium carbonate content: influencing the relationship between soil and water, and the availability of nutrient supply for plant. It is rated with regard to the CaCO3 content effect on soil profile.
– Salinity: rated on the base of the electrical conductivity of soil solution.
– Drainage: a limiting factor when it is imperfect or weak. The rating for drainage is related to texture.
– Slope: estimated considering the difference between terraced and non-terraced slopes.

These factors (including soil texture, soil depth, calcium carbonates status, electrical conductivity of soil solution, drainage properties and slope) were also considered and values were assigned to each as per the related tables (Tables 2–7) [Sys et al. (1991) for surface and drip irrigation & Albaji (2010) for sprinkler irrigation], thus, the capability index for irrigation (Ci) was developed as shown in the equation below:

$$Ci = A \times \frac{B}{100} \times \frac{C}{100} \times \frac{D}{100} \times \frac{E}{100} \times \frac{F}{100}$$

where A, B, C, D, E, and F are soil texture rating, soil depth rating, calcium carbonate content rating, electrical conductivity rating, drainage rating and slope rating, respectively.

In Table 8 the ranges of capability index and the corresponding suitability classes are shown.

In order to develop land suitability maps for different irrigation methods, a semi-detailed soil map (Fig. 2) prepared by Albaji was used, and all the data for soil characteristics were analyzed and incorporated in the map using ArcGIS 9.2 software.

The digital soil map base preparation was the first step toward the presentation of a GIS module for land suitability maps for different irrigation systems. The soil map was then digitized and a database prepared. A total of nine different polygons or land mapping units (LMU) were determined in

Table 5 Rating of salinity for irrigation.

EC (ds. m^{-1})	Rating for surface irrigation		Rating for sprinkler irrigation		Rating for drip irrigation	
	*C, SiC, SiCL, S, SC Textures	Other Textures	C, SiC, SiCL, S, SC Textures	Other Textures	C, SiC, SiCL, S, SC Textures	Other Textures
< 4	100	100	100	100	100	100
4–8	90	95	95	95	95	95
8–16	80	50	85	50	85	50
16–30	70	30	75	35	75	35
> 30	60	20	65	25	65	25

* C: Clay SiC: Silty Clay SiCL: Silty Clay Loam S: Sand SC: Sandy Clay.

Table 6 Rating of Drainage Classes for Irrigation.

Drainage classes	Rating for surface irrigation		Rating for sprinkler irrigation		Rating for drip irrigation	
	*C, SiC, SiCL, S, SC Textures	Other textures	C, SiC, SiCL, S, SC textures	Other textures	C, SiC, SiCL, S, SC textures	Other textures
Well drained	100	100	100	100	100	100
Moderately drained	80	90	90	95	100	100
Imperfectly drained	70	80	75	85	80	90
Poorly drained	60	65	65	70	70	80
Very poorly drained	40	65	45	65	50	65
Drainage status not known	70	80	70	80	70	80

* C: Clay SiC: Silty Clay SiCL: Silty Clay Loam S: Sand SC: Sandy Clay.

Table 7 Rating of slope for irrigation.

Slope Classes (%)	Rating for surface irrigation		Rating for sprinkler irrigation		Rating for drip irrigation	
	Non-terraced	Terraced	Non-terraced	Terraced	Non-terraced	terraced
0–1	100	100	100	100	100	100
1–3	95	95	100	100	100	100
3–5	90	95	95	100	100	100
5–8	80	90	85	95	90	100
8–16	70	80	75	85	80	90
16–30	50	65	55	70	60	75
> 30	30	45	35	50	40	55

Table 8 Suitability classes for the irrigation capability indices (Ci) classes.

Capability index	Definition	Symbol
> 80	Highly suitable	S_1
60–80	Moderately suitable	S_2
45–59	Marginally suitable	S_3
30–44	Currently not suitable	N_1
< 29	Permanently not suitable	N_2

the base map. Soil characteristics were also given for each LMU. These values were used to generate the land suitability maps for surface, sprinkler and drip irrigation systems using Geographic Information Systems.

Results and discussion

As shown in Tables 9 and 10 for surface irrigation, the soil series coded 3 and 8 (5275 ha – 35.17%) were highly suitable (S_1); only soil series coded 4 (2225 ha – 14.83%) were classified as moderately suitable (S_2), soil series coded 2 and 9 (4500 ha – the main limiting factor in using surface irrigation methods in this area was drainage and the main limiting factor in using sprinkler irrigation methods in this area were gravel soil texture, drainage and calcium carbonate and the main limiting factors in using drip irrigation methods were the drainage and calcium carbonate.

29.99% were found to be marginally suitable (S_3). Soil series coded 1, 5 and 6 (1875 ha – 12.51%) were classified as currently not-suitable (N_1) and only soil series coded 7 (400 ha – 2.67%) were classified as permanently not-suitable (N_2) for any surface irrigation practices.

The analysis of the suitability irrigation maps for surface irrigation (Fig. 3) indicates that the largest portion of the cultivated area in this plain (located in the center and north) is deemed as being highly suitable land due to deep soil, good drainage, texture, salinity and proper slope of the area. The moderately suitable area is located in the north of this area due to drainage limitation. Other factors such as depth, salinity and alkalinity have no influence on the suitability of the area whatsoever. The map also indicates that some part of the cultivated area in this plain was evaluated as marginally suitable because of the severe drainage limitation. The current non-suitable lands and permanently non-suitable land can be observed only in the north and south of the plain because of physical limitations especially gravelly soil texture and drainage limitation. For almost the total study area elements such as soil depth, salinity, and CaCO3 were not considered as limiting factors.

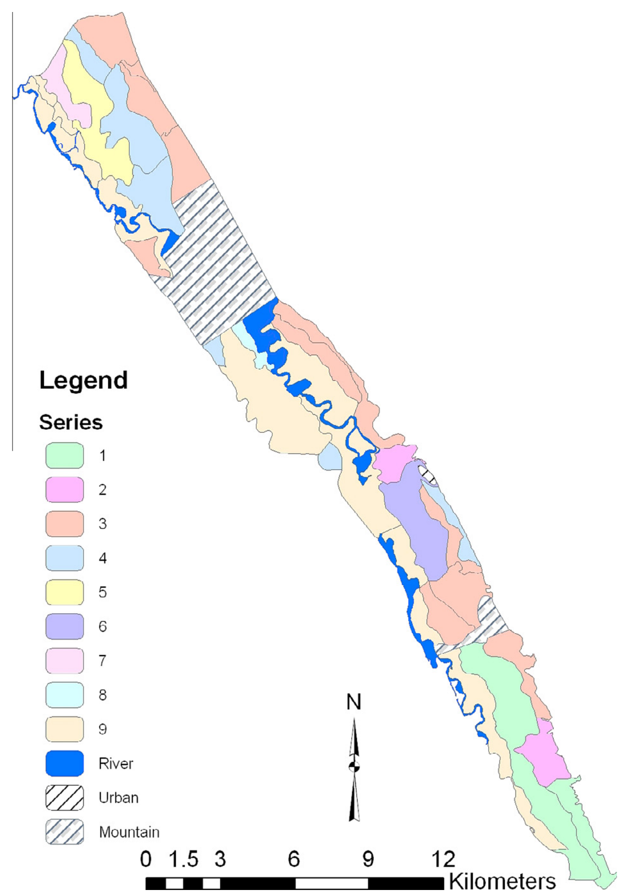

Figure 2 Soil map of the study area.

In order to verify the possible effects of different management practices, the land suitability for sprinkler and drip irrigation was evaluated (Tables 9 and 10).

For sprinkler irrigation, soil series coded 3, 4 and 8 (7500 ha – 50%) were highly suitable (S_1) while soil series coded 2 and 9 (4500 ha – 29.99%) were classified as moderately suitable (S_2). Further, soil series coded 1, 5 and 6 (1875 ha – 12.51%) were found to be marginally suitable (S_3) and only soil series coded 7 (400 ha – 2.67%) were classified as permanently not-suitable (N_2) for sprinkler irrigation.

Table 9 Ci values and suitability classes of surface, sprinkler and drip irrigation for each soil series s.

Codes of soil series	Surface irrigation		Sprinkler irrigation		Drip irrigation	
	Ci	Suitability classes	Ci	Suitability classes	Ci	Suitability classes
1	42.12	N_{1S}[a]	46.8	S_3 s[b]	44.1	N_1 s[c]
2	50.7	S_3 s	60	S_2 s	59.5	S_3 s
3	87.75	S_1	90	S_1	80	S_1
4	70.2	S_2 sw	81	S_1	80	S_1
5	44.75	N_1 sw	49.72	S_3 sw	47.6	S_3 sw
6	44.75	N_1 sw	49.72	S_3 sw	47.6	S_3 sw
7	19.96	N_2 snw	22.05	N_2 snw	22.4	N_2 snw
8	83.36	S_1	85.5	S_1	76	S_2 s
9	58.5	S_3 s	72	S_2 s	66.5	S_2 s

[a] Limiting factors for surface irrigation:w: (drainage).
[b] Limiting factors for sprinkler irrigation: s: (calcium carbonate & gravel soil texture) and w: (drainage).
[c] Limiting factors for drip irrigation: s: (calcium carbonate) and w: (drainage).

Table 10 Distribution of surface, sprinkler and drip irrigation suitability.

Suitability	Surface irrigation			Sprinkler irrigation			Drip irrigation		
	Soil series	Area (ha)	Ratio (%)	Soil series	Area (ha)	Ratio (%)	Soil series	Area (ha)	Ratio (%)
S_1	3, 8	5275	35.17	3, 4, 8	7500	50	3, 4	7325	48.83
S_2	4	2225	14.83	2, 9	4500	29.99	8, 9	3800	25.33
S_3	2, 9	4500	29.99	1, 5, 6	1875	12.51	2, 5, 6	2325	15.51
N_1	1, 5, 6	1875	12.51	–	–	–	1	425	2.83
N_2	7	400	2.67	7	400	2.67	7	400	2.67
Mis land[a]		725	4.83		725	4.83		725	4.83
Total		15,000	100		15,000	100		15,000	100

[a] Miscellaneous land: (hill, sand dune and river bed).

Regarding sprinkler irrigation, (Fig. 4) the highly suitable area can be observed in the largest part of the cultivated zone in this plain (located in the center and the north) due to deep soil, good drainage, texture, salinity and proper slope of the area. As seen from the map, some part of the cultivated area in this plain was evaluated as moderately suitable for sprinkler irrigation because of the light limitation of calcium carbonate & gravel soil texture. Other factors such as drainage, depth, salinity and slope never influence the suitability of the area. The marginally suitable lands are located in the center and north of the plain and their non-suitability of the land is due to the severe limitations gravelly soil texture and drainage. The current non-suitable lands did not exist in this plain. The permanently non-suitable land can be observed only in the north of the plain because of physical limitations especially gravelly soil texture and drainage limitations. For almost the entire study area slope, soil depth and salinity were never taken as limiting factors.

For drip irrigation, soil series coded 3 and 4 (7325 ha – 48.83%) were highly suitable (S_1) while soil series coded 8 and 9 (3800 ha – 25.33%) were classified as moderately suitable (S_2). Further, soil series coded 2, 5 and 6 (2325 ha, 15.51%) were found to be slightly suitable (S_3). Only soil series coded 1 (425 ha – 2.83%) was classified as currently non-suitable (N_1) and only soil series coded 7 (400 ha – 2.67%) were classified as permanently not-suitable (N_2) for drip irrigation.

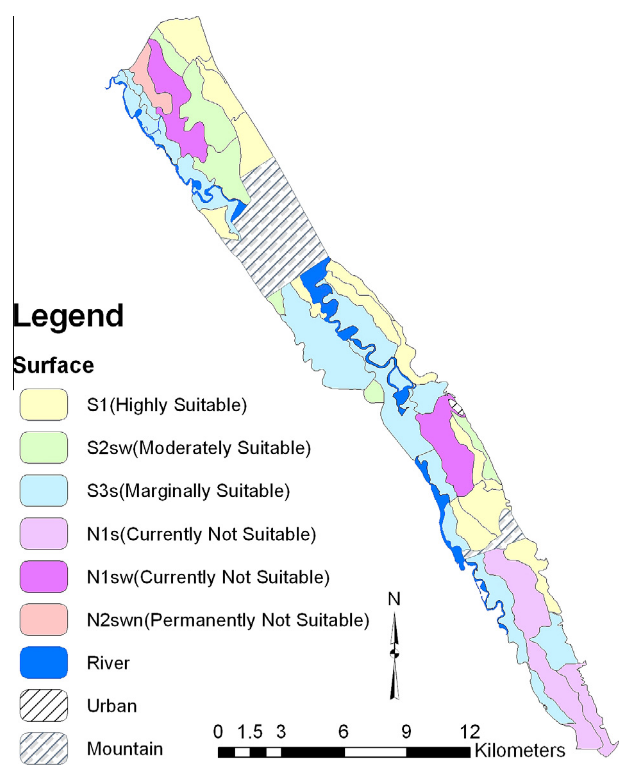

Figure 3 Land suitability map for surface irrigation.

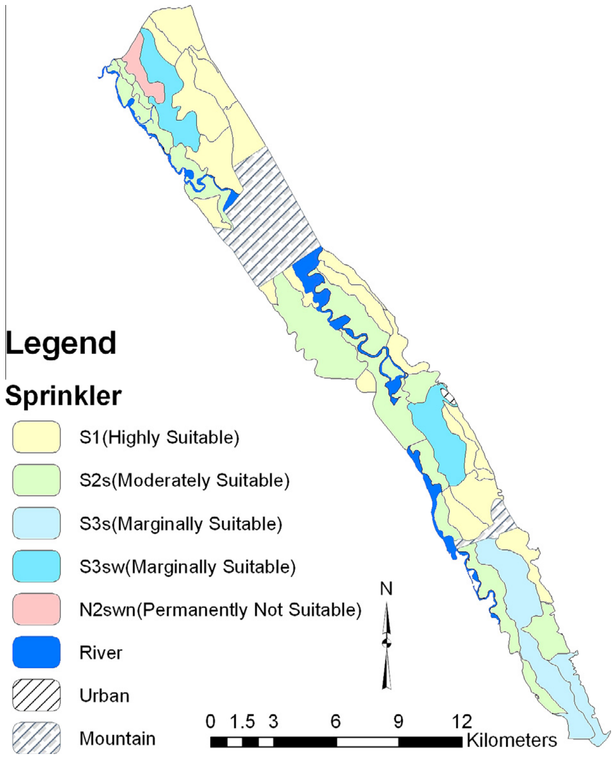

Figure 4 Land suitability map for sprinkler irrigation.

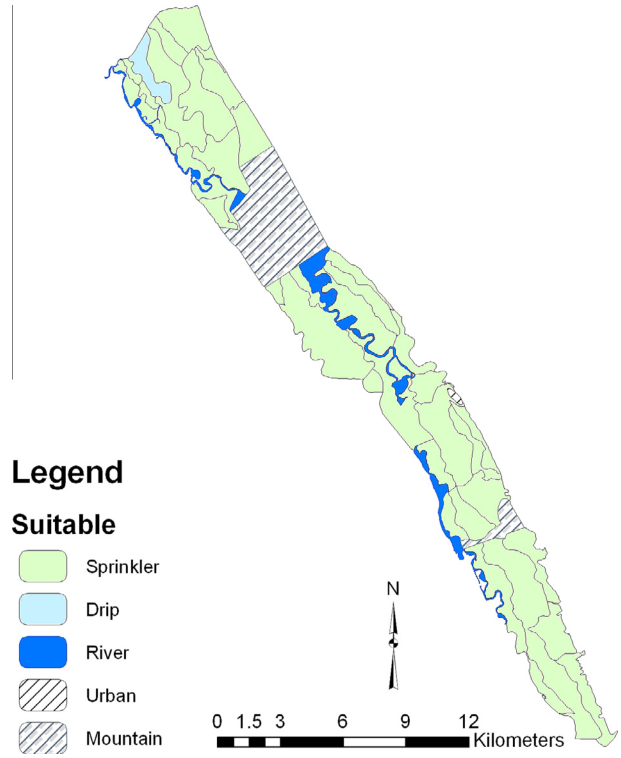

Figure 6 The most suitable map for different irrigation systems.

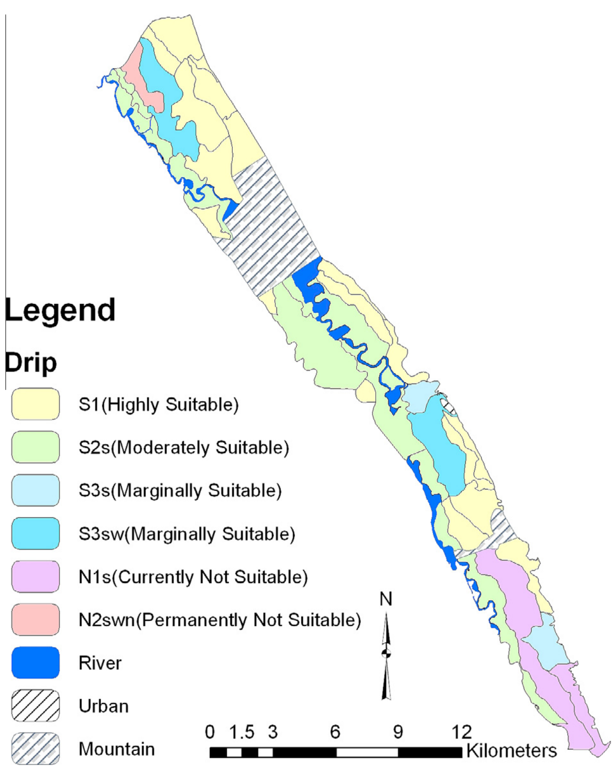

Figure 5 Land suitability map for drip irrigation.

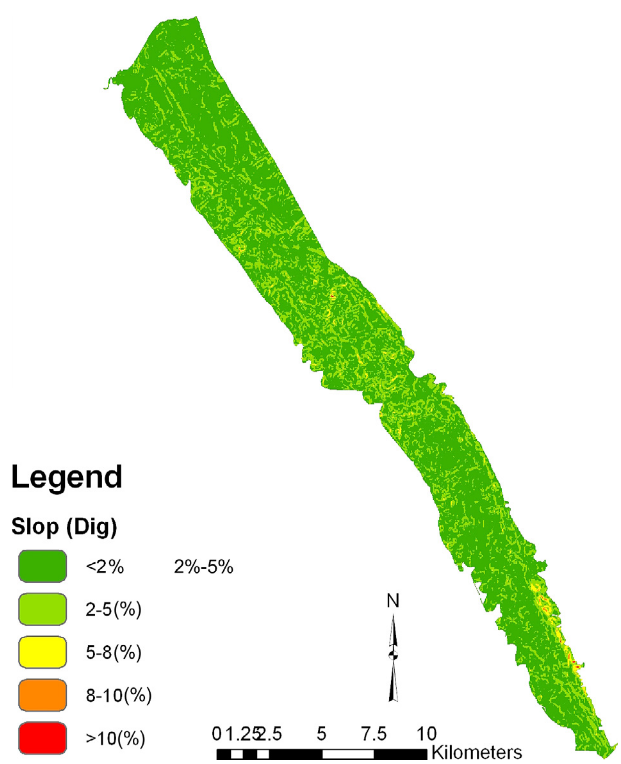

Figure 7 Slope map of the study area.

Regarding drip irrigation, (Fig. 5) the highly suitable lands covered the largest part of the plain (48.83%). The slope, soil texture, soil depth, calcium carbonate, salinity and drainage were in good conditions. The moderately suitable lands could be observed over a large portion of the plain (north, center and south parts) due to the medium content of calcium carbonate.

Table 11 The Most suitable soil series s for surface, sprinkler and drip irrigation systems by notation to capability index (Ci) for different irrigation systems.

Codes of Soil Series	The Maximum capability index for irrigation (Ci)	Suitability classes	The most suitable irrigation systems	Limiting factors
1	46.8	S_3 s	Sprinkler	$CaCo_3$ & gravel soil texture
2	60	S_2 s	Sprinkler	$CaCo_3$ & gravel soil texture
3	90	S_1	Sprinkler	No exist
4	81	S_1	Sprinkler	No exist
5	49.72	S_3 sw	Sprinkler	$CaCo_3$ & gravel soil texture and drainage
6	49.72	S_3 sw	Sprinkler	$CaCo_3$ & gravel soil texture and drainage
7	22.4	N_2 snw	Drip	$CaCo_3$, salinity & alkalinity and drainage
8	85.5	S_1	Sprinkler	No exist
9	72	S_2 s	Sprinkler	$CaCo_3$ & gravel soil texture

The marginally suitable lands were found in the center and north of the area. The limiting factors for this soil series were severe drainage limitation and the medium content of calcium carbonate. The current non-suitable lands and permanently non-suitable land can be observed in the north and south of the plain because of very severe drainage limitation and the high content of calcium carbonate. For the entire study area, slope, soil depth and salinity were never considered as limiting factors.

The mean capability index (Ci) for surface irrigation was 67.63 (Moderately suitable) while for sprinkler irrigation it was 74.85 (Moderately suitable). Moreover, for drip irrigation it was 70.29 (Moderately suitable). Tables 9 and 10 indicated that in soil series coded 7 applying drip irrigation systems was the most suitable option as compared to surface and sprinkler irrigation systems. In soil series coded 1, 2, 3, 4, 5, 6, 8 and 9 applying sprinkler irrigation systems was more suitable than surface and drip irrigation systems. Fig. 6 shows the most suitable map for surface, sprinkler and drip irrigation systems in the Jaizan Plain as per the capability index (Ci) for different irrigation systems. As seen from this map, the largest part of this plain was suitable for sprinkler irrigation systems and some parts of this area were suitable for drip irrigation systems. Fig. 7 shows the slope map of the study area. As seen from this map, the overall slopes of largest part of this plain (nearly all of this pain) are less than 2% (Level to very gently sloping) and 2–5% (Gently sloping).

The results of Tables 9 and 11 indicated that by applying sprinkler irrigation instead of surface and drip irrigation methods, the land suitability of 13,875 ha (92.5%) of the Jaizan Plain's land could be improved substantially. However by applying drip Irrigation instead of surface and sprinkler irrigation methods, the suitability of 400 ha (2.67%) of this Plain's land could be improved. The comparison of the different types of irrigation revealed that sprinkler irrigation was more effective and efficient than the drip and surface irrigation methods and improved land suitability for irrigation purposes. The second best option was the application of drip irrigation which was considered as being more practical than the surface irrigation method. To sum up the most suitable irrigation systems for the Jaizan Plain' were sprinkler irrigation, drip irrigation and surface irrigation, respectively. Moreover, the main limiting factor in using surface irrigation methods in this area was drainage and the main limiting factor in using sprinkler irrigation methods in this area were gravel soil texture, drainage and calcium carbonate and the main limiting factors in using drip irrigation methods were the drainage and calcium carbonate.

Conclusion

Several parameters were used for the analysis of the field data in order to compare the suitability of different irrigation systems. The analyzed parameters included soil and land characteristics. The results obtained showed that sprinkler and drip irrigation systems are more suitable than surface irrigation method for most of the study area. The major limiting factor in using surface irrigation methods in this area was drainage and the main limiting factors in using sprinkler irrigation methods in this area were gravel soil texture, drainage and calcium carbonate and the main limiting factors in using drip irrigation methods were the drainage and calcium carbonate.

The results of the comparison between the maps indicated that the introduction of a different irrigation management policy would provide an optimal solution such that the application of sprinkler and drip irrigation techniques could prove beneficial and advantageous. This is the current strategy adopted by large companies cultivating in the area and it will provide to be economically viable for Farmers in the long run.

Such a change in irrigation management practices would imply the availability of larger initial capitals to farmers (different credit conditions, for example) as well as a different storage and market organizations. On the other hand, because of the insufficiency of water in arid and semi arid climate, the optimization of water use efficiency is necessary to produce more crops per drop and to help resolve water shortage problems in the local agricultural sector. The shift from surface irrigation to high-tech irrigation technologies, e.g. sprinkler and drip irrigation systems, therefore, offers significant water-saving potentials. On the other hand, since sprinkler and drip irrigation systems typically apply lesser amounts of water (as compared with surface irrigations methods) on a frequent basis to maintain soil water near field capacity, it would be more beneficial to use sprinkler and drip irrigations methods in this plain.

In this study, an attempt has been made to analyze and compare three irrigation systems by taking into account various soil and land characteristics. The results obtained showed that sprinkler and drip irrigation methods are more suitable than surface or gravity irrigation method for most of the soils tested. Moreover, because of the insufficiency of surface and ground water resources, and the aridity and semi-aridity of the climate in this area, sprinkler and drip irrigation methods are highly recommended for a sustainable use of this natural resource; hence, changing of current irrigation methods from gravity (surface) to pressurized (sprinkler and drip) in the study area is proposed.

Conflict of interest

The authors have declared no conflict of interest.

Acknowledgements

The author gratefully acknowledges the Shahid Chamran University, Science Excellency of Irrigation & Drainage Networks Management of Shahid Chamran University and the Research and Standards Office for Dam and Power Plant of Khuzestan Water and Power Authority (KWPA) for their financial support and assistance during the study and field visits (Grant No; 636410).

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