Transactions of the Royal Society of South Africa
Vol. 66(3), November 2011, 163–169

Investigation of different irrigation systems based on the parametric evaluation approach on the Dasht Bozorg Plain

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The main objective of this study was to compare different irrigation systems based on a parametric evaluation system in an area of 3070 ha on the Dasht Bozorg Plain, Khuzestan Province, southwestern Iran. Soil properties in the study area such as texture, depth, electrical conductivity, drainage, calcium carbonate content and slope were derived from a semi-detailed soil study carried out on the Dasht Bozorg Plain on a scale of 1:20 000. Once the soil properties were analysed and evaluated, suitability maps were generated for surface, sprinkle and drip irrigation systems using remote sensing (RS) techniques and GIS (Geographic Information System). The results showed that for 1567.6 ha (51.1%) in the study area sprinkle irrigation was highly recommended, whereas for 1876.6 ha (61.3%) in the study area drip irrigation would be extremely efficient and suitable. However, there were no highly suitable lands for surface irrigation, but for all irrigation systems no unsuitable land exists in the study area. The results showed that by applying sprinkle irrigation instead of drip and surface irrigation, the arability of 1611.6 ha (52.5%) on the Dasht Bozorg Plain will improve. In addition, by applying drip irrigation instead of sprinkle or surface irrigation, the land suitability of 802.4 ha (26.2%) on this plain will improve. A comparison of the different types of irrigation systems revealed that sprinkle and drip irrigation were more effective and efficient than surface irrigation for improving land productivity. It is noteworthy, however, that the main limiting factor in using sprinkle and/or drip irrigation in this area is the soil calcium carbonate content and the main limiting factors in using surface irrigation are soil calcium carbonate content together with drainage.

Keywords: surface irrigation, sprinkle irrigation, drip irrigation, land suitability evaluation, parametric system, soil series.

INTRODUCTION

Owing to the depletion of water resources and an increase in the human population, the extent of irrigated area per capita is declining and irrigated lands now produce 40% of the food supply worldwide (Hargreaves & Mekley, 1998). According to FAO methodology (1976) land suitability is strongly related to "land qualities" including erosion resistance, water availability and flood hazards that are derived from slope angle and length, rainfall and soil texture. Sys *et al.* (1991) suggested a parametric evaluation system for irrigation methods which is primarily based on physical and chemical soil properties. According to their proposed system, factors affecting the land suitability for irrigation purposes can be divided into four groups:

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

Briza *et al.* (2001) applied the parametric system of Sys *et al.* (1991) to evaluate land suitability for both surface and drip irrigation in the Ben Slimane province of Morocco. The greatest part of the agricultural area was classified as marginally suitable.

Bazzani and Incerti (2002) also provided a land suitability evaluation for surface and drip irrigation systems in the Larche province of Morocco, using parametric evaluation systems. Their results showed a marked difference between the two irrigation systems.

Bienvenue *et al.* (2003) evaluated land suitability for surface (gravity) and drip (localised) irrigation in Senegal using Sys *et al.*'s parametric evaluation system. With regard to surface irrigation, no area was classified as highly suitable (S1). For drip (localised) irrigation, a quarter (25.03%) of the area was classified as highly suitable (S1).

Mbodj *et al.* (2004) performed a land suitability evaluation for two types of irrigation systems, i.e. surface irrigation and drip irrigation, in the Tunisian Oued Rmel Catchment using the suggested parametric evaluation. They found that drip irrigation would provide more irrigable areas than surface irrigation.

Barberis and Minelli (2005) provided land suitability classifications for both surface and drip irrigation in Shouyang county, Shanxi province, China, where the study was carried out using a modified parametric system. The results indicated that due to the unusual morphology, areas suitable for surface irrigation (34%) is smaller than areas for drip irrigation (62%).

Dengise (2006) also compared different irrigation systems,

ISSN 0035-919X Print / 2154-0098 Online

DOI: 10.1080/0035919X.2011.622809
http://www.informaworld.com

including surface and drip irrigation, in pilot fields at lkizce research farm located in southern Ankara. He concluded that that drip irrigation increased and suitability by 38% compared to surface irrigation.

Liu *et al.* (2006) evaluated land suitability for surface and drip irrigation in the Danling county, Sichuan province, China, using Sys *et al.*'s parametric evaluation system. Drip irrigation was shown to be more suitable than surface irrigation due to the minor environmental impact that it caused.

Albaji *et al.* (2008) carried out a land suitability evaluation for surface and drip irrigation on the Shavoor Plain in Iran. Their results showed that 41% of the area was suitable for surface irrigation; 50% of the area was highly recommended for drip irrigation. Owing to soil salinity and drainage problems the remainder of the area was not considered suitable for either irrigation system.

Albaji *et al.* (2009) compared the suitability of land for surface and drip irrigation according to the parametric evaluation system on the plains west of the city of Shush in southwestern Iran. Their results indicated that a larger portion of land (30 100 ha; 71.8%) can be classified as more suitable for drip irrigation than for surface irrigation.

Albaji *et al.* (2010a) investigated different irrigation methods based on the parametric evaluation system in an area of 29 300 ha on the Abbas Plain in the Elam province in western Iran. Their results showed that by applying sprinkler irrigation instead of surface or drip irrigation, the arability of 21 250 ha (72.53%) on the Abbas Plain would improve.

Albaji *et al.* (2010b) compared different irrigation systems on Dosalegh Plain, Iran, using the parametric evaluation system. Their results revealed that drip and sprinkler irrigation were more effective and efficient than surface irrigation in improving land productivity. However, the main limiting factors in using surface or/and sprinkler irrigation in this area were soil texture, salinity and slope, and the main limiting factors in using drip irrigation were calcium carbonate content, soil texture and salinity.

Irrigation systems used in farmlands on the Dasht Bozorg Plain in the Khuzestan province, are furrow, basin and border irrigation schemes. The objective of the present study was to evaluate and compare land suitability with regard to surface, sprinkler and drip irrigation methods, using the parametric evaluation system and soil characteristics.

MATERIALS AND METHODS

The present study was conducted in an area of about 3070 hectares on the Dasht Bozorg Plain, Khuzestan Province, southwestern Iran, during 2010–2011. The study area is located 20 km northwest of the city of Shushtar at 32°07′–32°12′N and 48°52′–48°57′E. The average annual temperature and precipitation for the period 1965–2004 were 26.1°C and 371.4 mm, respectively. Also, the annual evaporation in the area is 1710 mm (KWPA, 2005). The Karin River supplies the bulk of the water for the region. The application of irrigated agriculture has been common in the study area. Currently, the irrigation systems used on farmlands in the region are furrow irrigation, basin irrigation and border irrigation schemes.

The area comprises two distinct physiographic features, i.e. Piedmont Alluvial Plains and Plateaux, of which the Piedmont Alluvial Plains physiographic unit is the dominant feature. Also, six different soil series were found in the area. A semi-detailed soil survey of the Dasht Bozorg Plain (KWPA, 2003) was used to determine soil characteristics. Land evaluation was based on topography and soil characteristics. 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 plant requirements without further limitations, thus, fertility properties can be excluded from land evaluation if it is done for the purpose of irrigation.

Based upon the profile description and laboratory analysis, the groups of soils that had similar properties and were located in the same physiographic unit, were categorised as soil series and were taxonomied to form a soil family as per the *Keys to Soil Taxonomy* (2000). Ultimately, six soil series were selected for evaluating surface, sprinkle 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 six 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, sprinkle 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.

Six parameters including slope, drainage properties, electrical conductivity of soil solution, calcium carbonate status, soil texture and soil depth were also considered and rates were assigned to each as per the related tables, 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 1 the ranges of the capability index and the corresponding suitability classes are shown.

Table 1. Suitability classes for the irrigation capability indices (Ci).

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

In order to develop land suitability maps for different irrigation systems (Figures 2–5), a semi-detailed soil map (Figure 1) prepared by Albaji was used, and all the data for soil characteristics were analysed and incorporated into the map using ArcGIS 9.2 software.

The digital soil map base preparation was the first step towards the presentation of a GIS module for land suitability maps for different irrigation systems. The soil map was then digitised and a database prepared. A total of six different land mapping units (LMU) were determined in the base map. Soil characteristics were also given for each LMU. These values were used to generate the land suitability maps for surface, sprinkle and drip irrigation systems using Geographic Information Systems.

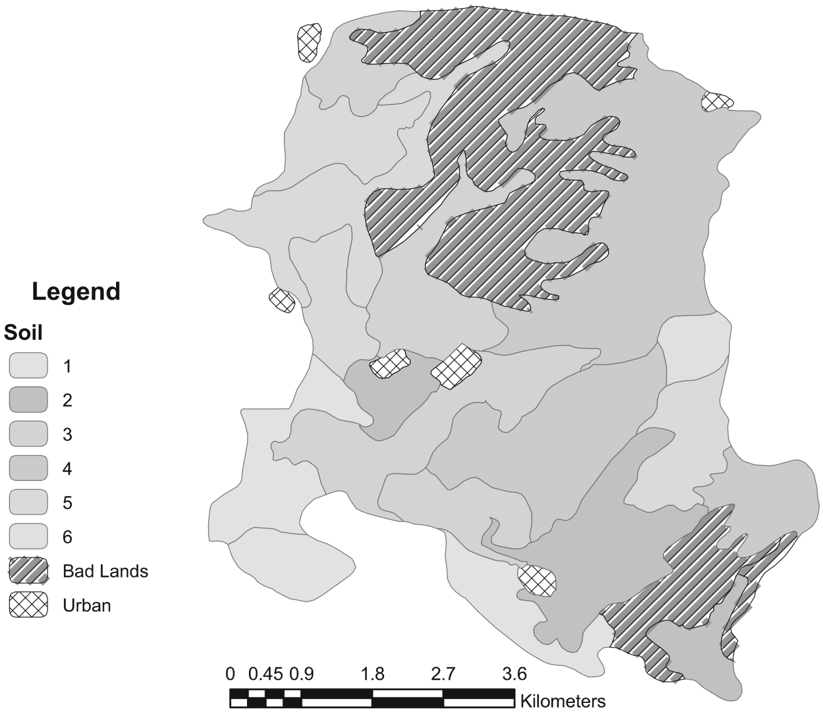

Figure 1. Soil map of the study area.

Table 2. Ci values and suitability classes of surface, sprinkle and drip irrigation for each land unit.

Codes of land units	Surface irrigation		Sprinkle irrigation		Drip irrigation	
	Ci	Suitability class	Ci	Suitability class	Ci	Suitability class
1	74.92	S_{2SW}*	83.36	S_1**	80.00	S_1***
2	70.20	S_{2SW}	81.00	S_1	80.00	S_1
3	75.02	S_{2SW}	81.22	S_1	76.00	S_{2S}
4	66.60	S_{2SW}	78.97	S_{2S}	80.00	S_1
5	78.97	S_{2SW}	85.50	S_1	80.00	S_1
6	60.77	S_{2SW}	69.44	S_{2S}	68.40	S_{2S}

*Limiting factors for surface irrigation: s = calcium carbonate; w = drainage.
** & *** Limiting factors for sprinkle and drip irrigation: s = calcium carbonate.

RESULTS AND DISCUSSION

Over much of the Dasht Bozorg Plain surface irrigation schemes are used for field crops, meeting 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 sprinkle and drip irrigation on large-scale farms on the Dasht Bozorg Plain.

Six soil series or land units and 17 series phases were derived from the semi-detailed soil study of the area. The land units are shown in Figure 1 as the basis for further land evaluation practice. The soils in the area are of inceptisols and entisols orders. Also, the soil moisture regime is ustic while the soil temperature regime is hyperthermic (KWPA, 2003).

As shown in Tables 2 and 3 for surface irrigation, there were no highly suitable lands (S1) in this area. All of the soil series coded 1, 2, 3, 4, 5 and 6 (2414 ha; 78.7%) were classified

Table 3. Distribution of surface, sprinkle and drip irrigation suitability

Suitability	Surface irrigation			Sprinkle irrigation			Drip irrigation		
	Land unit	Area (ha)	Ratio (%)	Land unit	Area (ha)	Ratio (%)	Land unit	Area (ha)	Ratio (%)
S_1	–	–	–	1 , 2 , 3 , 5	1567.6	51.1	1 , 2 , 4 , 5	1878.6	61.3
S_2	1 , 2 , 3 , 4 , 5 , 6	2414	78.7	4 . 6	846.4	27.6	3 , 6	535.4	17.4
S_3	–	–	–	–	–	–	–	–	–
N_1	–	–	–	–	–	–	–	–	–
N_2	–	–	–	–	–	–	–	–	–
*Mis land		656	21.3		656	21.3		656	21.3
Total		3070	100		3070	100		3070	100

*Miscellaneous land: hill, sand dune and river bed.

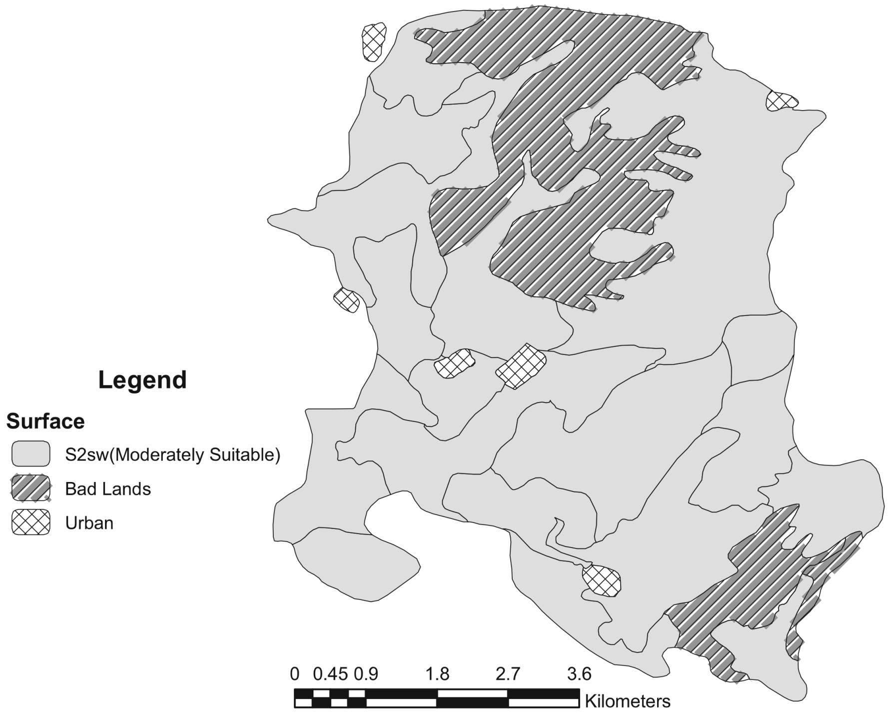

Figure 2. Land suitability map for surface irrigation.

as moderately suitable (S2), Furthermore, there were no marginally suitable lands (S_3) and unsuitable lands (N1 & N2) for surface irrigation.

Analysis of the suitability irrigation maps for surface irrigation (Figure 2) indicated that the entire cultivated area on this plain (78.7%) is deemed to be moderately suitable land due to the medium rate of $CaCO_3$ and moderate drainage limitation. For almost the total study area elements such as soil depth, salinity, texture and slope were not considered limiting factors.

In order to verify the possible effects of different management practices, the land suitability for sprinkle and drip irrigation was evaluated (Tables 2 and 3).

For sprinkle irrigation, soil series coded 1, 2, 3 and 5 (1567.6 ha; 51.1%) were highly suitable (S_1) while soil series coded 4 and 6 (846.4 ha; 27.6%) were classified as moderately suitable (S_2). Moreover, no lands were found to be marginally suitable (S_3) or unsuitable (N1 & N2) for sprinkle irrigation.

Regarding sprinkler irrigation (Figure 3), a highly suitable area can be seen in the largest part of the cultivated zone on this plain (located in the west and the south) due to deep soil, good drainage, texture, salinity and proper slope. However, part of the cultivated area on this plain (located in the east) was considered moderately suitable for sprinkle irrigation because of the medium rate of $CaCO_3$. Other factors such as soil texture,

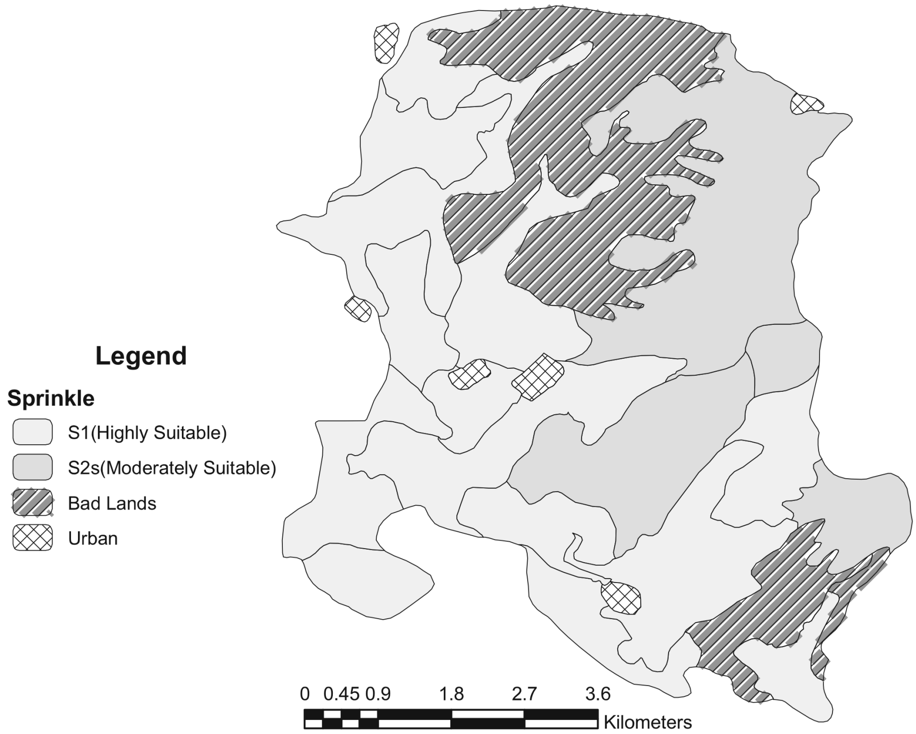

Figure 3. Land suitability map for sprinkle irrigation.

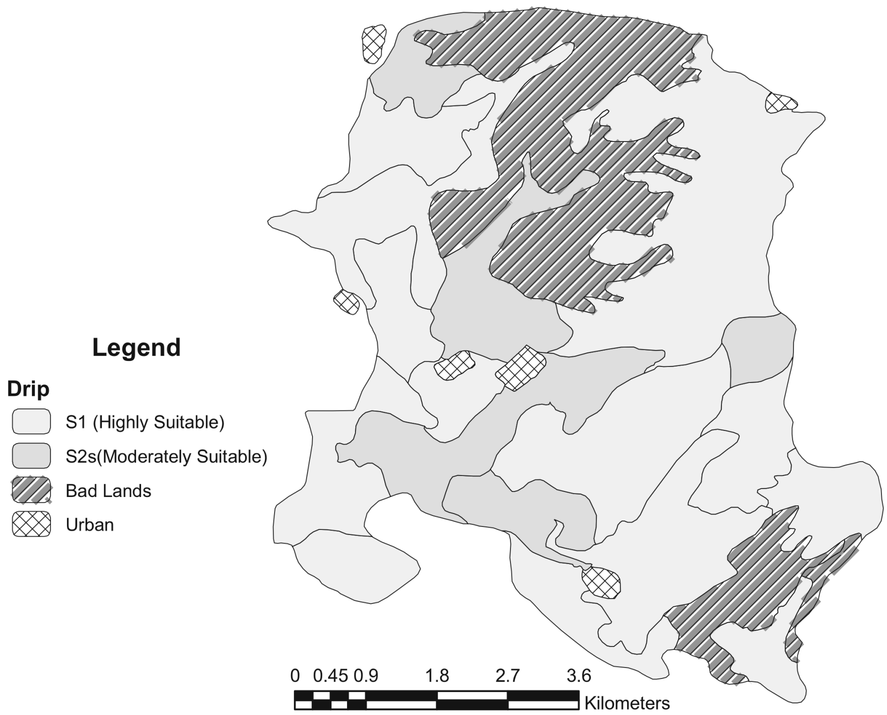

Figure 4. Land suitability map for drip irrigation.

depth, drainage, salinity and slope never influenced the suitability of the area. For almost the entire study area slope, soil depth, texture, drainage and salinity were never shown to be limiting factors.

For drip irrigation, soil series coded 1, 2, 4 and 5 (1878.6 ha; 61.3%) were highly suitable (S_1) while soil series coded 3 and 6 (535.4 ha; 17.4%) were classified as moderately suitable (S_2). Also, there were no marginally suitable lands (S_3) or unsuitable lands (N1 & N2) for drip irrigation.

Regarding drip irrigation (Figure 4), the highly suitable lands covered the largest part of the plain (61.30%; located in the west, east and the south of this zone). The slope, soil texture, soil depth, calcium carbonate, salinity and drainage were favourable conditions. Moderately suitable lands were present in some parts of the area (especially in central parts) due to the medium content of calcium carbonate. For the entire study area, slope, soil depth, drainage and salinity were never considered to be limiting factors.

The mean capability index (Ci) for surface irrigation was 72.06 (moderately suitable) while for sprinkle irrigation it was 81.30 (highly suitable). Moreover, for drip irrigation it was 78.97 (moderately suitable). Tables 2 and 4 indicate that in soil series coded 4, applying drip irrigation was the most suitable option as compared to surface and sprinkle irrigation systems. In soil series coded 1, 2, 3, 5 and 6 applying sprinkle irrigation was more suitable than surface and drip irrigation. Figure 5 shows

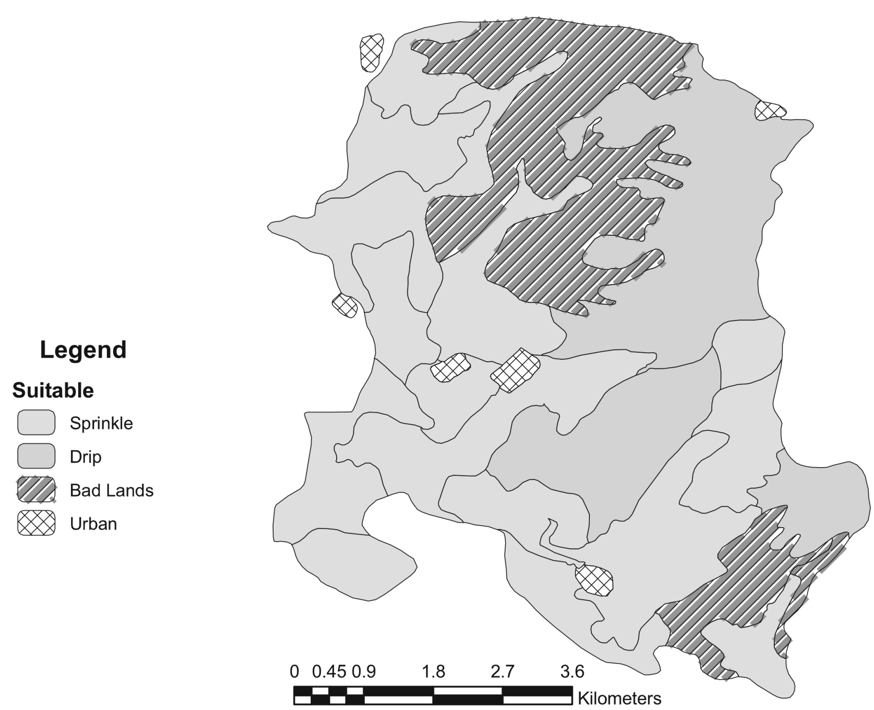

Figure 5. The most suitable map for different irrigation systems.

Table 4. The most suitable land units for surface, sprinkle and drip irrigation systems by notation to capability index (Ci) for different irrigation systems.

Codes of land units	Maximum capability index for irrigation (Ci)	Suitability classes	Most suitable irrigation systems	Limiting factors
1	83.36	S1	Sprinkle	None
2	81.00	S_1	Sprinkle	None
3	81.22	S_1	Sprinkle	None
4	80.00	S_1	Drip	None
5	85.50	S_1	Sprinkle	None
6	69.44	S_{2s}	Sprinkle	Calcium carbonate

the most suitable map for surface, sprinkle and drip irrigation systems on the Dasht Bozorg 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 sprinkle irrigation and one part of the area was suitable for drip irrigation; however, no lands were found to be suitable for surface irrigation.

Tables 2 and 4 indicate that by applying sprinkle irrigation instead of drip or surface irrigation, the land suitability of 1611.6 ha (52.5%) on the Dasht Bozorg Plain's land could be improved substantially. However, by applying drip irrigation instead of sprinkle and surface irrigation, the suitability of 802.4 ha (26.2%) could be improved. The application of surface irrigation instead of sprinkle and drip irrigation would not provide land suitability improvement on this plain. A comparison of the different types of irrigation systems revealed that sprinkle irrigation was more effective and efficient than drip and surface irrigation and improved land suitability for irrigation purposes. The second best option was the application of drip irrigation which was considered to be more practical than the surface irrigation. To summarise, the most suitable irrigation systems for the Dasht Bozorg Plain were shown to be sprinkle irrigation, followed by drip irrigation and and lastly surface irrigation. Moreover, the main limiting factors in using surface irrigation in this area were shown to be calcium carbonate content and drainage, and the main limiting factor in using drip and sprinkle irrigation was the soil's calcium carbonate content.

CONCLUSIONS

Several parameters were used in the analysis of field data in order to compare the suitability of different irrigation systems. The parameters included soil and land characteristics. The results showed that sprinkle and drip irrigation systems would be more suitable than surface irrigation in most of the study area. The major limiting factor for both sprinkle and drip irrigation systems is the soil's calcium carbonate content. However, in surface irrigation, soil calcium carbonate content together with drainage were restricting factors. A comparison of the generated maps indicated that the introduction of a different irrigation management system could provide an optimal solution in the sense that the application of sprinkle and drip irrigation would prove to be beneficial and advantageous. This is in fact the current strategy of large companies operating in the area and and could well be an economically viable route for farmers in the long run.

Such a change in irrigation management practices would necessitate larger initial capital outlays by farmers (linked to alternative credit conditions, for example) as well as different storage and market management practices. On the other hand, because of the insufficiency of water supply in the arid and semi-arid climate, the efficiency with which water is used should be improved in order 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. sprinkle and drip irrigation systems, therefore, offers significant water-saving potentials. On the other hand, since sprinkle and drip irrigation systems typically apply lesser amounts of water (compared to surface irrigation systems) on a frequent basis to maintain soil water near field capacity, it would be more beneficial to switch to these systems on this plain.

In this study an attempt has been made to analyse and compare three irrigation systems by taking into account various soil and land characteristics. The results obtained showed that sprinkle and drip irrigation systems are more suitable than surface or gravity irrigation systems 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 environment in this area, sprinkle and drip irrigation systems are highly recommended for a sustainable use of this natural resource; hence, switching from the current, gravity-dependent (surface) irrigation system to a pressurised (sprinkle and drip) system in the study area is highly recommended.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the Research and Standards Office of Khuzestan Water and Power Authority (KWPA) for financial support and assistance during the study and field visits.

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