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Application Possibilities of Different Irrigation Methods in Hofel Plain

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Abstract: The main objective of this research was to compare different irrigation methods based upon a parametric evaluation system in an area of 11 533 ha in the Hofel plain located in the Khuzestan Province, in the South West of Iran. Once the soil properties were analyzed and evaluated, suitability maps were generated for surface, sprinkler and drip irrigation methods using Remote Sensing (RS) Techniques and Geographic Information System (GIS). The obtained results showed that for 1 562.2 ha (13.5 %) of the study area surface irrigation method was highly recommended; whereas for 5 989.3 ha (51.90 %) of the study area a sprinkler irrigation method would provide to be extremely efficient and suitable. The results demonstrated that by applying sprinkler irrigation instead of surface and drip irrigation methods, the arability of 7 083 ha (61.7 %) in the Hofel Plain will improve. In addition by applying drip irrigation instead of surface and sprinkler irrigation methods, the land suitability of 4 052.3 ha (35.1 %) of this 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 factors in using surface irrigation methods in this area were heavy soil texture, $CaCO_3$, drainage and slope. Moreover, the main limiting factors in using sprinkler irrigation methods in this area were heavy soil texture, drainage, salinity, and alkalinity; the main limiting factors in using drip irrigation methods were the $CaCO_3$ and heavy soil texture.

Keywords: Surface irrigation, Sprinkler irrigation, Drip irrigation, Land suitability evaluation, Parametric method, Soil series.

Hofel Ovası'nda Farklı Sulama Yöntemlerinin Uygulama Olanakları

Özet: Bu araştırmanın temel amacı, İran'ın Güney Batı, Huzistan eyaletinde bulunan Hofel Ovası'nda 11533 hektarlık bir alanda bir parametrik bir değerlendirme sistemine dayalı farklı sulama yöntemlerinin karşılaştırılmasıdır. Toprak özellikleri analiz edilip ve değerlendirildiğnde, uygunluk haritaları, Uzaktan Algılama (UA) Teknikleri ve Coğrafi Bilgi Sistemi (CBS) kullanılarak yüzey, yağmurlama ve damlama sulama yöntemleri için üretilmiştir. Elde edilen sonuçlar, yüzey sulama yönteminin çalışma alanının 1562.2 ha (% 13.5) için şiddetle tavsiye edildiğini; çalışma alanının 5 989.3 ha (% 51.90) için ise yağmurlama sulama yönteminin son derece verimli ve uygun olduğunu göstermiştir. Sonuçlar, yüzey ve damla sulama yöntemleri yerine yağmurlama sulama sisteminin kullanılmasının Hofel Ovası'nda 7 083 ha (% 61.7) alanın tarıma elverişliliğini artıracağını ortaya koymuştur. Buna ek olarak, yüzey ve yağmurlama sulama yöntemleri yerine damla sulama sisteminin kullanılmasının Hofel Ovası'nda 4 052.3 ha (% 35.1) alanın tarıma elverişliliğini iyileştireceğini göstermiştir. Farklı sulama tekniklerinin karşılaştırılması, yağmurlama ve damlama sulama yöntemlerinin yüzey sulama yöntemlerine göre daha etkili ve arazi verimliliğini artırmak için daha elverişli olduğunu ortaya koymuştur. Bununla birlikte, bu alanda yüzey sulama yöntemleri kullanımının ana sınırlayıcı faktörleri ağırtoprak yapısı, $CaCO_3$, drenaj ve eğim olarak; yağmurlama sulama yöntemleri kullanımının ana sınırlayıcı faktörlerinin tuzluluk ve alkalilik, drenaj ve ağır toprak dokusu; damla sulama yönteminin ana sınırlayıcı faktörlerinin ise tuzluluk ve alkalilik, $CaCO_3$ ve ağır toprak yapısı olduğu göz önünde tutulmalıdır.

Anahtar kelimeler: Yüzey sulama, Yağmurlama sulama, Damla sulama, Arazi uygunluk değerlendirmesi, Parametrik yöntem, Toprak serisi

Introduction

Food security and stability in the world greatly depend on the management of natural resources. Due to the depletion of water resources and increases in population, the extent of irrigated area per capita has been declining and irrigated lands nowadays have produced 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 in 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. 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 irrigation 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 with in 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.

Dengize (2006) also compared different irrigation methods including surface and drip irrigation in the pilot fields of 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. (2006) evaluated the land suitability for surface and drip irrigation in the Danling County, Sichuan province, China, using a Sys's parametric evaluation system. Drip irrigation was everywhere more suitable than surface irrigation due to the minor environmental impact that it caused.

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 the 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 Hofel Plain, in the Khuzestan Province, Iran.

Materials and Methods

The present study was conducted in an area about 11 533 hectares in the Hofel Plain, in the Khuzestan Province, located in the West of Iran during 2007-2008. The study area is located 15 km west of the city of Susangerd, 34°95'39" to 35°15'98" N and 21°20'15" to 23°66'46" E. The Average annual temperature and precipitation for the period of 1965-2004 were 24.5 ^{o}C and 231.7 mm, respectively. Also, the annual evaporation of the area is 2 550 mm (KWPA.2005). The Kharkhe 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.

The area is composed of three distinct physiographic features i.e. River Alluvial Plain and Sand Dune, of which the Piedmont Alluvial Plains physiographic unit is the dominating features. Moreover, five different soil series were found in the area. The semi-detailed soil survey report of the Hofel plain (KWPA. 2003) was used in order to determine the soil characteristics. 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.

The groups of soils that had similar properties and were located in a same physiographic unit were categorized as soil series and were classified to form a soil family as per the Keys to Soil Taxonomy (2006). Ultimately, five 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 150cm 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.

Six parameters including slope, drainage properties, electrical conductivity of soil solution, calcium carbonates status, soil texture and soil depth were also considered and rates were assigned to each as per the related tables (Sys et al. (1991) and IAO (2005) for surface and drip irrigation and 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 1 the ranges of capability index and the corresponding suitability classes are shown.

Table 1. 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

In order to develop land suitability maps for different irrigation methods, a semi-detailed soil map (Figure.1) prepared by Albaji was used, and all the data for soil characteristics were analyzed and incorporated in the map using ArcGIS 9.2 software.

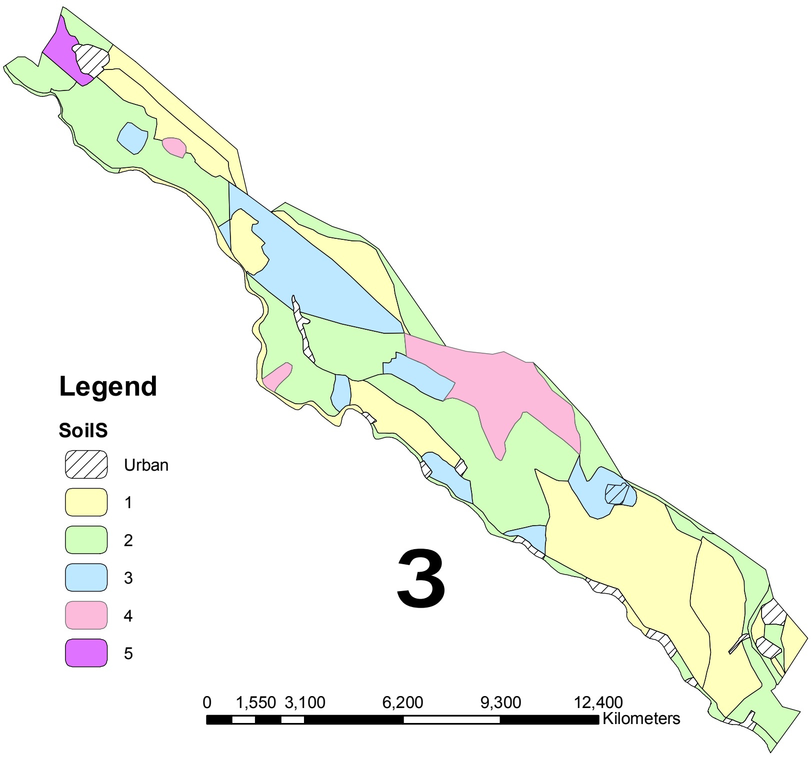

Figure 1. Soil Map of the Study Area

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 digitized and a database prepared. A total of five different polygons or 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, sprinkler and drip irrigation systems using Geographic Information Systems. In Figure 2 schematic chart of GIS application for land suitability map for different irrigation methods is shown.

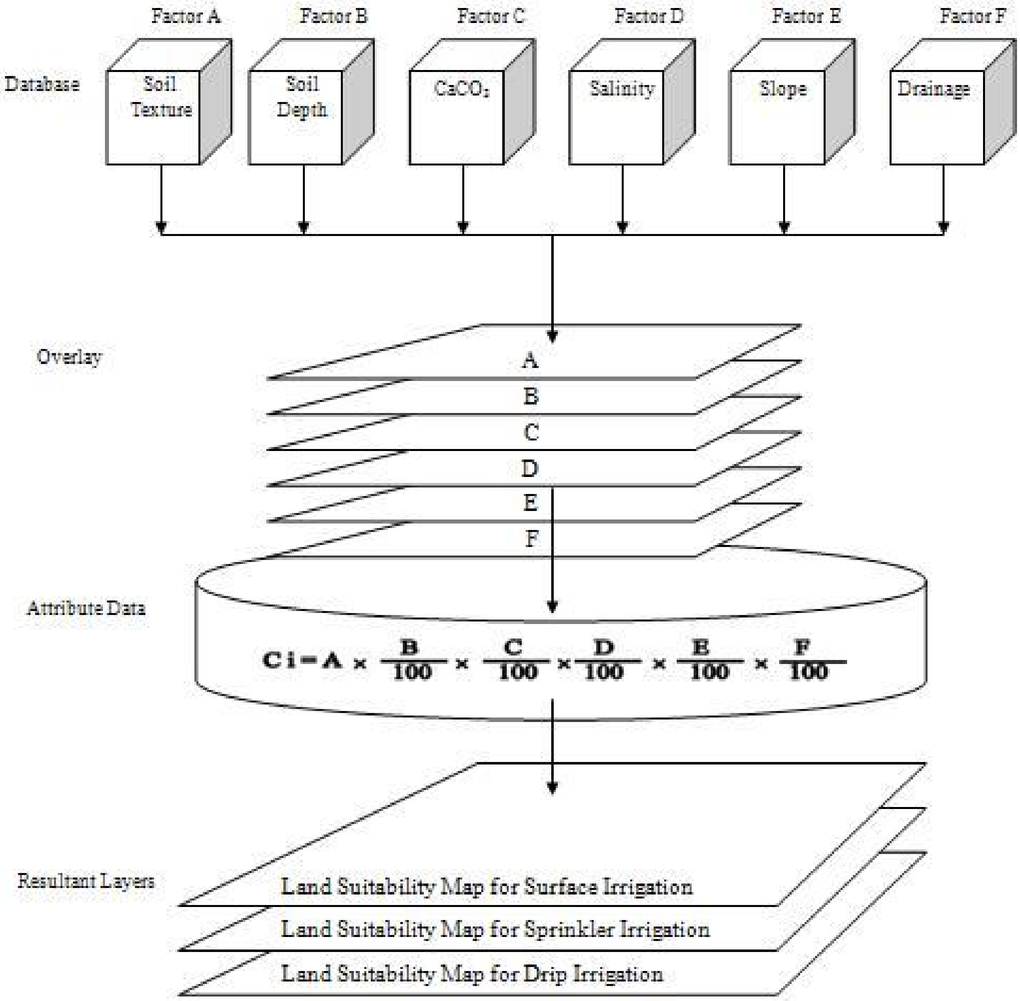

Figure 2. Schematic Chart of GIS Application for Land Suitability Map for Different Irrigation Methods

Results and Discussion

In Hofel plain, farmers are becoming increasingly aware of irrigation as a tool for optimizing production. When all other management practices are carried out efficiently, irrigation can help the farmers achieve the top yields and quality demanded for self food security and even to the market. In the study area irrigation is practiced from many water sources: surface water like Kharkhe River, water harvesting and digging wells from the ground water. During the field work, a good observation in Hofel Plain there is soil and water conservation practice on the hill sides that enhance the increment of water table level at the foot slope field, encouraging farmers to dig a well for irrigation practice. Over much of the Hofel 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 Hofel Plain.

Five soil series and thirty six series phases were derived from the semi-detailed soil study of the area. The soil series are shown in Figure.1 as the basis for further land evaluation practice. The soils of the area are of Entisols and Aridisols 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, the only soil series coded 3 (1 562.2 ha – 13.5 %) were highly suitable (S_1); only soil series coded 2 (4 427.1 ha – 38.4 %) were classified as moderately suitable (S_2), and soil series coded 1, 4 and 5 (5 146 ha – 44.5 %) were classified as permanently not-suitable (N_2) for any surface irrigation practices.

Table 2. Ci Values and Suitability Classes of Surface, Sprinkler and Drip irrigation for Each Soil series.

Codes of Soil series	Surface Irrigation		Sprinkler Irrigation		Drip Irrigation	
	Ci	Suitability classes	Ci	Suitability classes	Ci	Suitability classes
1	24.97	N_{2SW}[a]	46.31	S_{3} s[b]	66.5	S_2 s[c]
2	75.02	S_2 sw	81.22	S_1	76	S_2 s
3	83.36	S_1	85.5	S_1	76	S_2 s
4	27.64	N_2 snw	29.92	N_2 sn	29.92	N_2 sn
5	26.85	N_2 snw	32.32	N_1 snw	30.94	N_1 snw

[a,b] Limiting Factors for Surface and Sprinkler Irrigations: n: (Salinity & Alkalinity), w: (Drainage) and s :(Heavy Soil Texture).
[c] Limiting Factors for Drip Irrigation: n: (Salinity & Alkalinity) and s: (Calcium Carbonate & Heavy Soil Texture).

Table 3. 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	1562.2	13.5	2, 3	5989.3	51.9	-	-	-
S_2	2	4427.1	38.4	-	-	-	1, 2, 3	10041.6	87
S_3	-	-	-	1	4052.3	35.1	-	-	-
N_1	-	-	-	5	131.7	1.1	5	131.7	1.1
N_2	1 , 4 , 5	5146	44.5	4	962	8.3	4	962	8.3
[a]Mis Land		398.1	3.5		398.1	3.5		398.1	3.5
Total		11533	100		11533	100		11533	100

[a] Miscellaneous Land: (Hill, Sand Dune and River Bed)

The analysis of the suitability irrigation maps for surface irrigation (Figure 4), indicate that the small portion of the cultivated area in this plain (located in the center) 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 to the South and North of this area due to sandy loam soil texture. Other factors such as drainage, depth, salinity and alkalinity have no influence on the suitability of the area whatsoever. The permanently non-suitable land can be observed in the major portion of the plain because of physical limitations especially heavy soil texture. For almost the total study area element such as soil depth was not considered as limiting factor.

In order to verify the possible effects of different management practices, the land suitability for sprinkler and drip irrigation was evaluated (Tables 2 and 3). For sprinkler irrigation, soil series coded 2 and 3 (5989.3 ha – 51.90 %) were highly suitable (S_1). Further, only soil series coded 1 (4 052.3 ha – 35.10 %) were found to be marginally suitable (S_3). only soil series coded 5 (131.7 ha- 1.1 %) was classified as currently non-suitable (N_1) and only soil series coded 4 (962 ha – 8.3 %) were classified as permanently not-suitable (N_2) for sprinkler irrigation.

Regarding sprinkler irrigation (Figure 3), 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 marginally suitable for sprinkler irrigation because of the heavy soil texture. Other factors such as $CaCO_3$, soil depth and slope never influence the suitability of the area. The current non-suitable lands are located only in the north of the plain and their non-suitability of the land is due to the heavy soil texture, salinity and drainage. The permanently not-suitable lands are located in the center of the plain and their non-suitability of the land is due to the severe limitations such as heavy soil texture and salinity. The moderately suitable lands did not exist in this plain. For almost the entire study area slope, soil depth and $CaCO_3$ were never taken as limiting factors.

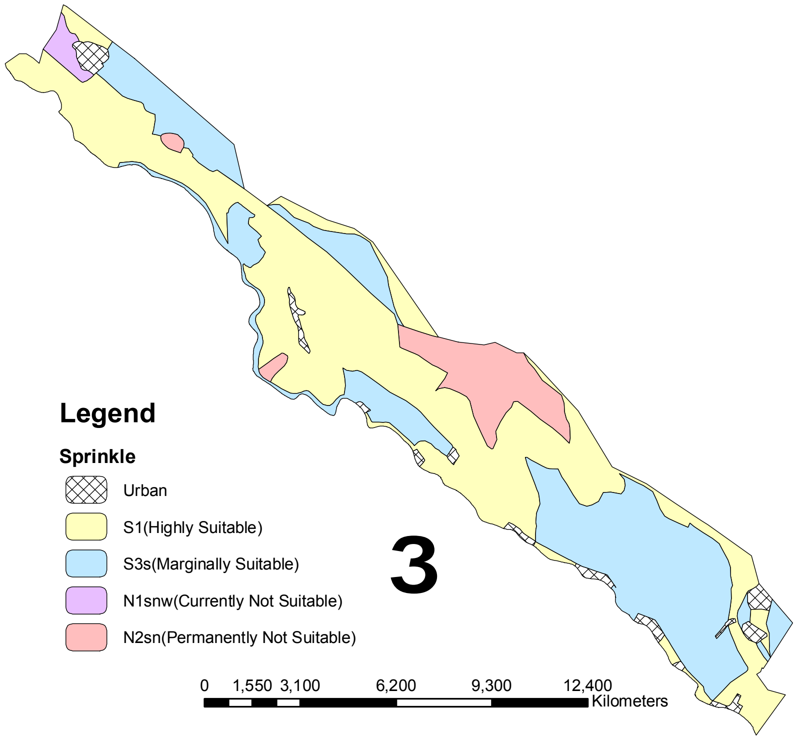

Figure 3. Land Suitability Map for Sprinkler Irrigation.

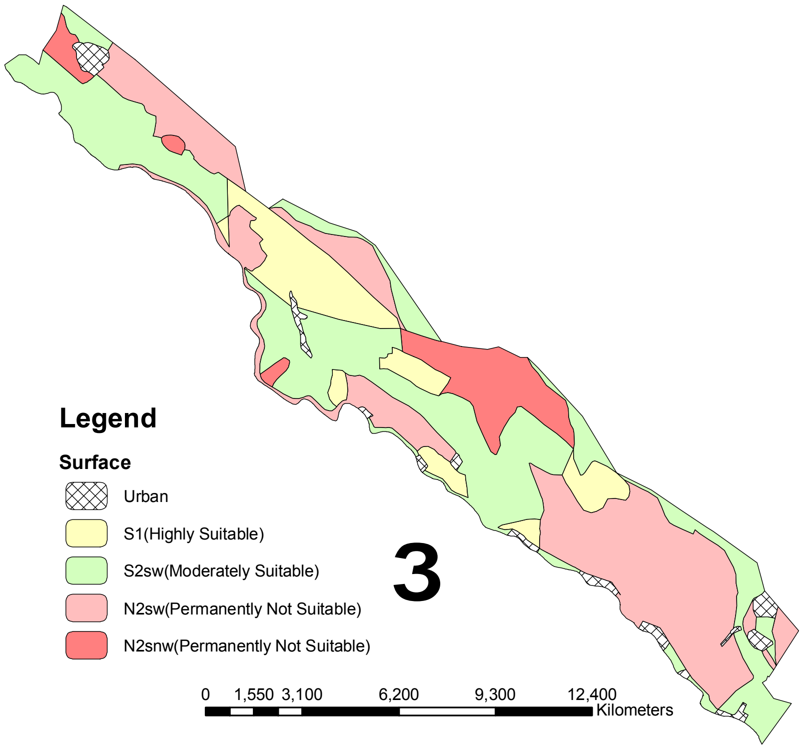

Figure 4. Land Suitability Map for Surface Irrigation.

For drip irrigation, while soil series coded 1, 2 and 3 (10 041.6 ha- 87 %) were classified as moderately suitable (S_2). only. soil series coded 5 (131.7 ha- 1.1 %) was classified as currently non-suitable (N_1) and only soil series coded 4 (962 ha – 8.3 %) were classified as permanently not-suitable (N_2) for drip irrigation.

Regarding drip irrigation (Figure 5), the moderately suitable lands covered the largest part of the plain (87 %). The slope, soil depth, salinity and drainage were in good conditions. The current non-suitable lands are located only in the north of the plain and their non-suitability of the land is due to the heavy $CaCO_3$, soil texture, salinity and drainage. The permanently not-suitable lands are located in the center of the plain and their non-suitability of the land is due to the severe limitations such as $CaCO_3$, heavy soil texture and salinity. The highly and marginally suitable lands did not exist in this plain. For almost the entire study area slope and soil depth were never taken as limiting factors.

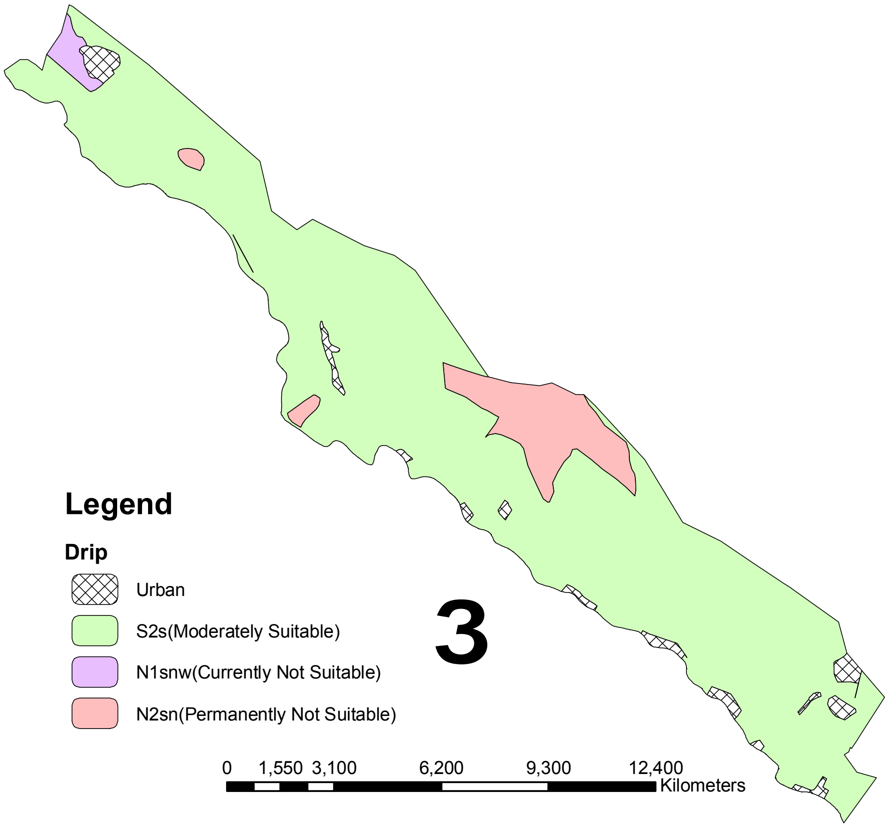

Figure. 5. Land Suitability Map for Drip Irrigation.

For the comparison of the capability indices for surface, sprinkler and drip irrigation Tables 2 and 4 indicated that in soil series coded 1 applying drip irrigation systems was the most suitable option as compared to surface and sprinkler irrigation systems. In soil series coded 2, 3, 4 and 5 applying sprinkler irrigation systems was more suitable then surface and drip irrigation systems. Figure 6 shows the most suitable map for surface, sprinkler and drip irrigation systems in the Hofel 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 was suitable for drip irrigation systems.

Table 4. The Most Suitable Soil series 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	66.5	$S_{2\ S}$	Drip	$CaCO_3$& Heavy Soil Texture
2	81.22	S_1	Sprinkler	No Exist
3	85.5	S_1	Sprinkler	No Exist
4	29.92	N_2 sn	Sprinkler	Heavy Soil Texture and Salinity & Alkalinity
5	32.32	N_1 snw	Sprinkler	Heavy Soil Texture, Salinity & Alkalinity and Drainage

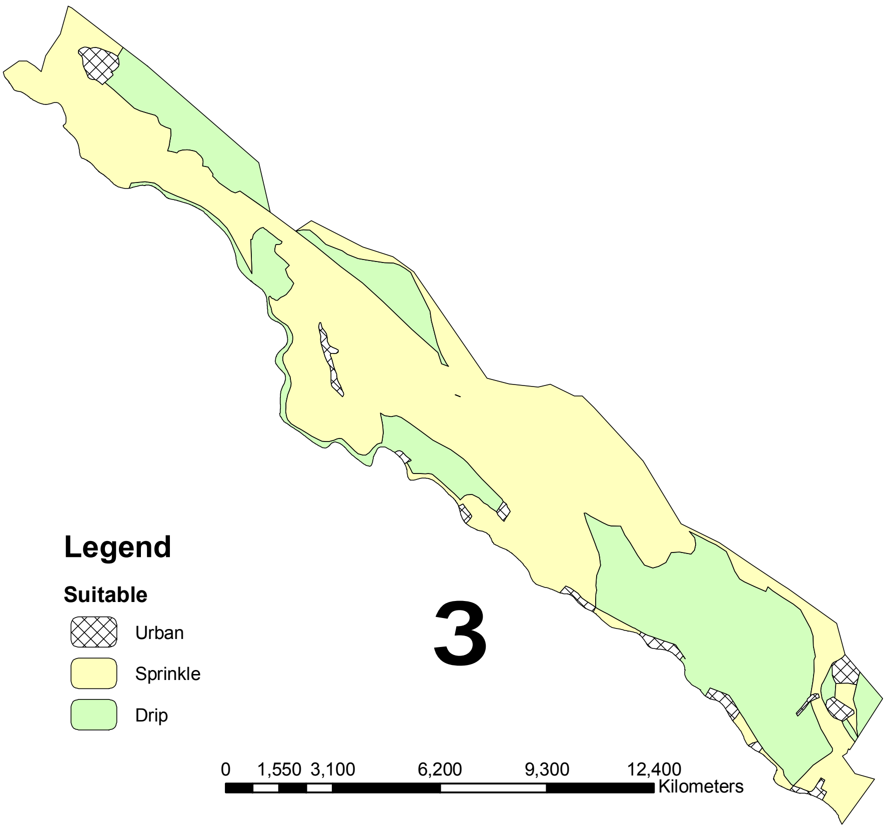

Figure 6. The Most Suitable Map for Different Irrigation Systems.

The results of Tables 2 and 4 indicated that by applying sprinkler irrigation instead of surface and drip irrigation methods, the land suitability of 7083 ha (61.7%) of the Hofel Plain's land could be improved substantially. However by applying drip Irrigation instead of surface and sprinkler irrigation methods, the suitability of 4052.3 ha (35.1%) 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 then 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 Hofel Plain' were sprinkler irrigation, drip irrigation and surface irrigation respectively. Moreover, the main limiting factors in using surface irrigation methods in this area were heavy soil texture, CaCO3, drainage and slope. Moreover, the main limiting factors in using sprinkler irrigation methods in this area were heavy soil texture, drainage and salinity & alkalinity and the main limiting factors in using drip irrigation methods were the $CaCO_3$and heavy soil texture.

Conclusions

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 for both sprinkler and surface irrigation methods were salinity and alkalinity, drainage and heavy soil texture. However for drip irrigation method, calcium carbonates and heavy soil texture were restricting factors. The results of the comparison between the maps indicated that the introduction of a different irrigation management policy would provide an optimal solution in as such that the application of sprinkler and drip irrigation techniques could provide 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 organization. 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, the changing of current irrigation methods from gravity (surface) to pressurized (sprinkler and drip) in the study area are proposed.

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