Land Suitability Evaluation for Surface, Sprinkler and Drip Irrigation Systems

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Abstract:
The main objective of this research is to compare different irrigation methods based upon a parametric evaluation system in an area of 13300 ha in the Gotvand plain located 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 Geographic Information System (GIS). The obtained results showed that for 3220 ha (24.2%) of the study area surface irrigation method was highly recommended ; whereas for 9015 ha.(67.6%) of the study area a sprinkler irrigation method would provide to be extremely efficient and suitable ;moreover, it was found that 3515 ha (26.4%) 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 12590 ha (94.7%) in the Gotvand Plain will improve. 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. It is of note however that the main limiting factors in using surface, sprinkler and drip irrigation methods in this area were drainage and calcium carbonate content.
Key words: Surface irrigation, sprinkler irrigation, drip irrigation, land suitability evaluation, parametric method, soil series.

Introduction

An adequate supply of water is important for plant growth. When rainfall is not sufficient, crops must be provided with additional water (irrigation) from other sources. The big problem affecting the agriculture sector on the Iran is the lack of rainfall. In Gotvand's district, the irrigation development constitutes a privileged solution for improving agricultural production. Irrigation reduces the crop failure risk due to rainy deficit and ensures the possibility to cultivate during dry season. Mismanagement of irrigation results in severe problems such as salinisation, alkalinisation and water logging. In order to avoid land degradation, irrigation water and techniques must be compatible with the soil properties. To decide where to apply irrigation and to choose the appropriate method, natural conditions, previous experience with irrigation, required labor inputs, type of crops and technology, costs and benefits; including other factors should be considered .For this reason, it is necessary to evaluate the suitability of land for irrigation. According to FAO methodology (1976) land suitability is strongly related to "land qualities" including erosion resistance, water availability and flood hazards which are derived from slope angle and length, rainfall and soil texture. Sys *et al*., (1991) suggested a parametric evaluation system for irrigation methods which was primarily based on physical and chemical soil properties.

Dengiz (2006) compared different irrigation methods including surface and drip irrigation in the pilot fields of 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.

Azzat *et al.*, (2007) provided a land suitability evaluation for irrigation in the Essaouira Province, Morocco, by using parametric evaluation systems. The largest part of this province was classified as marginally suitable and permanently not suitable. Also, the smallest portion of the cultivated area in this plain (located in the center) is deemed as being moderately suitable for irrigation.

Gizachew and Ndao (2008) evaluated the land suitability for surface (gravity) and drip (localized) irrigation in the Enderta District, Tigray, Ethiopia, using Sys's parametric evaluation systems. Regarding the surface irrigation, the result indicate that 1.5% of the land is highly suitable (S1), 14.3% moderate suitable (S2), 22.3% slightly suitable (S3). Most of the study area is permanently unsuitable (55.6%) and currently unsuitable (1.2%). For drip (localized) irrigation, the result show 15.8 % of the land is highly suitable (S1), 22.8 % moderately suitable (S2), 2.3 % slightly suitable (S3), 49.2 % permanently unsuitable (N2) and 4.9 % currently unsuitable (N1). Drip irrigation can be a good method of irrigation in this region, if it is managed properly (proper design, filters, etc.)

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.

Albaji *et al.* (2010b) investigated different irrigation methods based upon a parametric evaluation system in an area of 29,300 ha in the Abbas plain located in the Elam province, in the West of Iran. The results demonstrated that by applying sprinkler irrigation instead of surface and drip irrigation methods, the arability of 21,250 ha (72.53%) in the Abbas plain will improve.

Brou Yao and Woldegiorgis Hishe (2010) performed a land suitability evaluation for surface irrigation and drip irrigation, in the Kilte Awulaelo District - Tigrayregion – Ethiopia using the Sys et al parametric evaluation. The drip irrigation suitability gave more irrigable areas compared to the surface irrigation practice, due to the topographic (slope), soil (depth and texture), surface stoniness and drainage limitations worked out in the surface irrigation suitability evaluation.

Albaji *et al.* (2010c) compared the different irrigation methods based on the parametric evaluation approach in Dosalegh plain: Iran, using a parametric evaluation system. The results revealed that the drip and sprinkler irrigations methods were more effective and efficient than that of surface irrigation for improved land productivity.

Diouf and Sarr (2011) compared different irrigation methods including surface and drip irrigation in the Sant'Antioco Island- Southern Sardinia, Italy. The comparison between the two irrigation systems show that the drip irrigation can be a good irrigation method in this region, if properly managed (good planning, use of filters, etc).

The main objective of this research is to evaluate and compare land suitability for surface, sprinkler and drip irrigation methods, using the parametric evaluation systems, and soil characteristics in the Gotvand Plain, in the Khuzestan Province, South West of Iran.

Materials and Methods

The present study was conducted in an area about 13300 hectares in the Gotvand Plain, in the Khuzestan Province, located in the South West of Iran during 2011-2012 (Fig. 1). The study area is located 20 km west of the city of Shushtar, 81.000 to 100.000 N and 93.000 to 110.000 E. The Average annual temperature and precipitation for the period 1961–2007 were 24.6^{o}C and 404.6 mm, respectively. (Table.1) (Khuzestan Water and Power Authority, 2010). The Karun River supplies the bulk of the irrigation water demands of the region. Irrigation 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 two distinct physiographic features i.e. Alluvial Flood Plains and Terraces of which the Alluvial Flood Plains physiographic unit is the dominating feature. Also, sixteen different soil series have been identified in the area (Table.2). The semi-detailed soil survey report of the Gotvand plain (Khuzestan Water and Power Authority. 2009) was used in order to determine the soil characteristics. Table 3 shows some of physico–chemical characteristics for reference profiles of the 16 different soil series in the plain. The land evaluation was determined based upon topography (soil slope) and soil characteristics, particularly soil texture, depth, salinity, drainage and calcium carbonate content. Soil properties such as cation exchange capacity (CEC), percentage of basic saturation (PBC), organic matter (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 upon the conventional methods of the Iranian Soil and Water Research Institute (1997), and the following properties were measured by due methods: Electrical Conductivity (EC, $dS.m^{-1}$ at 25ºC) was measured in soil water extract; the soil texture was determined using the Gravimetric method (pipette). The proportional distribution of coarse sand (2.0-0.2mm), medium sand (0.2-0.1mm), fine sand (0.1-0.05mm), coarse silt (0.05-0.02mm), fine silt (0.02-0.002mm), and clay (<0.002mm) 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 classified to form a soil family as described by Soil Survey Staff (2008). Sixteen soil series were selected for the surface, sprinkler and drip irrigation land suitability.

To obtain the average soil texture, salinity and CaCO3 for the upper 150 cm of soil surface, the profile was subdivided into 6 equal sections 25 cm apart. 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 (Olson, 1981).
The Chemical and physical soil proprieties are determined in the soil laboratory of Khuzestan Water and Power Authority. 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).
- 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 4-9) [Sys *et al*., (1991) for surface and drip irrigation & Albaji (2010a) 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 = rating of soil texture;
- B = rating of soil depth;
- C = rating of calcium carbonate content;
- D = rating of electrical conductivity;
- E = rating of soil drainage;
- F = rating of soil slope.

The capability index and the corresponding suitability classes are then ranked according to Table 10.

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 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 sixteen different polygons or soil series were determined in the base map. Soil characteristics were also given for each soil series. These values were used to generate the land suitability maps for surface, sprinkler and drip irrigation systems using Geographic Information Systems.

Results and Discussion

In Gotvand 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 Karun River, water harvesting and digging wells from the ground water. The major irrigated broad-acre crops grown in this area are wheat, barley, and maize. There are very few instances of sprinkler and drip irrigation on large area farms in the Gotvand Plain.
Sixteen soil series were derived from the semi-detailed soil study of the area. The soil series are shown in Fig.2 as the basis for further land evaluation practice. The soils of the area are of Entisols and Inceptisols orders. Also, the soil moisture regime is Ustic while the soil temperature regime is Hyperthermic (Khuzestan Water and Power Authority.2009).
As shown in Tables 11 and 12 for surface irrigation, the soil series coded 2 and 6 (3220 ha, 24.2% of the study area) were highly suitable (S_1); soil series coded 1, 3, 4, 5, 10, 13 and 15 (7445 ha, 55.9 %) were classified as moderately suitable (S_2), soil series coded 9, 12 and 14 (965 ha, 7.3%) were found to be marginally suitable (S_3). soil series coded 7, 8 and 11 (715 ha, 5.4%) were classified as currently not-suitable (N_1) and only soil series coded 16 (245 ha, 1.9 %) 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), indicate that some part of the cultivated area in this plain (located in the north) is deemed as being highly suitable land (S1). This was due to deep soil, good drainage, suitable texture, salinity and proper slope of the area. The moderately suitable area (S2) can be observed in the largest part of the cultivated zone in this plain (located in the north, center and the south) and is due to the medium calcium carbonate content and drainage limitations. Other factors such as depth, salinity and alkalinity have no influence on the suitability of this S2 area. The map also indicated that only some part of the cultivated area in this plain was evaluated as marginally suitable (S3), because of the sever calcium carbonate content and drainage limitations. The current non-suitable land (N1) can be observed in the largest part of the plain (located in the south, center and north); due to severe salinity and alkalinity. The permanently non-suitable land (N2) located in east part of this area studied was due to very severe salinity, alkalinity, calcium carbonate content and drainage limitations.

In order to verify the possible effects of different management practices, the land suitability for sprinkler and drip irrigation was evaluated (Tables 11 and 12).

For sprinkler irrigation, soil series coded 1, 2, 3, 4, 6, 10 and 15 (9015 ha, 67.6% of the study area) were highly suitable (S1) while soil series coded 5, 12, 13 and 14 (2290 ha, 17.3%) were classified as moderately suitable (S2). Further, soil series coded 7, 8, 9 and 11 (1040 ha, 7.9%) were found to be marginally suitable (S3) and only soil series coded 16 (245 ha, 1.9 %) were classified as permanently not-suitable (N2) for sprinkler irrigation.

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 north , center and the south) due to deep soil, good drainage, adequate texture, low salinity and proper slope of the area. As seen from the map, part of the cultivated area in this plain was evaluated as moderately suitable for sprinkler irrigation because of the medium calcium carbonate content and moderate drainage limitation. Other factors such as depth, salinity and slope never influence the suitability of the area. The marginally suitable lands were found only in the east and south of the area studied. The limiting factors for these soil series were high content of calcium carbonate and severe drainage limitations. The current non-suitable lands did not exist in this plain. The permanently not-suitable lands are located only in the smallest part of the plain, and their non-suitability is due to high content of calcium carbonate and very severe salinity and alkalinity limitations. For almost the entire study area slope, soil depth and soil texture, were never taken as limiting factors.

For drip irrigation, soil series coded 2, 6 and 10 (3515 ha, 26.4%) were highly suitable (S_1) while soil series coded 1, 3, 4, 5, 12, 13, 14 and 15 (7790 ha, 58.5%) were classified as moderately suitable (S_2). Further, soil series coded 7, 8, 9 and 11 (1040 ha, 7.9%) were found to be slightly suitable (S_3) and only soil series coded 16 (245 ha, 1.9 %) were classified as permanently not-suitable (N_2) for drip irrigation.

In this case, (Fig. 5) the highly suitable area can be observed in the some part of the cultivated zone located in the north and west area. They were due to deep soil, good drainage, suitable texture, low salinity and proper slope of the area. The largest portion of the cultivated area in the plain was evaluated as moderately suitable for drip irrigation; because of the medium calcium carbonate content. The map also indicated that the some part of the cultivated area in this plain which is located in the east and south of the zone was evaluated as marginally suitable; due to the to high content of calcium carbonate and severe drainage limitations The current non-suitable lands did not exist in this plain. The permanently not-suitable lands are located only in the smallest part of the plain, and their non-suitability of the land is due to high content of calcium carbonate and very severe salinity and alkalinity limitations. For almost the entire study area slope, soil depth and soil texture, were never taken as limiting factors.

The mean capability index (Ci) for surface irrigation was 74.54 (Moderately suitable) while for sprinkler irrigation it was 82.93 (Highly suitable). Moreover, for drip irrigation it was 78.94 (Moderately suitable). the comparison of the capability indices for surface, sprinkler and drip irrigation (Tables 11 and 13)indicated that in soil series coded 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15 and 16 (all of the soil series)applying sprinkler irrigation systems was more suitable then surface and drip irrigation systems. Fig.6 shows the most suitable map for surface, sprinkler and drip irrigation systems in the Gotvand plain as per the capability index (Ci) for different irrigation systems. As seen from this map, sprinkler irrigation is the best suitable of all irrigation technologies in all soil series.

The results of Tables 11 and 13 indicated that by applying sprinkler irrigation instead of surface and drip irrigation methods, the land suitability of 12590 ha (94.7%) of the Gotvand Plain's land could be improved substantially. 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. Pressurized Irrigation (sprinkler and drip irrigations) is characterized by higher water distribution efficiency, minimization of soil erosion, and reduction of leaching. In case of reduced water availability, this method can be much preferable to surface irrigation. For this reason, it is better to promote this irrigation system in Gotvand Plain. Also, due to Khuzestan Province, is the biggest producer of oil, gas and electricity in Iran, the cost of infrastructures and energy are not expensive in this region, therefore the development of pressurized Irrigation (sprinkler and drip irrigations) is necessary for this province. Moreover, surface irrigation is strongly dependant on the water source. To sum up the most suitable irrigation systems for the Gotvand Plain' were sprinkler irrigation, drip irrigation and surface irrigation respectively. Moreover, the main limiting factors in using surface sprinkler and drip irrigation methods in this area were drainage and calcium carbonate content.

Conclusions

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 irrigation method for most of the soils tested. Therefore, sprinkler and drip irrigation methods are highly recommended for a sustainable use of the soil resource; i.e. changing the surface to pressurized (sprinkler and drip) system in the study area. Sprinkler and drip irrigation systems are more suitable than surface irrigation method for all the study area. The major limiting factors for surface, sprinkler and drip irrigation methods in this area were drainage and calcium carbonate content. The comparison of the maps indicated that the introduction of a different irrigation management policy would provide an optimal solution, 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 operating in the area and it proves to be economically viable for farmers in the long run. 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. The shift from surface irrigation to high-tech irrigation, e.g. sprinkler and drip irrigation systems offers significant water-saving potentials. 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 the plain.

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