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Parametric Land Evaluation for Different Irrigation Systems in El-Bahariya Oasis, Western Desert, Egypt

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ABSTRACT

Water use efficiency is a research topic of increasing importance, especially in arid lands. The main objective of this work is to apply parametric evaluation techniques for assessing the most suitable irrigation systems in an area of 36 km2 in the south of Bahariya Oasis of the Western Desert in Egypt using GIS. Twelve soil profiles were made to represent the different landforms of the study area. The soil physicochemical analyses were carried out and input in the Geographic Information System to produce suitability maps for irrigation methods. The results indicated that the application of drip irrigation increased the suitability of the land by 37.9% compared to sprinkler irrigation and 47.2% compared to surface irrigation. On the other hand, the application of surface irrigation reduced land suitability by 9.4% compared to sprinkler irrigation and 47.3% compared to drip irrigation. The main Limitations in using surface, and sprinkler irrigation methods are salinity , coarse texture and slope while limitations in using drip irrigation are salinity and coarse texture. Based on these results, applying the drip irrigation method in the study area is efficient and useful in improving land productivity and conservation.

Keywords: Water use efficiency, drip irrigation, sprinkler irrigation, surface irrigation, land suitability.

INTRODUCTION

The management of water resources in its broad sense includes not only the development of water resources but also the management of water in a way that ensures the long-term sustainable use of future generations. In this context, prudent irrigation management is important because it helps determining future irrigation expectations and achieving the most profitable way to use water at sustainable production levels (Ali, 2011).

Water is one of the most important natural resources in the world, especially in arid and semi-arid regions and in parts of the world where there are insufficient water resources. Therefore, irrigation water management and increasing irrigation efficiency, by efficiently reducing the amount of water and energy consumed, has become the primary limiting factor for the production of a crop (Sheta & Fayed, 2021, Asres, 2016 and Surendran *et al*., 2016).

The process of land evaluation mainly includes determining the suitability of the land in an area for certain uses, taking into account the cost of that. Land valuation methods have been adopted to predict the potential of land under various changes, such as crop rotation, different management practices, water management procedures, and climate change. The aims of land evaluation are the identification of adverse effects and benefits of land uses (Mahmoud *et al*., 2020 and Abdel Rahman *et al*., 2017)

Geographic Information System (GIS) can be used as an effective tool in many agricultural applications such as cropland assessment for sustainable agricultural land use planning (Aldabaa & Yousif,2020).

Abdellatif (2021) carried out an evaluation of the application of surface and Drip irrigation in the Matrouh area, northwest coast of Egypt, the results indicated that the system of drip irrigation increased the suitability of land by 31% compared to surface irrigation. The most limiting factors were texture, profile depth, drainage condition, and the ratio of CaCO3 in profile. Thus, drip irrigation is more beneficial than surface irrigation in this region. Naseri *et al.* (2009) studied soil qualities governing the use of the surface, drip, and sprinkler irrigation systems in Lali Plain in Iran, and found that there are 6 factors that limit the application of irrigation systems, namely; Texture, depth, CaCO3, EC, drainage, and slope. The results showed that about half of the area was suitable for the studied irrigation methods, while only about 11% of the area was unsuitable for surface irrigation and suitable for the other two types of irrigation. Albaji *et al*. (2015) In the Jizan Plain, Iran, evaluated an area of 15000 ha for different irrigation methods (surface, sprinkler, and drip) using GIS. The results showed that about 35.17% of the study area is highly recommended for surface irrigation while about 50% of the study area is extremely suitable for sprinkler irrigation while about 48.83% of the study area is highly suitable for drip irrigation. It was found that there are limitations for the use of sprinkler irrigation methods including gravel percentage, soil texture, drainage, and calcium carbonate, and others for drip irrigation methods where the drainage and calcium carbonates were limiting factors.

In the Bahariya Oasis, as a depression in the Western Desert of Egypt, where the drainage process is carried out internally, the presence of groundwater and the problem of drainage is common. The challenge is to be aware of the problem and to design a proper soil and water management system based on the compatibility of soil and terrain characteristics to prevent soil degradation and increase productivity (Al-Ashri & Belal,2010 and Elwan & Khalil,2018).

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El Bastawesy *et al*. (2013) studied the evolution of waterlogging in Bahariya Oasis as a natural depression in the central part of the Western Desert of Egypt, where the drainage process takes place through a closed drainage basin; Therefore, the downward leaching of excess irrigation water is limited by the development of a solid layer under the surface, as a result of which the upper layer of the soil becomes waterlogged.

Therefore, the main objective of this work is to assess the most suitable method of irrigation, which is compatible with the characteristics of the soil and the study area, by applying parametric evaluation in GIS environment. Consequently, this could maximize water use efficiency to maintain optimal agricultural production and reduce soil degradation.

MATERIALS AND METHODS

Study Area

The study area has located south of The Bahariya oasis, in the Western Desert of Egypt (Fig. 3), It extends with a surface area of 36 km2 and bounded between latitudes of 28º10" and 29º00" N and in longitudes of 28º46" and 28º52"

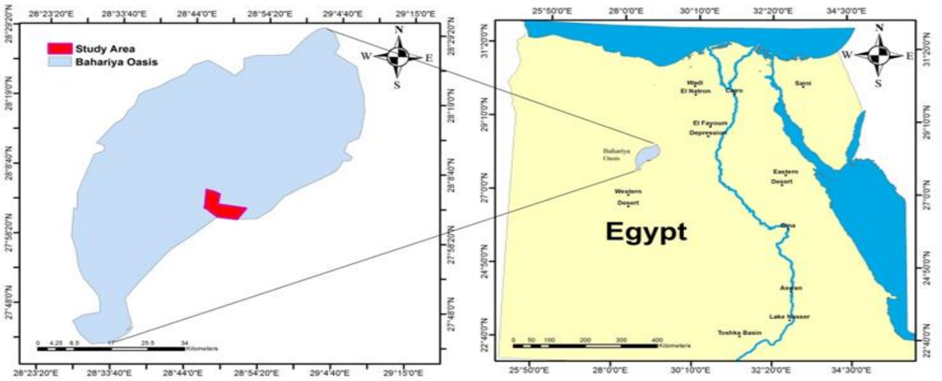

Fig. 1. Location of the study area in El-Bahariya oasis at the western

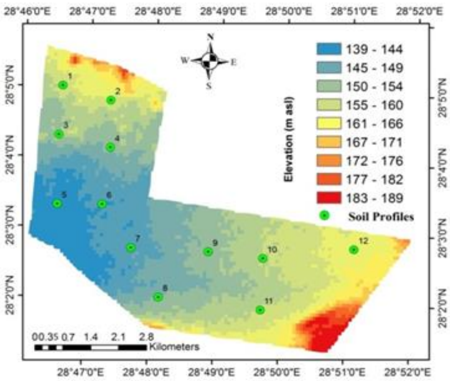

Fig. 2. DEM of the study area and profiles location.

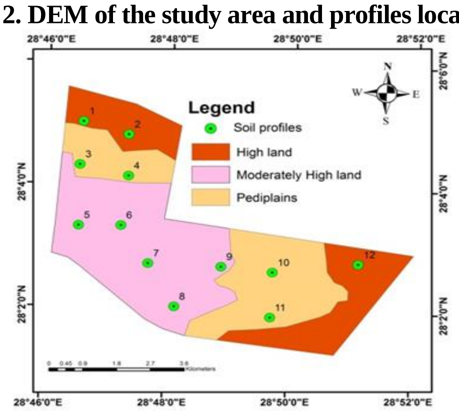

Fig. 3. Physiographic map of the study area and profiles location.

The air temperature of the El-Bahariya Oasis varies from 10-20 ºC in winter to 20-30 ºC in summer. Mean annual precipitation is about 4 mm (Elnaggar *et al*., 2013).

Therefore, according to the keys to Amirican Soil Taxonomy system, the soil in the study area has a temperature regime that is Hyperthermic, while the moisture regime is Torric and the mostly soil in the study area is *Entisols* (Soil Survey Staff, 2014). According to Moustafa, *et al.*, 2003, the geological deposits in the study area consisted of two ages: the first is the Eocene and underlain by upper Cretaceous. Cretaceous is divided into El-Bahariya formation, El-Heiz formation, and El-Hefhuf formation. The previous formations consisting of a 660 m thick layer of undifferentiated sandstones, sands, and clays intercalated with each other and occupying the Oases floor while Eocene is overlying the previous formation and appears as a remnant in the depression. The surrounding plateau is mainly of Eocene limestone. The Eocene limestone forms the surface of the discontinuous plateau surrounding the El-Bahariya depression and some ridges within it.

Soil mapping and sampling

A digital elevation model (DEM) was created using SRTM (Shuttle Radar Topography Mission) with a resolution of 30 m, and the extracted data showed that the Surface elevation of the Study area varies from 139 to 189 m (a.s.l), (Fig. 2). Landsat ETM images (2018) and DEM were used in ENVI 5.0 software to establish the physiographic map of the studied area according to (Dobos *et al*., 2002 and Zinck & Valenzuela, 1990). Twelve soil profiles were selected for the study according to types of landforms (Fig. 3). These profiles were described morphologically and samples were taken for each layer according to the soil survey manual (USDA, 2012).

Laboratory analysis

The soil samples were collected during 2018, transferred to the laboratory, and then air-dried, crushed to pass through a 2 mm sieve for physiochemical analyses according to the method mentioned in Estefan *et al*. (2013) and Ryan *et al.* (1996) The analyzes performed included the following: Soil pH (1:2 soil: water suspension), Electrical conductivity (in saturated soil paste extraction), Total calcium carbonate (Collin's calcimeter), gypsum content, (precipitation with acetone), and Particle size distribution (pipette method).

Parametric Evaluation System (Sys *et al.* 1991)

To assess the suitability of the land for surface irrigation, drip irrigation, and flood irrigation, a standard evaluation system based on the physicochemical properties of the soil was used, especially the slope, drainage condition, soil salinity, lime content, soil texture, and soil profile depth, and then set their respective rates according to the relevant tables. Thus, the land capability index for irrigation (Ci) types was developed as shown in the OLSEN equation (1981) below:

$$C_i = A \cdot \frac{B}{100} \cdot \frac{C}{100} \cdot \frac{D}{100} \cdot \frac{E}{100} \cdot \frac{F}{100}$$

where:

A⇨Soil texture rating;
B ⇨ Profile depth rating ;
C⇨ Total calcium carbonate rating;
D ⇨ Soil salinity rating;
E ⇨ Drainage condition rating;
F ⇨ Slope rating.

In order to assess the soil of the study area in terms of the suitability of applying different irrigation methods, whether surface irrigation, sprinkler, or drip, the capability index of the studied soils was calculated to be placed on the final scale of soil suitability for different irrigation systems

Table 1, shows the ranges of capability index and the corresponding suitability classes for the irrigation capability indices (Ci) classes.

Table 1. Rating and description of drainage classes for different irrigation types.

Capability index	Definition (symbol)	Extent limitation
> 80	highly suitable (S_1)	no limitations
60–80	moderately suitable (S_2)	minor limitations
45–59	marginally suitable (S_3)	moderate limitations
30–44	currently not suitable (N_1)	severe limitations
< 29	permanently not suitable (N_2)	severe limitations

Spatial Analysis

The data obtained from the fieldwork and laboratory analyses were imported to Arc-GIS software and linked with their relevant soil profiles. Spatial interpolation by collecting data at distinct locations (e.g. soil profiles character) is often used to produce continuous information such as the creation of land suitability maps using the kriging method. The kriging method is based on predicting the value of a function at a particular point by calculating the weighted average of the known values of the function near the point. Arc-GIS 10.3 software (ESRI, 2011) was used to interpolate the suitability of different irrigation systems in the study area. (Fig. 4).

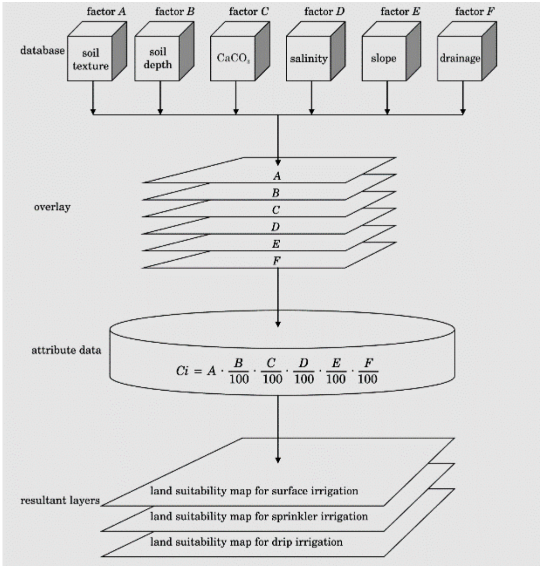

Fig. 4. GIS application scheme to produce land suitability maps for irrigation methods.

RESULTS AND DISCUSSION

Depending on the soil data as shown in Tables 2 and 3 which are soil depth, soil texture, electrical conductivity, total calcium carbonate, drainage, and slope, the indicators of suitability of irrigation methods were calculated and evaluated for each soil profile separately so that the resulting values were entered into a system of Geographic information system to produce suitable soil maps for different irrigation systems as shown in Fig. 5,6,7 and 8.

Soil properties

The morphological characteristics showed that the soil surface is gently sloping to the sloping terrain (3.3-7.6%), and the depth of its profiles is very deep to moderately (170-90 cm). Soil textures varied from sandy to clay, but most soil profiles have coarse to Moderately fine textures. They are Slight to Moderately calcareous with 6.6 to 77.0 g kg^{-1} calcium carbonate content (Table 2). The data in the same table confirms that the soils are slightly to moderately alkaline, where having pH values between 7.3 to 8.37. These soils are ranged from very slightly to strongly saline, with ECe values between 3.04 to 65.13 dSm^{-1}. The content of gypsum is slightly to Moderately gypsiric (6.0 to 67.0 g kg^{-1}).

Table 2. Some physiochemical and environmental characteristics of reference soil profiles

Profiles No.	Depth, cm	pH	EC, ds m^{-1}	CaCO3, g kg^{-1}	Gypsum, g kg^{-1}	Sp%	Soil texture	CEC, cmolc kg^{-1}	slope
1	170	7.77	19.67	50.0	40.0	5.1	S	2.3	3.3
2	135	7.87	60.03	34.0	55.0	6.5	S	2.2	5.7
3	150	7.83	25.17	33.0	67.0	4.7	S	3.5	7.6
4	120	7.81	25.72	48.0	37.0	4.6	S	2.9	4.1
5	150	7.77	18.67	77.0	35.0	6.5	S	3.5	6.6
6	90	7.82	11.56	57.0	56.0	20.5	SL	6.1	3.8
7	150	7.57	15.73	15.0	11.0	39	SCL	10.5	7.4
8	165	7.67	44.67	9.0	6.0	39.5	SCL	9.5	6.1
9	150	8.23	4.04	11.0	9.0	50	SCL	14	6.8
10	160	8.37	10.90	16.0	14.0	24	SL	8	7.5
11	175	7.30	65.13	7.0	6.0	78	C	30	4.5
12	140	7.37	35.67	6.6	13.0	43	CL	17.5	3.9

EC, electrical conductivity; CEC, Cation exchange capacity; Sp, saturation percent; S, sand; SL, Sandy loam; SCL, Sandy clay loam; C, Clay; C L, clay loam

Table 3. Suitability classes and limitations of irrigation systems of soil in study area

profiles	Surface irrigation			Sprinkler irrigation			Drip irrigation		
No.	Ci	Classes	limiting factor	Ci	Classes	limiting factor	Ci	classes	limiting factor
1	16.2	N2	T.E	32.2	N1	T.E	49.9	S3	T.E
2	12.3	N2	T.E.S	24.9	N2	T.E.S	38.9	N1	T.E
3	14.4	N2	T.E.S	28.8	N2	T.E.S	44.9	S3	T.E
4	16.2	N2	T.E	32.2	N1	T.E	49.9	S3	T.E
5	14.4	N2	T.E.S	28.8	N2	T.E.S	44.9	S3	T.E
6	23.1	N2	T.E	32.8	N1	T.E	40.6	N1	E
7	32.5	N1	T.E.S	36.4	N1	T.E.S	40.6	N1	E
8	13.0	N2	T.E	14.6	N2	T.E	20.3	N2	E
9	58.1	S3	T.S	72.9	S2	S	78.2	S2	E
10	25.7	N2	T.E.S	34.5	N1	T.E.S	40.6	N1	E
11	34.9	N1	T.E	44.9	S3	T.E	52.5	S3	E
12	15.4	N2	T.E	17.1	N2	T.E	23.8	N2	E

Ci, capability index; T, Soil texture; S, Slope; E,EC

Land suitability for irrigation systems

The results indicated that Land suitability indices and classes for irrigation systems presented in Tables 3 and 4 and Fig. 5,6,7 and 8 show that the studied soils are classified into four suitability classes namely S2, S3, N1, and N2. Where moderately suitable soil (S2) represented 5.3% for sprinkler irrigation and 8.5% for drip irrigation. while marginally suitable soil (S3) represented 9.4% for surface, 13.4% for sprinkler, and 48.2% for drip. Thus, the suitable soil under drip irrigation represents 56.7% of the study area, while this area decreased when using sprinkler irrigation (18.8%) and decreased even more under the surface irrigation system (9.5%).

In contrast, the soil that is currently not suitable (N1) represented 19.5% for surface, 52.5% for sprinkler, and 35.6% for drip. In the same context, the Permanently not suitable soil (N2) represented 71.0% for surface, 28.7% for sprinkler, and 7.6% for drip. Thus, the unsuitable soil under drip irrigation represented 43.3% of the study area, while it wanted this area when using sprinkler irrigation (81.2%) and increased more under the surface irrigation system (90.6%).

According to former results, the effect of salinity, coarse texture, and slope as main limiting factors for using irrigation methods in the study area varied. Coarse texture and slope had the greatest effect on the use of surface irrigation and sprinkler irrigation, where it can be arranged in descending order in terms of the degree of its limit for use of both surface irrigation and sprinkler as follows: salinity, coarse texture, slope. On the other hand, the salinity and coarse texture were limiting factors to the use of drip irrigation, but the coarse texture was less effective as limiting factors to the use of drip irrigation, where water could be added in small quantities and at successive times to prevent water loss due to deep percolation

Based on these results, the application of drip irrigation increased the suitability of the land by 37.9% compared to sprinkler irrigation and 47.2% compared to surface irrigation. On the other hand, the application of surface irrigation reduced land suitability by 9.4% compared to sprinkler irrigation and 47,3% compared to drip irrigation.

When comparing different irrigation methods, it will be clear that drip irrigation is more suitable compared to surface irrigation and sprinkler irrigation, while sprinkler irrigation is more suitable than surface irrigation. These results could be enhanced with those obtained by Albaji *et al.* (2015) and Seyedmohammadi *et al.* (2016).

Table 4. Distribution of irrigation suitability for irrigations methods

Ci	Surface			Sprinkler			Drip		
	Km^2	%	Feddans	Km^2	%	Feddans	Km^2	%	Feddans
S2	00	00	00	1.9	5.3	458.2	3.1	8.5	733
S3	3.4	9.4	809.8	4.8	13.4	1151.7	17.3	48.2	4126.7
N1	7.0	19.5	1673.4	18.9	52.5	4500.2	12.8	35.6	3053.8
N2	25.6	71.0	6084.2	10.3	28.7	2457.3	2.7	7.6	653.9
total	36.0	100.0	8567.4	36.0	100.0	8567.4	36.0	100.0	8567.4

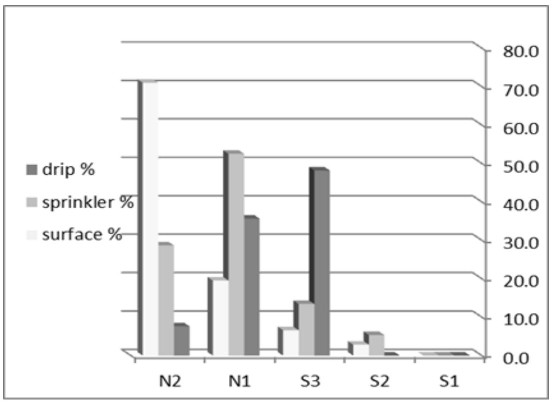

Fig. 5. percent of suitability for irrigations methods

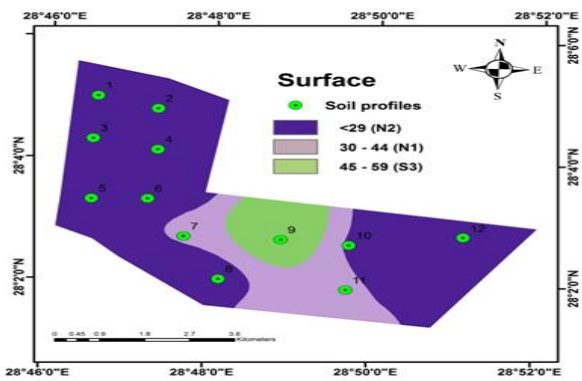

Fig. 6. Surface irrigation suitability

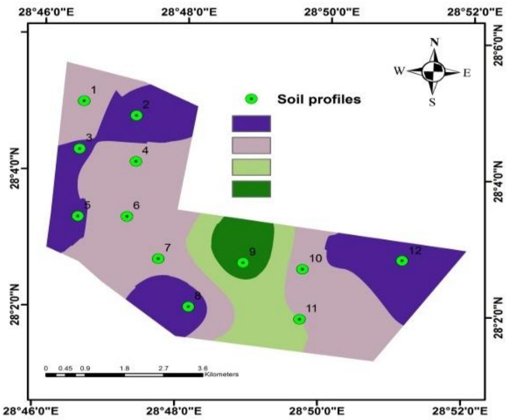

Fig. 7. Sprinkler irrigation suitability

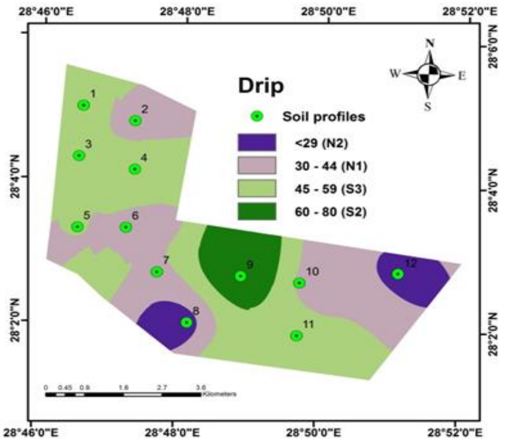

Fig. 8. Drip irrigation suitability

CONCLUSION

Good irrigation practices by choosing the type of irrigation commensurate with the characteristics of the soil are one of the important pillars of sustainable soil use, improving production and increasing water use efficiency. The main objective of this research was to identify which irrigation systems were more efficient for use in the study area based on soil characteristics. To do this, the results of the evaluation were compared using three different irrigation methods. The results showed that the most suitable irrigation methods were drip irrigation, followed by sprinkler irrigation then surface irrigation, where the suitability of the land by applying drip irrigation increased by 37.9% compared to sprinkler irrigation and 47.2% compared to surface irrigation. The limitations to the use of sprinkler and surface irrigation were first the high salinity, followed by the coarse texture of the soil and then the high slope, while for drip irrigation, the first limiting factor is high salinity, followed by the coarse texture. therefore, it is highly recommended to use drip irrigation in the studied area. Despite the importance of this work, this point still needs further study, but taking into account some other factors that may have an impact on the selection of the most suitable irrigation type such as Climate, Water availability, Water quality, and type of crop. where the drip irrigation system usually applies less water than the other irrigation methods, and because of the limited surface and groundwater resources in the region. This research can be a scientific beginning to ensure the sustainable management of water resources in the study area and Egypt in general.

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التقييم المعياري لأنظمة الري المختلفة في الواحة البحرية ، الصحراء الغربية ، مصر

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تعتبر كفاءة استخدام المياه من الموضوعات البحثية ذات الأهمية المتزايدة ، خاصة في الأراضي القاحلة. الهدف الرئيسي من هذه الدراسة هو تطبيق تقنيات التقييم البارامترية لتقييم أنسب أنظمة الري في منطقة تبلغ مساحتها 36 كيلومترًا مربعًا في جنوب الواحات البحرية في الصحراء الغربية في مصر باستخدام نظم المعلومات الجغرافية. تم عمل اثني عشر قطاعا للتربة لتمثيل الأشكال الأرضية المختلفة لمنطقة الدراسة. تم إجراء التحليلات الفيزيائية والكيميائية للتربة اللازمة ومن ثم إدخالها في بيئة نظم المعلومات الجغرافية لإنتاج خرائط ملائمة لطرق الري المختلفة. أشارت النتائج إلى أن تطبيق الري بالتنقيط زاد من ملاءمة الأرض بنسبة 37.9٪ مقارنة بالري بالرش و 47.2٪ مقارنة بالري السطحي. من ناحية أخرى ، أدى تطبيق الري السطحي إلى تقليل ملاءمة الأرض بنسبة 9.4٪ مقارنة بالري بالرش و 47.3٪ مقارنة بالري بالتنقيط. تتمثل المحددات الرئيسية على استخدام طرق الري السطحي والري بالرش في ارتفاع الملوحة والقوام الخشن والانحدار الشديد بينما المحددات على استخدام الري بالتنقيط هي الملوحة والقوام الخشن. بناءً على هذه النتائج ، فإن تطبيق طريقة الري بالتنقيط في منطقة الدراسة فعال ومفيد في تحسين إنتاجية الأرض والحفاظ عليها.