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Soil Water Erosion Vulnerability and Suitability under Different Irrigation Systems Using Parametric Approach and GIS, Ismailia, Egypt

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Abstract: Preserving the sustainable agriculture concept requires identifying the plant response to the water regime and rationing the water for irrigation. This research compares different irrigation designs coupled with a parametric evaluation system on soil water erosion and soil suitability to assess the sites vulnerable to soil erosion based on a soil water erosion model (ImpelERO) in an area of 150.0 hectares, Ismailia Governorate, Egypt. Land suitability maps are prepared using the Geographic Information System (GIS), and the soil properties are analyzed and evaluated for the different surface, sprinkler, and drip irrigation methods. The results show that the sprinkler and drip irrigation strategies are more practical irrigation methods and additional environment friendly than surface irrigation for enhancing land productivity. Moreover, the principle acumen for creating use of the surface irrigation on this space is for lowering the soil salinity. Land capability index for surface irrigation ranges from 20.5 to 72.2% (permanently not suitable N2 to moderately suitable S2); and the max capability index (Ci) for drip irrigation was 81.3% (highly suitable-S1), while the mean capability index (Ci) was 42.87% (Currently not suitable-NI). The land suitability of the study area using sprinkler irrigation was ranked as highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and currently not suitable (N1). Thus, the obtained data indicated that applying drip irrigation (trickle irrigation) was the most efficient system compared to the sprinkle and surface irrigation systems. To identify the soil, water erosion vulnerability, and soil optimal management strategies for the agricultural parcel in that region, the ImpelERO model (soil erosion vulnerability/impact/management) was applied. Erosion risk classes ranged from V2 (small) to V3 (moderate), that that region categorized as small-sensitive to water erosion by alfalfa, to moderate-sensitive to water erosion by olive. The results of soil losses varied from 7.1 to 37.9 t ha^{-1} yr^{-1} with an average of 17.7 t ha^{-1} yr^{-1}. Thus, guarantee efficient water use and soil suitability for food production in the future will require the use of an efficient irrigation system.

Keywords: soil water erosion; irrigation systems; parametric methods; ImpelERO model; soil degradation

1. Introduction

Water scarcity is the lack of water resources that sufficiently meet the demands of water usage in the Middle East and North Africa (MENA) regions. Due to the rapidly growing population in Egypt, it is ranked among the top ten countries by 2025 with water shortages. Mechanisms of water scarcity could be identified by two main approaches: (2) Physical water scarcity that takes place, due to the inadequate natural water resources used to supply the region's demand; and (2) economic water scarcity, which prevails as a result of water resources poor management [1–3]. Since soil is the main natural resource that is prepared for land conservation and land management, so the key factor for success in this strategic plan is based on relevant agricultural practices with suitable land-use planning. Thus, there should be a clear vision to improve and use the optimal irrigation systems [4]. Furthermore, climate changes and environmental stresses through their impacts on crop losses affect agricultural production and food supply [5–7]. In addition to the limited relevant lands for agricultural purposes, the water resources constrain Egypt's ambitious expansion plans to increase the cultivated area [8,9]. Where Egypt initiated its main strategic plan that aims to reclaim approximately 600 thousand hectares till 2030. Nevertheless, climate change and the current status quo of the environmental stresses had compelled the scientists, and the stakeholders to think about the water resources future [6,10], considering the high population growth rate and the shortage of water from Ethiopia to Egypt [11]. Therefore, using modern irrigation techniques was recommended instead of traditional surface irrigation [12,13], such as sprinkler and/or drip irrigation. Identifying a relevant irrigation regime is considered a vital strategy to enhance the water use efficiency for agriculture purposes in arid regions. Therefore, preserving a sustainable agriculture concept would require identifying the plant response to the water regime and rationing the water for irrigation [14,15]. In the arid regions that suffered from water scarcity phenomena and long summer drought, such as the Ismailia region (Suez Canal, Egypt), relevant irrigation strategies are extremely important to mitigate the yield reductions and increase the water use efficiency [14,16].

Parametric systems (land evaluation systems) are the simple quantified numerical correlation of soil productivity [17]. The parametric land evaluation methods are a semi-quantitative technique for land evaluation and consider the halfway between the qualitative and quantitative methods [17,18]. Parametric methods under different irrigation systems were examined in different arid and semi-arid regions for land suitability, such as the North Western coastal plain and Siwa Oasis, Egypt [19,20]. Land suitability for surface and drip irrigation in soils adjacent to El Hammam canal, North Western coastal, Egypt were evaluated by using the parametric methods. In addition, the same techniques were applied in several places in Iran, such as Dosalegh plain, Shush, Abbas, Jaizan, Dasht Bozorg, West North Ahwaz, and Sabzevar plains [21–25]. That drip irrigation system was more efficient for improving land productivity than surface irrigation methods [18].

The soil water erosion model (ImpelERO), a decision neural hybrid network model, was prepared to predict and identify the soil vulnerability to water erosion, and productivity reduction of field-scale of agricultural parcel [26]. The water process on land suitability for agriculture uses is analyzed as a static performance, including the interrail and rill erosion together [27]. According to Reference [28], the ImpelERO model was investigated and applied in 14 natural regions of East Azerbaijan province, Iran. The results showed that the soil, water erosion vulnerability indexes varied from 0.03 to 1.32, while the risk classes varied from very small (V1), small (V2), moderate (V3), large (V4), and extremely large (V5) in a region of 1080, 1860, 1184, 2981, and 1772 hectares, respectively. Furthermore, the ImpelERO model was used to develop a physically valid model for a large area, and to predict the soil, water erosion in Sevilla Province (Spain) based on the soil type and its management. According to the validation results, ImpelERO was performed well to identify and predict the effect of different managements on sediment yield [29].

The main purpose of this research is to assess and compare the suitability of soils under different irrigation systems using parametric evaluation systems. To identify the soil vulnerable to water erosion, productivity, reduction, and optimal irrigation and management strategies for a cultivated parcel at the western part of the Suez Canal, Ismailia, Egypt.

2. Materials and Methods

2.1. Study Area Description

Ismailia is an Egyptian city located in the middle of the Suez Canal territory—the entire area of Ismailia governorate is 5067 km^2. The study area is bounded by longitudes 32°8′29″ and 32°9′46″ E, latitudes 30°29′8″ and 30°28′11″ N, covering a surface area of roughly 150 hectares (Figure 1).

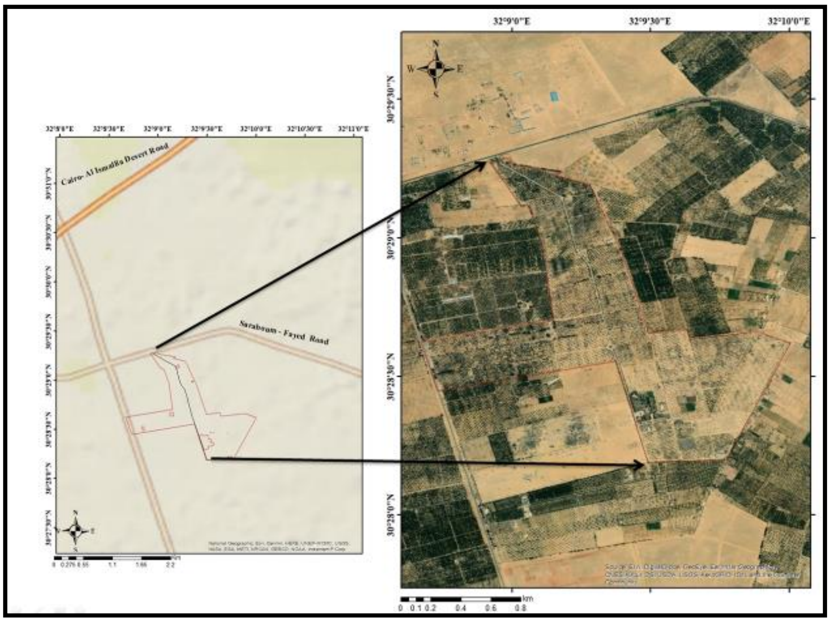

Figure 1. Location of the study area at Ismailia governorate, Egypt.

The analysis of meteorological data of the recent time coupled with the back-history reflects the weathering status, as well as the soil genesis. The studied region is characterized by a long dry summer with a high temperature and evaporation rate, and a short, mild winter with rare rainfall in autumn. The utmost amount of rainfall was 15.7 mm/month in February. The highest humidity percent is 75% that recorded in January (Meteorological Station of Port Said/El Gamil, 2017–2018, 31°28′ N and 32°23′ E). Ismailia climate is distinguished into three forms (cold winter for an extended time, intermediate with light rains, moderate summer with humidity of 75%), that generally dominant by moderate climate the whole year. Rainfalls do not exceed 50 mm/year, mainly in winter seasons—therefore, the limited rainfall coupled with the rise of evaporation rate results in the drought phenomena cases in that region. The presence of Ismailia canal water and groundwater was used as the main irrigation sources for the Ismailia lands [30,31].

According to Reference [32], the area under investigation is completely covered by deposits of Quaternary sediments that possibly mask earlier tectonic deformations. The Miocene bedrock exposures southward are composed of sandstone, clay, and limestone. The area around the Ismailia Canal consists of two hydrogeological units: The shallow and the deeper aquifers. The salinity of groundwater in the deeper aquifer is low and rarely exceeds 1500 mg/L, while the groundwater salinity of shallow aquifer ranges from 340 to 7650 mg/L [33].

The morphological properties greatly affect the hydraulic conditions of the shallow aquifer around the Ismailia canal. Sand accumulations as dunes bound these pools and separate from the gravelly and sandy slopes in the southwest of the studied area. The natural hydrogeological conditions of the study area are poor, due to the saline water content of the underlying sediments, which are characterized by poor hydraulic properties and moderate to high salt content [32].

2.2. In-Situ Field Investigations

The soil survey was accomplished at the detailed soil survey level, and the soil profiles were prepared every 250.0 m. Twenty-one soil profiles were chosen to represent the lands under reclamations based on a detailed soil survey (Figure 2). The soil profiles were wide open to a depth of 150 cm. Soil profiles were expected to reflect the wide variations in soil texture and soil salinity. A morphological description of the soil profiles was undertaken according to the criteria established by FAO, Guidelines for soil description [34]. Soil erosion was described according to Reference [35], based on category and degree. Soil samples, collected from different profile layers, were air-dried and passed through a 2 mm sieve. The rock fragments (>2 mm diameter) were determined volumetrically to measure their sizes and percentages from a total sample, while the fine soil (<2 mm) was subjected to physical and chemical analyses as indicated by Reference [36]. The Soil Particle size distribution was carried out for the sandy soils by the dry sieving method. $CaCO_3$ contents were determined using Collin's calcimeter. Soil pH, soil salinity, and soluble cations and anions were determined in the soil extract. Sodium and potassium ions were measured photometrically. Calcium, magnesium, chloride, carbonates, and bicarbonates were determined titrimetrically. Cation exchange capacity (CEC) of soil was determined using the sodium and ammonium acetate method, and exchangeable sodium percentage (ESP) was determined using the ammonium acetate method [36]. Organic matter content was determined using the Walkley and Black titration method [36].

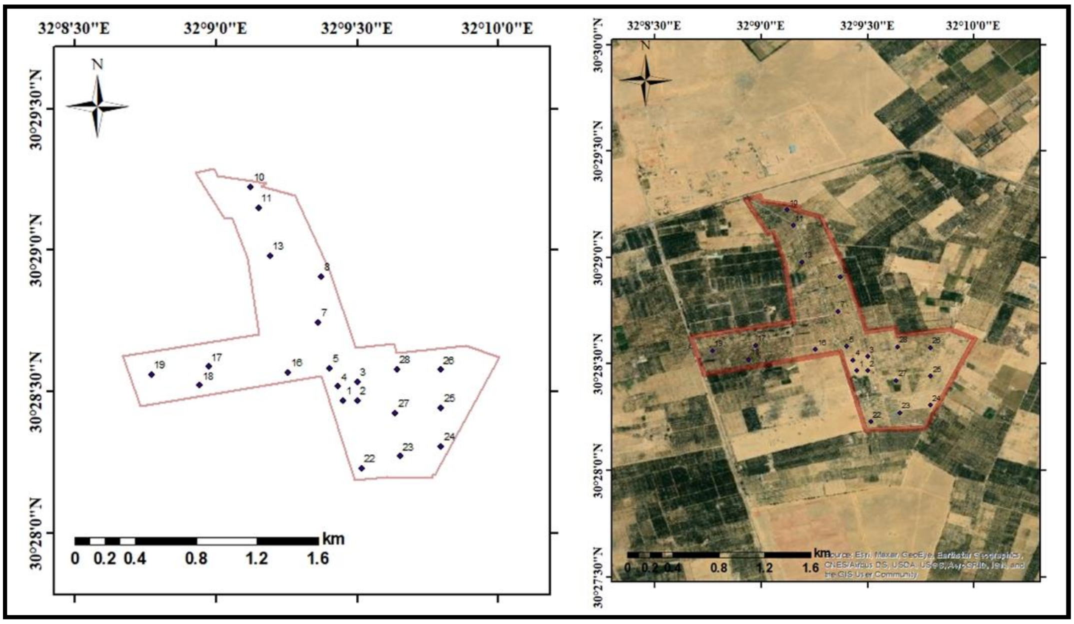

Figure 2. Locations of the representative soil profile.

2.3. Parametric Approach for Soil Suitability

To assess the land appropriateness for various irrigation systems techniques, the parametric assessment framework portrayed by Reference [37] was applied. These qualities are appraised and used to compute the capacity record for capability index for irrigation (**Ci**) as indicated by the formula:

$$(\mathbf{Ci}) = [A \times B/100 \times C/100 \times D/100 \times E/100 \times F/100] \quad (1)$$

where: Capability index for irrigation = **Ci**; soil texture rating = *A*; soil depth rating = *B*; $CaCO_3$ status = *C*; electro-conductivity rating = *D*; drainage rating = *E*; and slope rating = *F*. These factors and capability index and also the corresponding suitability class ratings are described by Reference [24], and presented in Table 1.

Table 1. Suitability classes for the irrigation capability indices (Ci) classes according to Reference [24].

Capability Index	Definition		Symbol
>80	Excellent	Highly suitable	**S1**
60–80	Suitable	Moderately suitable	**S2**
45–59	Slightly suitable	Marginally suitable	**S3**
30–44	Almost unsuitable	Currently not suitable	**N1**
<30.0	Unsuitable	Permanently not suitable	**N2**

The land assessment was carried out according to the topography and soil characteristics of the region. Topographical features consisted of slope and soil properties, such as texture, depth, salinity, drainage, and calcium carbonate. Under the parametric method, the land evaluation is assessed using a numerical index. In this classification system, first of all, a degree, the rate of which is between 0 and 100, is attributed to any property characteristic by comparison with the tables of land requirements.

2.4. Assessment of Soil, Water Erosion Vulnerability

Soil erosion continues to be an essential concern for the improvement of sustainable agricultural management systems. The ImpelERO model (soil erosion vulnerability/impact/management) is used to quantify the soil erosion vulnerability and the result of the soil erosion impact on crop production and on the optimal management strategies (https://evenor-tech.com/microleis/microlei/microlei.aspx) Figure 3.

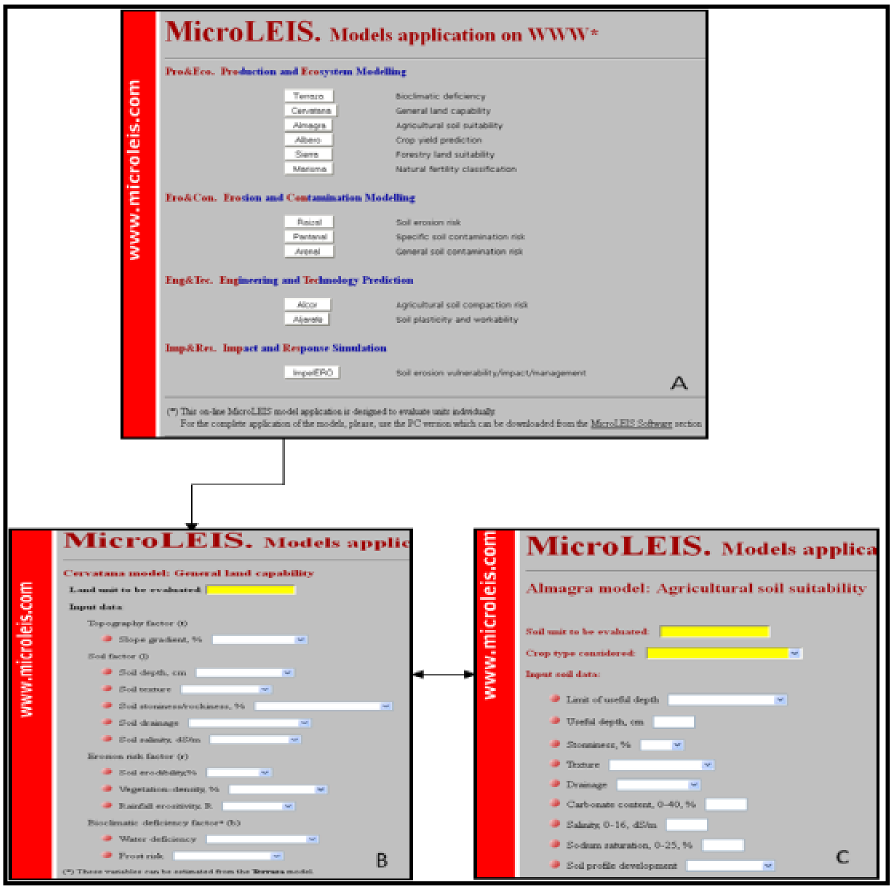

Figure 3. Interface of the ImpelERO model (De la Rosa et al., 1998). (https://evenor-tech.com/microleis/microlei/microlei.aspx).

Land quality will be described by land characteristics associated with soil parameters. A set of management features, which essentially the crop properties and cropping practices will be considered. This is a simple attribute of agricultural management that can be estimated and can be used as a means of describing management qualities.

ImpelERO Model parameters:

- Region: That the evaluated region is a set of field-units. Moreover, it can be named evaluating-scenario.
- Field-unit: To identify each spatial unit that is analyzed and will be evaluated in the ImpelERO model. The field-unit is composed of climate, soil, and management components [27].
- Soil: The set of soil characteristics that referred to as the soil types which will define the field-unit [27].
- Climate: The set of land characteristics (LC's) referred to as the climate, which defines a field-unit [27].
- Management: Management characteristics (MC's), that mainly consider the crop properties and cultivation practices [27].

3. Results and Discussion

3.1. Characterization of the Studied Soil

3.1.1. Morphological Description and Analytical Results

The study area is characterized as a sandy plain and alluvial deposits. The dominant fruit trees cultivated in this area are (apple, mango, olive, and citrus) besides fodders (alfalfa) and the vegetable crop (tomato). The detailed morphological descriptions of the soil profiles were recorded based on the basis outlined by References [34,35,38]. The topography of the landscape generally ranges between flat (<0.5%) and almost flat (0.5–2.0%) with a nearly-level sloping surface (0.5–1.0%), according to Reference [34]. Very few scattered desert shrubs are found near the new reclamation areas. The common features of this soil type with a depth of 150 cm [35], ranged from sand to sandy clay loam, and clay loam texture with slightly calcium carbonate content and moderately well-drained. Four profiles were selected as a guide from the collected profiles; in the following Tables 2 and 3, an overview of morphological description and analytical data is given. The dominant dry soil color, shown in Table 2, was yellow (10 YR 7/6) and very pale brown (10 YR 7/4). On moistening, these colors become brownish-yellow (10 YR 6/6) and yellowish-brown (10 YR 6/4). Soil structure is generally massive throughout the successive layers of single-grain surface, and dry consistency is losses, soft to slightly hard to increase soil compaction downward from the soil profiles. Being non-sticky and non-plastic, it agrees well with coarse soil texture. With the exception of fine profile texture layers (13), whose wet consistency has been changed to sticky and plastic. Erosion may be defined as water or wind erosion in accordance with Reference [35], and the degree of erosion varies from slight to moderately severe.

Table 3 indicates that these soils are non-calcareous to moderately calcareous, where the content of calcium carbonate varies widely from 0.8 to 9.75%, and the surface layers detect the highest carbonate content. As indicated by pH values that range from 7.7 to 9.7, the soil response ranges from slightly alkaline to strongly alkaline. Electrical conductivity values vary from 0.33 to 9.75 dSm^{-1} based on soil texture, suggesting non-saline to very high saline values.

Table 2. Morphological description of representative soil profiles.

Profile No.	Land Use	Surface Characteristics: Topography and Slope	Surface Characteristics: Vegetation and Surface Cover	Erosion Category Degree	Drainage	Depth/cm	Color: Dry	Color: Moist	Texture	Structure	Consistence: Dry or Moist	Consistence: Wet/Stickiness	Consistence: Wet/Plasticity	Lime %	Gravel %	Boundary	
1	None	Almost flat	None	W	WD	0–20	10YR 7/6	10YR 6/6	FS	SG	L	NST	NPL	MO	VF	A	S
		Nearly level	Drift sand	S		20–60	10YR 7/6	10YR 6/6	MS	MA	SO	NST	NPL	MO	Few	C	S
						60–80	10YR 7/6	10YR 6/6	MS	MA	SO	NST	NPL	SL	VF	D	S
						80–120	10YR 7/6	10YR 6/6	MS	MA	SO	NST	NPL	SL	VF	C	S
						120–150	10YR 7/6	10YR 6/6	FS	SG	L	NST	NPL	MO	VF		
16	Cultivated land	Almost flat	Olive and Citrus	WA	WD	0–30	10YR 7/6	10YR 6/6	MS	MA	SO	NST	NPL	MO	VF	C	S
		Very gently sloping	Drift sand	M		30–100		10YR 6/4	FS	MA	FR	NST	NPL	MO	VF	D	S
						100–150		10YR 6/4	MS	MA	FR	NST	NPL	MO	VF		
13	Cultivated land	Almost flat	Olive and Citrus	W	SP	0–35		10YR 6/4	SCL	MA	VFR	ST	PL	MO	VF	A	S
		Nearly level	Few scattered desert shrubs	S		35–100		10YR 5/4	SCL	MA	FR	ST	PL	MO	VF	C	S
						100–150		7.5 YR 5/4	SL	MA	FR	SST	SPL	MO	VF		
27	Cultivated land	Almost flat	Fodders and vegetables	W	MW	0–25	10YR 7/4	10YR 6/4	FS	MA	SHA	NST	NPL	MO	VF	D	S
		Nearly level	Alfalfa and tomatoes	M		25–100	10YR 7/6	10YR 6/6	MS	MA	SHA	NST	NPL	MO	VF	C	S
						100–150		10YR 6/6	CS	MA	FR	NST	NPL	MO	VF		

Erosion (W = wind, S = slight, WA = water and wind erosion and M = Moderate), drainage (WD = well drainage, MW = moderate drainage and SP = somewhat poor drainage), texture (FS = fine sand, MS = medium sand, CS = coarse sand, SCL = sandy clay loam and SL = sandy loam), structure (SG = single grain and MA = massive), consistence (L = loose, SO = soft, FR = friable, VFR = very friable, SHA = slightly hard, NST = non-sticky, NPL = non-plastic, Pl = plastic, ST = sticky and SPL = slightly plastic), lime (SL = slightly calcareous and MO = moderate calcareous), gravel (few and VF = very few), boundary (A = abrupt, S = smooth, D = diffuse and C = clear).

Table 3. Analytical data of the selected reference profiles. (top) Particle size distribution and textural classes. (bottom) Chemical composition of the soil extract.

Profile	Depth	$CaCO_3$	Gravel			Particle Size Distribution (%)				Sand	Silt	Clay	Soil
No	Cm	%	%	2–1 mm	1–0.5 mm	0.5–0.25 mm	0.25–0.125	0.125–0.063	<0.063				Texture
1	0–20	3.52	0.80	2.60	6.80	25.20	40.00	22.20	3.20				FS
	20–60	3.19	2.80	17.90	32.10	29.80	15.70	3.70	0.80				MS
	60–80	1.43	0.90	5.90	30.90	58.90	2.90	0.40	1.00				MS
	80–120	0.80	1.80	4.40	19.20	33.70	40.70	1.00	1.00				MS
	120–150	3.52	0.50	11.24	12.25	25.32	26.93	18.82	5.44				FS
16	0–30	9.75	0.40	5.90	30.90	58.90	2.90	0.40	1.00				MS
	30–100	3.37	0.80	7.87	15.62	25.62	26.24	18.25	6.40				FS
	100–150	5.80	0.60	67.40	13.40	1.40	14.40	1.40	2.00				MS
13	0–35	8.80	1.60							55.0	14.0	31.0	SCL
	35–100	7.60	0.80							57.0	12.86	30.14	SCL
	100–150	7.90	1.60							66.25	21.6	12.15	SL
27	0–25	6.20	1.80	7.20	10.60	28.94	34.63	16.94	1.69				FS
	25–100	4.60	1.20	8.73	10.92	38.62	21.33	16.53	3.87				MS
	100–150	6.60	0.80	12.48	18.50	33.08	20.85	12.66	2.43				CS

Profile	Depth	EC.	pH			Soluble Cation and Anions meq/l						CEC	ESP
No	Cm	dSm^{-1}		Na^+	K^+	Ca^{++}	Mg^{++}	Cl^-	CO_3^-	HCO_3^-	SO_4^-	meq/100 g	%
1	0–20	3.68	8.05	20.80	0.54	9.77	4.44	32.20	tr.	1.50	1.85	3.50	11.00
	20–60	2.41	8.18	13.60	0.73	6.75	2.64	21.20	tr.	2.00	0.52	3.54	10.39
	60–80	0.49	9.56	12.40	0.25	3.04	1.17	2.30	tr.	2.00	0.16	2.10	9.47
	80–120	0.37	9.77	2.04	0 47	1.70	0.44	1.47	tr.	1.00	1.71	5.59	9.42
	120–150	1.47	8.40	10.60	0.52	2.32	1.50	11.91	tr.	1.00	2.03	6.36	9.94
16	0–30	0.41	8.90	2.17	0.42	2.21	1.55	1.88	tr.	3.00	1.47	3.90	9.44
	30–100	0.94	9.00	7.40	0.15	4.72	2.51	7.35	tr.	2.00	5.43	5.80	9.69
	100–150	1.51	8.40	7.10	0.90	5.76	2.13	14.30	tr.	1.00	0.59	3.33	9.96
13	0–35	4.50	8.19	1.16	0.72	1.54	0.63	1.74	tr.	1.00	1.31	28.70	9.41
	35–100	9.79	8.94	90.80	2.10	16.37	7 74	98.20	tr.	2.00	9.07	27.30	13.92
	100–150	8.60	9.29	18.60	0.54	9.77	4.44	30.50	tr.	1.00	1.85	16.30	10.22
27	0–25	5.34	7.70	66.20	2.10	13.31	7.90	66.30	tr.	1.00	22.21	6.55	11.79
	25–100	1.44	9.27	14.20	2.80	8.00	3.71	12.60	tr.	2.00	14.11	5.50	9.93
	100–150	0.33	9.20	2.17	0.42	2.21	1.55	1.88	tr.	3.00	1.47	4.98	9.40

FS = fine sand, MS = medium sand, CS = coarse sand, SL = sandy loam, SCL = sandy clay loam, according to Guidelines for soil description, (F.A.O, 1990) and (Jahn, and Blume, 2006). CEC = cation exchange capacity.

3.1.2. Weighted Mean of Soil Characteristics

The physical, chemical, and physical-chemical weighted average of the soil properties are determined and shown in Table 3. Based on the formation of the parent material, the results obtained indicate that soil texture varies from area to area (such as profiles 13 and 16) and subsequent layers within each soil profile. A combination of alluvial soils and sand dune soils is the parent content between soil profiles. Soil texture throughout the entire depth is variable textural composition, from sandy clay to coarse sand at the soil surface.

Soil salinity values as represented in Figure 4 ranged widely between 0.33 and 9.70 dSm^{-1} (non-saline to very strongly saline), with an average value of 2.9 dSm^{-1} (moderately saline) according to Reference [35]. The relatively low EC values in these soils with coarse sand textured and low content of fine fractions of silt and clay are mainly affected by the particle size distribution of texture. The lowest values of EC exist in the top surface layer, which is dominated by coarse texture. The electrical conductivity weighted mean of the soil saturation extract varies from 0.90 to 8.74.0 dSm^{-1}, indicating non-saline to strongly saline condition; the lowest values are mostly detected in the coarse texture profiles. The distribution of the weighted mean of soil salinity (EC) values showed in Table 3. Salinity is one of the main edaphic factors which limits the distribution of plant communities in their natural habitats and which is causing increasingly severe agricultural problems [14,15].

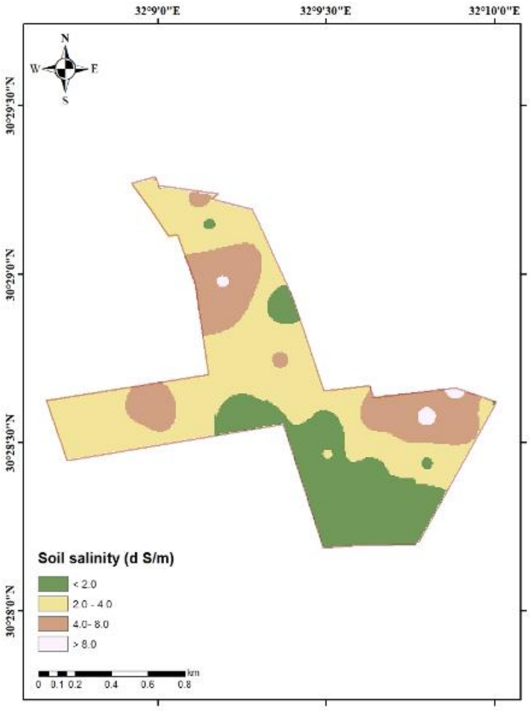

Figure 4. Distribution of weighted mean soil salinity values.

Soil reaction pH is an important parameter, due to its effects on nutrient availability, microbial activity, and plant growth. From the data presented in Table 3, the weighted mean of soil reaction varies considerably from 7.94 to 9.63, indicating moderately alkaline to strongly alkaline soil reaction [38], as shown in Figure 5. Soil profiles under study are slightly calcareous to moderately calcareous according to Reference [35], where the $CaCO_3$ content ranges from 0.9% to 9.75% with an average value of 4.4%. In addition, weighted mean values of $CaCO_3$ content in soil profiles varied from 1.72% to 7.94%, as presented in Figure 6. The highest $CaCO_3$ contents are mostly detected in the surface layers and increased with fine soil texture.

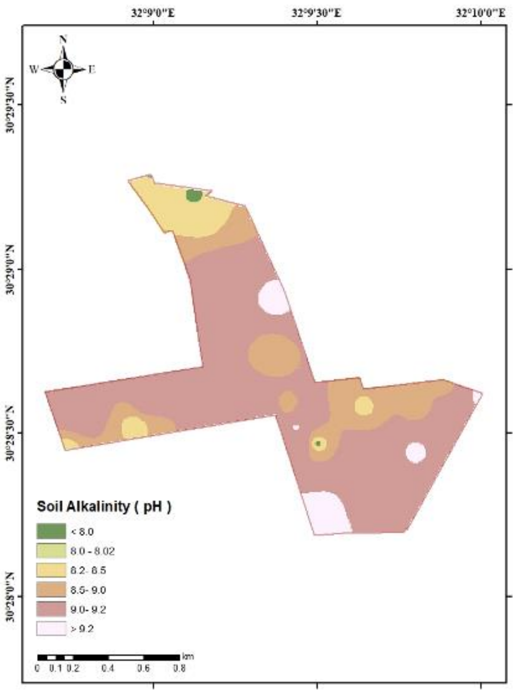

Figure 5. Distribution of weighted mean soil reaction (pH) values.

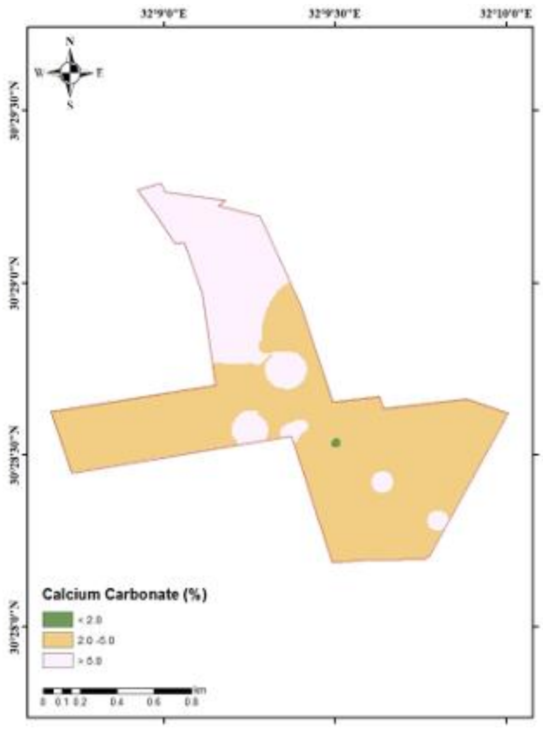

Figure 6. Distribution of $CaCO_3$%.

Concerning the levels of organic matter values in the upper soil layers, Table 4 shows that organic matter content varied from very low to low, and ranges from 0.27 to 0.82%. The bulk density values vary from 1.52 g/cm^3 to 1.59 g/cm^3—these contents were coinciding very well with texture classes. The cation exchange capacity is used as a parameter for the fertilizers buffering capacity. Cation exchange capacity (CEC) of soils is closely related to the content of clay content. The exchange characteristics of the soils under study dictate that CEC weighted mean values are low and coincide well with soil texture [39], being in the range from 3.49 to 27.16 meq/100 g soil with an average of 15.3 meq/100 g soil and coincide very well with texture classes (Figure 7). In addition, the essential substantial water high-quality popular on crop productiveness is that the water salinity hazard. That the quantity of water transpired via a crop was once immediately associated to yield; therefore, irrigation water with excessive EC reduces the yield potential. Groundwater salinity (ECw) ranges from 2500 to 5500 µmhos (Figure 8). According to permissible limits for classes of irrigation water [40], the study classification for EC indicated that the water quality varies from Class 4 (doubtful) to Class 5 (unsuitable). For groundwater, approximately 40% may be used with no troubles, and 40% may be used with occur moderate problems.

Table 4. Weighted mean soil characteristics of the representative soil profiles.

Profile	Drainage Classes	Soil Depth	Gravel	Soil	$CaCO_3$	Soil Salinity	Soil Alkalinity	Organic Matter	CEC	Bulk Density	Water
No		cm	%	texture	%	dSm^{-1}	pH	%	meq/100 g	g/cm^3	µmhos
1		150	1.55	FS	2.43	1.59	8.81	0.46	4.45	1.53	2995
2		150	0.79	FS	3.76	2.08	7.94	0.42	4.30		
3		150	0.59	MS	1.72	1.23	8.52	0.46	3.50		
4	Well-drained	150	2.11	MS	3.22	0.87	9.03	0.55	3.60		
5		150	1.84	MS	5.23	3.20	8.32	0.75	3.53		
7		150	1.74	FS	5.46	4.22	8.26	0.85	5.12	1.53	2575
8		150	0.90	CS	3.57	1.06	9.20	0.56	4.58		

Table 4. *Cont.*

Profile	Drainage Classes	Soil Depth	Gravel	Soil	$CaCO_3$	Soil Salinity	Soil Alkalinity	Organic Matter	CEC	Bulk Density	Water
No		cm	%	texture	%	dSm^{-1}	pH	%	meq/100 g	g/cm^3	μmhos
16	Well drained	150	0.65	CS	5.46	1.02	8.78	0.27	4.60	1.53	2575
17		150	0.59	CS	3.19	5.07	8.70	0.46	3.55	1.53	5295
18		150	0.67	MS	3.75	3.39	8.00	0.42	3.49		
19		150	0.74	MS	3.57	2.91	9.00	0.81	4.67		
22		150	0.56	CS	4.30	0.79	9.63	0.56	3.76	1.53	3663
23		150	0.39	CS	3.61	0.90	8.59	0.46	3.92		
24		150	1.58	CS	5.51	1.49	8.93	0.27	3.71		
25		150	1.97	CS	3.33	1.87	9.11	0.82	3.73		
26		150	2.97	CS	4.78	8.74	8.40	0.62	3.53	1.53	3515
27		150	1.17	MS	5.53	1.72	8.99	0.46	5.50		
28		150	2.85	CS	2.89	4.84	8.10	0.42	4.59		
10	Moderately drained	150	0.95	SCL	6.91	4.45	7.96	0.68	26.46	1.58	3950
11		150	1.04	SC	7.15	1.81	8.09	0.82	27.16	1.52	
13		150	1.23	SCL	7.94	8.20	8.91	0.74	23.91	1.59	

Desertification is also termed soil erosion of dry land. Human-made issues comprise the plurality of ways of soil degradation. While some physical parameters are involved, an important aspect is misuse. Poor land management and irrigation, including used surface irrigation, increase the pace of land degradation [41].

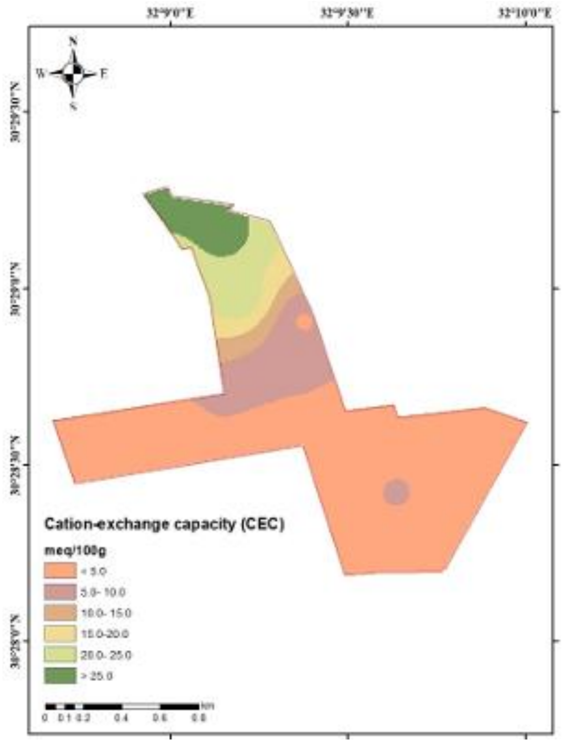

Figure 7. Distribution of CEC meq/100 g.

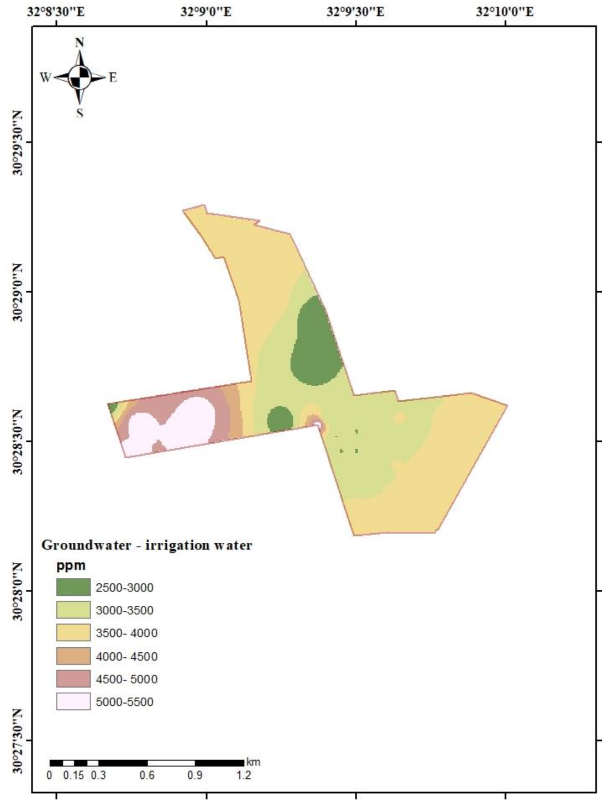

Figure 8. Distribution of electrical conductivity (Ecw) for groundwater wells (μmhos).

3.2. Parametric System and Land Suitability for Different Irrigation Methods

The applied irrigation methods; surface (gravity), sprinkler, and drip (trickle) irrigation, were classified as highly suitable (S1), moderately suitable (S2), marginally (S3), currently not suitable (N1), and permanently not suitable (N2), according to [24], and the results of the land suitability in the study area under these systems presented in Table 5 and Figure 9. Comparing the three irrigation systems revealed that using drip irrigation (trickle irrigation) was more efficient. The land capability index for surface irrigation ranges from 20.5 to 72.2% (N2 to S2), as shown in Figure 9. Soils that are permanently not suitable (N2) for surface irrigation cover 115 hectares (78.2%), whereas the moderately suitable soils (S2) cover 12 hectares (8.1%), as displayed in (Table 6). The results showed that the land suitability of sprinkler irrigations is highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and currently not suitable (N1), as shown in (Figure 10). By analyzing the land suitability maps for sprinkler irrigation, it is evident that a highly suitable area can only be observed in some parts (0.2 ha) Table 6. Furthermore, Sprinkler irrigation revealed the second priority investigated to cultivation by field crops, fodder, and some vegetables. The max capability index (Ci) for drip irrigation was 81.3% (highly suitable-S1), while the mean capability index (Ci) was 42.87% (currently not suitable-NI).

Table 5. Suitable land for surface, sprinkle, and drip irrigation systems using capability index (Ci).

Profile	Surface Irrigation		Sprinkler Irrigation		Drip Irrigation	
No	Capability Index	Suitability Classes	Capability Index	Suitability Classes	Capability Index	Suitability Class
1	25.65	N2	61.75	S2	45.13	S3
2	25.65	N2	61.75	S2	45.13	S3
3	25.65	N2	61.75	S2	45.13	S3
4	25.65	N2	61.75	S2	45.13	S3
5	25.65	N2	61.75	S2	45.13	S3
7	23.09	N2	58.66	S3	42.87	N1
8	25.65	N2	61.75	S2	45.13	S3
10	64.98	S2	72.20	S2	77.16	S2
11	72.20	S2	76.00	S2	81.23	S1
13	36.10	N1	38.00	N1	40.61	N1
16	25.65	N2	61.75	S2	45.13	S3
17	25.65	N2	61.75	S2	45.13	S3
18	25.65	N2	61.75	S2	45.13	S3
19	25.65	N2	61.75	S2	45.13	S3
22	25.65	N2	61.75	S2	45.13	S3
23	25.65	N2	61.75	S2	45.13	S3
24	25.65	N2	61.75	S2	45.13	S3
25	25.65	N2	61.75	S2	45.13	S3
26	20.52	N2	52.49	S3	38.36	N1
27	25.65	N2	61.75	S2	45.13	S3
28	23.09	N2	58.66	S3	42.87	N1

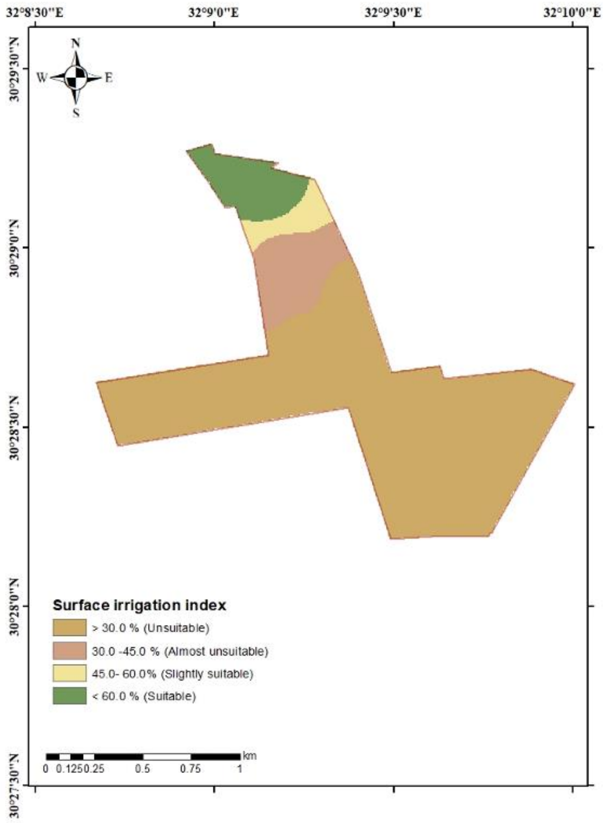

Figure 9. Land suitability classes for surface irrigation.

Table 6. Distribution of surface, sprinkler, and drip irrigation suitability.

Surface Irrigation			Sprinkler Irrigation			Drip Irrigation		
Suitability Class	Ratio %	Area per Feddan	Suitability Class	Ratio %	Area per Feddan	Suitability Class	Ratio %	Area per Feddan
N2	78.2	273.8	N1	41.9	146.6	N1	1.5	5.1
N1	9.9	34.7	S3	47.8	167.2	S3	30.0	105.0
S3	3.8	13.1	S2	9.9	34.7	S2	68.5	239.9
S2	8.1	28.4	S1	0.4	1.5			

Highly suitable (S1); moderately suitable (S2); marginally (S3); currently not suitable (N1), and permanently not suitable (N2).

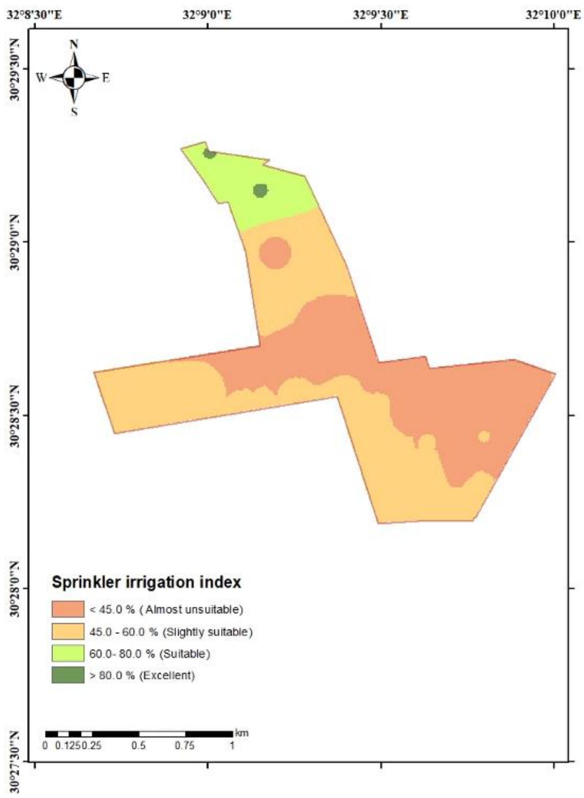

Figure 10. Land suitability classes for sprinkler irrigation.

Data represented in Figures 9–11 and Table 5, indicated that applying a drip irrigation system was the most efficient option compared to sprinkle and surface irrigation systems. Drip irrigation suitability gave more irrigable areas compared to the surface irrigation practice because of the topographic (slope), soil (depth and texture) consistent with main data [42]. Thus, our results are convenient with [43,44] which investigated the land suitability applying the parametric methods for the surface and drip irrigation in Southern Ankara, Turkey. In addition, the obtained results showed that 51.2% of the studied area were highly suitable for drip irrigation method, whereas 13.1% was highly suitable for surface irrigation methods. Moreover, the results revealed that the main limitation factors were soil texture and soil depth for both irrigation systems. These results are in agreement with Reference [18], which investigated the land suitability using the parametric for surface, sprinkler, and drip irrigation in North West of Egypt. The results obtained showed that the study of various types of irrigation techniques showed that sprinkler and drip irrigation systems were more efficient and effective than surface irrigation for increasing land productivity. Depth of soil, soil texture, $CaCO_3$, drainage, and slope were the key limiting factors for the use of surface irrigation techniques in Siwa, Western Northern Egypt [19].

Figure 11. Land suitability classes for drip irrigation.

3.3. Assessment of Soil Erosion Vulnerability and Potential Impact on Crop Productivity

Sustainability modeling analysis for soil erosion should include not only vulnerability prediction, but also address impacts and response assessment in an integrated way. In the present study, an integrated neural network-based model, ImpelERO, was applied to identify the vulnerability index, erosion risk class, and soil loss rates. Our results revealed that the soil vulnerability indices ranged from 0.21 to 0.34, and 0.44 for sandy clay, sandy clay loam, and sand texture, respectively. Moreover, the main data showed that the elevation ranges from 20.0 to 64.0 m above sea level (Figure 12)—these results indicated that the elevation and soil texture are the main limiting factors for soil loss rates. Data showed in Table 7 indicated that the values of erosion risk classes range from V2 (small) to V3 (moderate), as shown in Figure 13, which categorize the region as small-sensitive by alfalfa, to moderate-sensitive to erosion by olive. The values of soil losses varied between 7.1 to 37.9 t ha^{-1} yr^{-1} with an average of 17.7 t $ha^{-1}yr^{-1}$.

The overall approach of ImpelERO was applied for the three different soil textures selected to quantify the soil erosion vulnerability with several crops, the impact of soil erosion on crop production, and the optimal management strategies. The potential impact of soil erosion on crop productivity was interesting that the projection in a productivity reduction in 2050 will be 6.8, 2.3, and 0.9% for fine sand, sandy clay loam, and sandy clay, respectively. Thus, farming practices can be widely modified to protect environmental qualities.

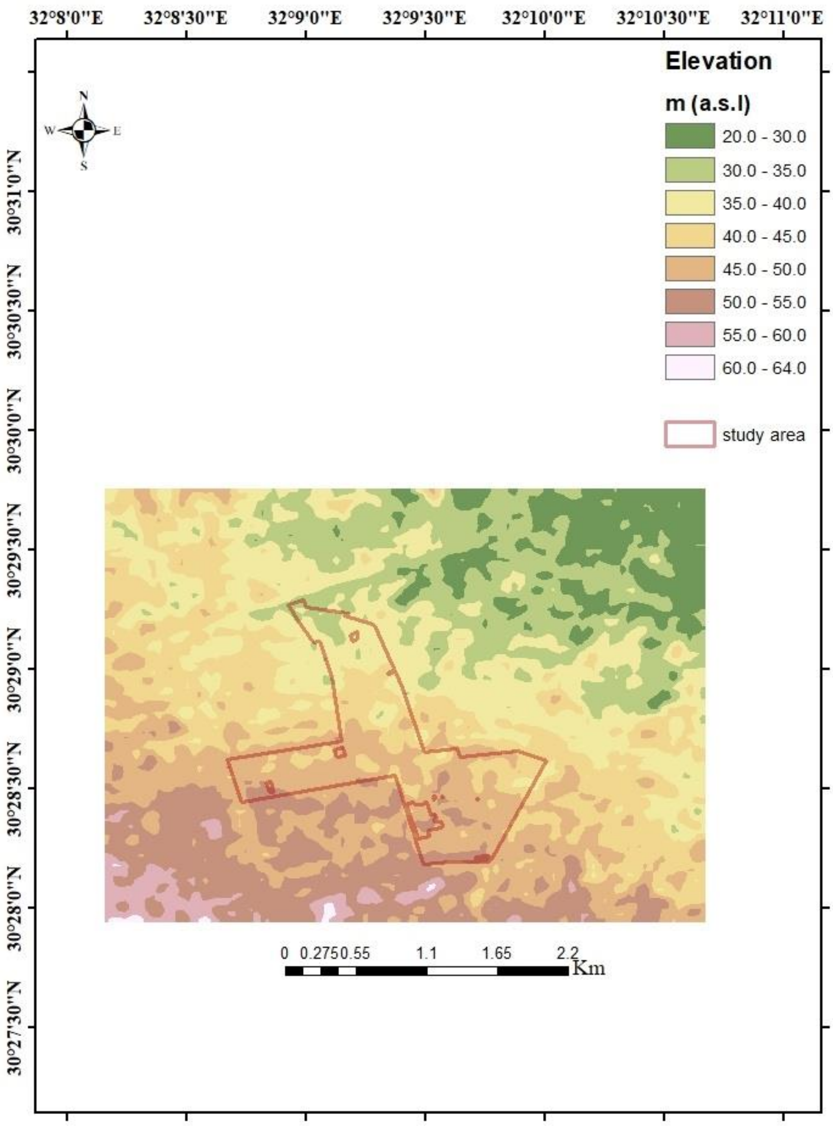

Figure 12. Distribution of elevation above sea level (m).

Table 7. Soil water erosion vulnerability under different soil types and land management using ImpelERO model.

Profile No	Soil Texture	Land Use	Soil Loss Prediction				Impact on Crop Productivity: Reduction (%)		
			Vulnerability Index	Risk Class	Soil Loss Rate	Soil Depth Loss	Productivity Reduction		
			(Vi: 0.00–1.00)	(V1–V6)	Mg/ha/y	(0–120)	2020	2050	2100
1	Sandy soil	Control	0.44	V3	37.9	0.25	0.0	6.8	19.1
10	Sandy clay loam	Alfalfa	0.34	V3	17.7	0.08	0.0	2.3	6.2
11	Sandy clay	Olive	0.21	V2	7.1	0.03	0.0	0.9	2.4

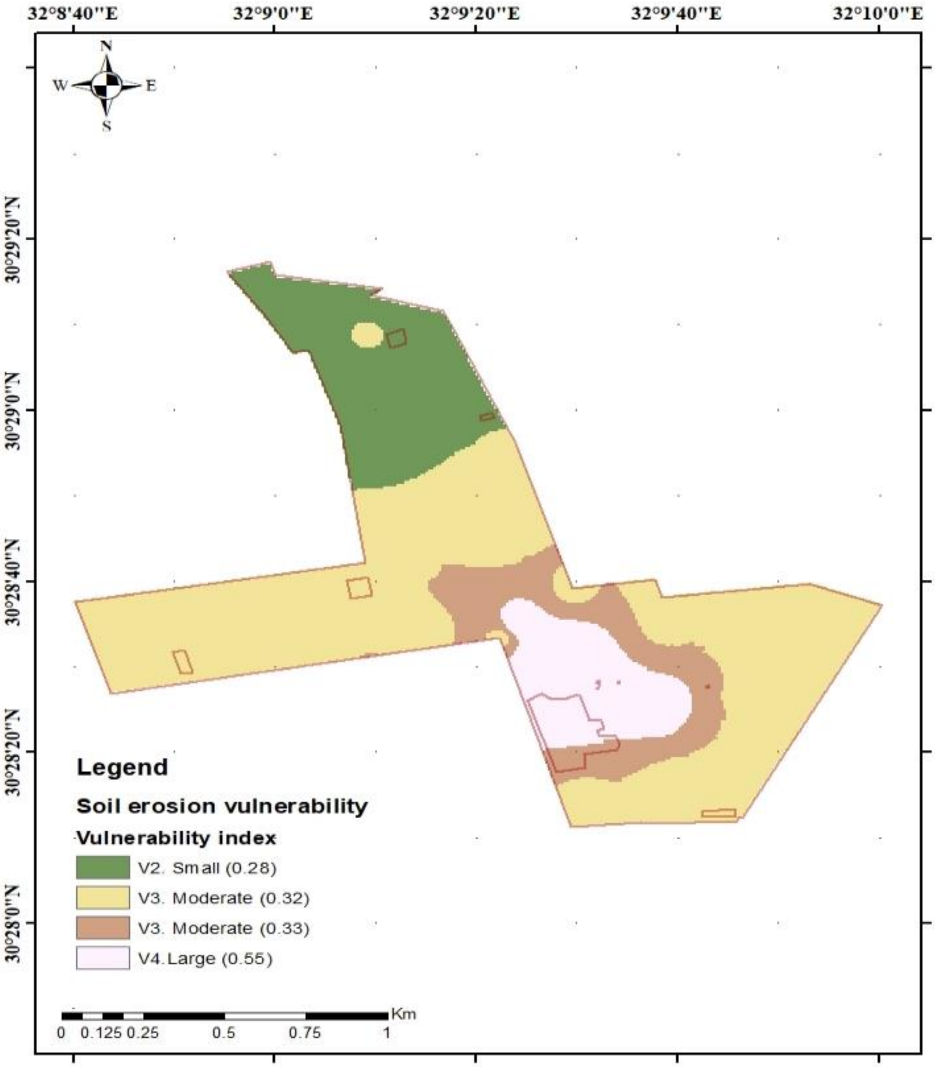

Figure 13. Soil water erosion vulnerability using ImpelERO model at the study area.

4. Conclusions

Evaluating the land suitability for different irrigation methods using the parametric evaluation systems is an essential strategy for the decision-makers from the viewpoint of water-saving. We found that the land suitability of 78.2% (109 hectares) will be improved through applying sprinkler and drip irrigations compared to the surface irrigation method. Nevertheless, the main limiting factors in choosing the relevant irrigation methods in this region were the soil salinity. Thus, the areas belong to highly salinity content in the soil surface layers and high $CaCO_3$ content; it is more relevant to use the surface irrigation method. That could help in leaching salts out of the soil profile. The exercise proved that soil characteristics, land capability, and suitability for crop systems, combined with tools of land evaluation and GIS maps, is a powerful tool that will be used as a decision support system.

Thus, the recommendation of the research revealed that it is more efficient to use the drip irrigation method to irrigate the soil as it ensures the sustainable use of the land for agriculture. Whereas, sprinkler irrigation is considered the second priority in the study area, the field crops, fodder, and some vegetables can be grown in priority lands in sprinkler irrigation.

In addition, for the soil water erosion, the sustainability modeling analysis should not consider only the vulnerability prediction, but also the response assessment. The integrated neural network-based model, ImpelERO, was successfully used to identify the soil water erosion vulnerability index, and soil loss rates. The soil water erosion potential impact on the crop productivity was interesting that the projection in productivity reduction in 2050 will be 6.8, 2.3, and 0.9% reductions for fine sand, sandy clay loam, and sandy clay, respectively. Thus, the relevant farming and irrigation practices can be widely modified to protect future environmental qualities.

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