Field Investigation of the Spectral Resolution of Soil Salinity and Its Impact on Vegetation Northeast of the Nile River Delta by Applying Geoinformatics Techniques

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Abstract

The study adopts a number of soil salinity indices by applying geoinformatics techniques in the northeast of the Nile River Delta, based on the different spectral reflectance of soil salinity. The field investigation is carried out by collecting soil samples, and chemically analyzing them in order to compare them with the results of the indices (8 indices), relying on field review so as to capture images indicative of soil salinity and its impact on the land use that is most vulnerable to it, and this is vegetation. This is mainly for the sake of supporting the accuracy of the spectral resolution. It is found that each index relies on different variables of spectral reflectance. Accordingly, the study identifies the most appropriate and effective indices for assessing salinity, both spatially and temporally, in the northeast of the Nile River Delta. This is done through determining the highest degree of correlation between the results of the indices and the results of the chemical analysis of soil samples. Moreover, the study relies on the best indices in determining vegetation, which is EVI, so as to find out the degree to which the vegetation density is affected by soil salinity. This is carried out with the aim of coming up with results that help decision-makers in addressing the problems resulting from soil salinity with the least effort, the lowest cost, and the highest accuracy and realism.

Key words: **Spectral Resolution, soil salinity, salinity indices, remote sensing, vegetation, Nile River Delta.**

التحقق الميداني من التمييز الطيفى لملوحة التربة وأثرها على الغطاء النباتى شمال شرق دلتا نهر النيل بتطبيق تقنيات الجيوانفورماتيكس

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المستخلص

اعتمدت الدراسة عدد من أدلة ملوحة التربة عن طريق تطبيق تقنيات الجيوانفورماتيكس شمال شرق دلتا نهر النيل، مستندة على الانعكاسات الطيفية المختلفة لملوحة التربة. وتم التحقق الميداني عن طريق تجميع عينات من التربة وتحليلها كيميائياً، بغرض مقارنتها بنتائج الأدلة (8 مؤشرات)، مع الاعتماد على المراجعة الحقلية لالتقاط الصور المعبرة عن ملوحة التربة وأثارها على أكثر استخدامات الأرض حساسية لها وهو الغطاء النباتي، وذلك لتدعيم دقة التمييز الطيفي. وقد تبين أن كل مؤشر يعتمد على متغيرات مختلفة من الانعكاسات الطيفية، ومن ثم لجأت الدراسة إلى تحديد أفضل المؤشرات المناسبة والفعالة في تقييم الملوحة زمانياً ومكانياً شمال شرق دلتا النيل، وذلك عن طريق تحديد أعلى درجة ارتباط بين نتائج المؤشرات ونتائج التحليل الكيميائي لعينات التربة، كما اعتمدت الدراسة على أفضل المؤشرات في تحديد الغطاء النباتي وهو EVI لمعرفة درجة تأثر كثافة الغطاء النباتي بملوحة التربة، وذلك بهدف الخروج بنتائج تساعد صناع القرار في معالجة المشاكل الناتجة عن ملوحة التربة بأقل جهد وأقل تكلفة وتكون أكثر دقة وواقعية.

الكلمات المفتاحية: التمييز الطيفى، التحقق الميدانى، أدلة الملوحة، الاستشعار عن بعد، الغطاء النباتى، شرق دلتا نهر النيل.

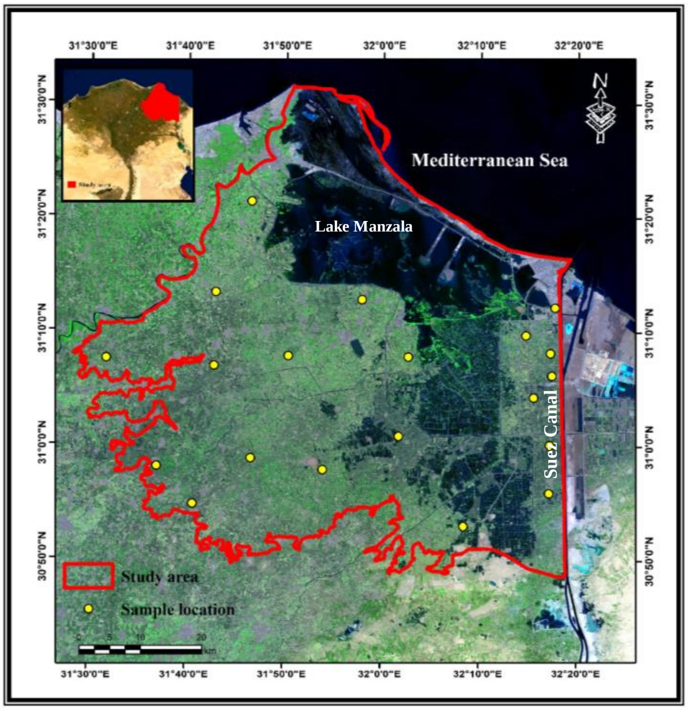
Introduction:

Soil salinity is a major form of land degradation in agricultural areas, which are characterized by development at the temporal and spatial levels. Hence, the use of traditional methods to monitor the soil salinity is considered insufficient and inappropriate with the dynamics of this phenomenon, in contrast to remote sensing data that can be a powerful tool in the continuous monitoring of salinity sequences in order to plan and implement the best soil reclamation programs.

The study aims at carrying out a field survey of the indices of soil salinity through the application of the index extracted from multi-spectral satellite images and laboratory measurement of soil salinity. This is to be done in order to determine the highest degree of correlation between them so as to reach the most accurate level of these indices, and then apply it in different years to measure the salinity dynamics, and its impact on the land use that is most vulnerable to it, and this would be vegetation.

The methodology of the study is based on the goal of the research subject, which is to know how to study soil salinity spatially and temporally with the least effort, the lowest cost, and the highest accuracy and realism. What is meant by time is not only the future (prediction), but also the past so as to know the development of the phenomenon, and the most important factors and processes affecting it, particularly in the northeast of the Nile River Delta, and the effect of this on the density of vegetation.

The study area is located between latitudes of 30° 47′ and 31° 32′ N, and between longitudes of 31° 28′ and 32° 19′ E, with an area of 3955 km^2. It is bordered by the Suez canal to the east, Damietta Branch to the west, the Mediterranean Sea to the north, and 3m contour line to the south. Figure (1).



Source: Satellite image Land Sat 8 OLI 2020, using ArcMap 10.5

Figure (1): Location of the Study Area

To achieve these goals, the study includes the following elements:

First: study sources or inputs such as satellite images to determine the spectral resolution, chemical analysis of soil samples, and the study of the factors affecting salinity.

Second: results and discussions, represented in identifying the best indices and using them in studying the development of salinity in time, and linking this development with the development of vegetation, which is one of the uses of land that is most vulnerable to salinity.

What follows is a study of these subjects:

First: Study Sources:

In order to achieve its objectives, the study relies on a number of sources, namely:

1. Satellite Images

The application of spectral resolution of soil salinity (salinity evidence or salinity indices) goes through several steps; the most important of which is image enhancement and processing through the process of radiometric correction and spectral calibration. This is mainly for correcting the radioactive distortions that result from the sensors or the effect of the atmosphere so that the reflectance and emission data from the intended target are available (James, 2007). This is carried out through the use of the ENVI 5 program.

Spectral resolution expresses the ability to record the reflected radiation from the components of the environment in multiple spectral fields; the most important of which are infrared, near-infrared and thermal infrared radiation. Such ability makes it possible to investigation between the components of the environment, such as soil and vegetation, due to the difference in the spectral response of each (Al-Nahri, 2014).

The study depends on a number of soil salinity indices, developing several mathematical algorithms to detect and map soil salinity by using remote sensing technology. Soil salinity indices are mainly based on the discovery of the salt mineral in the soil on the basis of the different spectral reflectance of salinized soils in different spectral channels (Awad, 2018).

Eight indices are applied to extract soil salinity in the study area.The salinity index combines the blue and red spectral channels;

this is owing to the fact that it is sensitive to the reflections of ground surfaces affected by salt with vegetation. It is noted that all the salinity indices used depend on four spectral channels, namely B, G, and R, in addition to the near-infrared channel and the satellite image Landsat8 OLI 2020 which are as follows (Table 1):

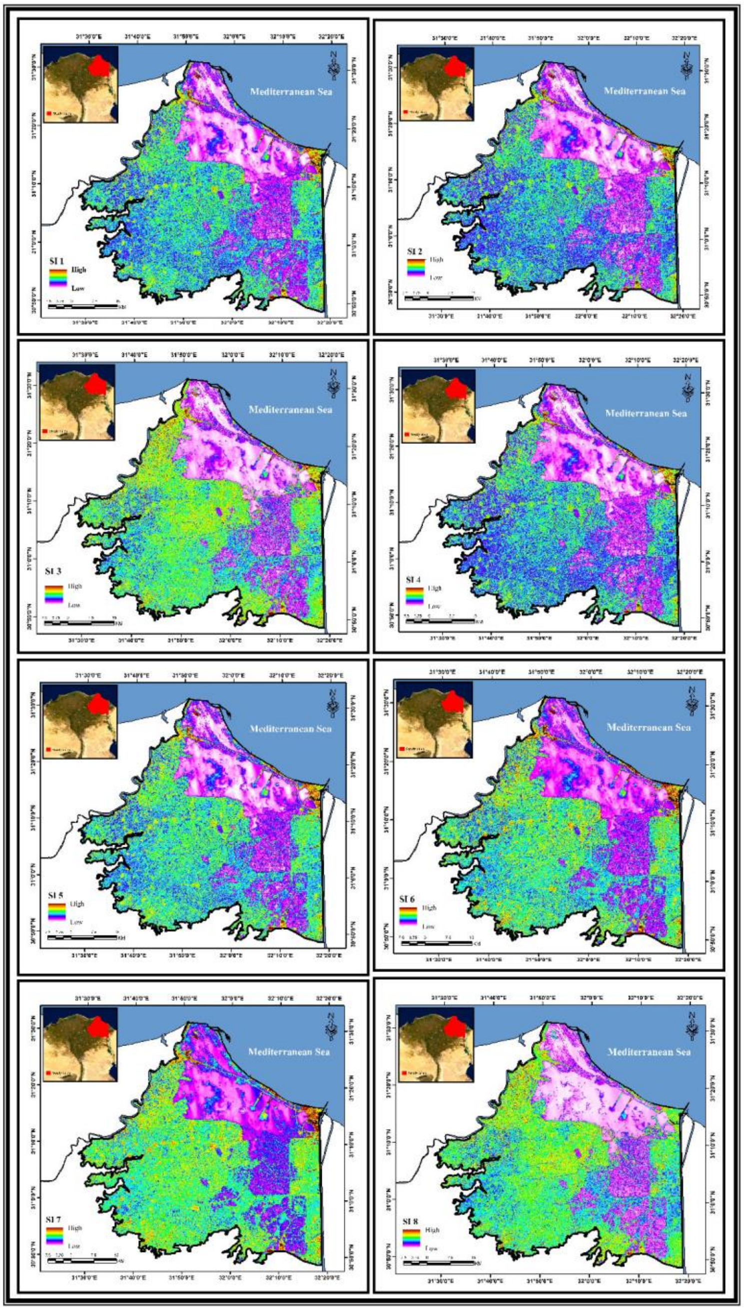
Table (1): Soil Salinity Indices (SI) in the Study Area

Salinity Indices	Equation	Reference
SI 1	$SI1=\sqrt{B^2 x R^2}$	Khan et al., 2005
SI 2	$SI2=\sqrt{G^2 x R^2}$	Douaoui et al., 2006
SI 3	$SI3=\sqrt{(G^2+R^2+NIR^2)}$	Douaoui et al., 2006
SI 4	$SI4=\sqrt{(G^2+R^2)}$	Gorji, 2016
SI 5	$SI5=\frac{B-R}{B+R}$	Dehni &Lounis 2012
SI 6	$SI6=\frac{G x R}{B}$	Mousavi et al., 2017
SI 7	$SI7=\frac{B x R}{G}$	Elhag, 2016
SI 8	$SI8=\frac{NIR x R}{G}$	Elhag, 2016

*B= (Blue band), G = (Green band), R= (Red band), NIR= Near Infrared (appendix 2 and 3).

2. Soil Salinity in the Field

The study relies on collecting 20 soil samples from the study area (Table 2), preparing and chemically analyzing them at the Faculty of Agriculture, Zagazig University, 2020, with the aim of comparing them with the results of the indices on which the study rests. As previously mentioned, these indices are extracted through the process of the spectral resolution of the satellite image range.



Source: Satellite image Landsat 8-2020, using ENVI 5 &Arc GIS 10.5 & ERDAS IMAGINE 2014

Figure (2): Soil Salinity Indices (SI) in the Study Area

Table (2): Results of Laboratory Analysis of Soil Salinity in the Study Area

No.	X	Y	ECe (dsm/m)
1	383485.423	3469641.651	76.2
2	377610.82	3454982.592	1.2
3	377265.038	3443087.174	6.8
4	401395.086	3453670.528	5.5
5	408909.268	3444357.176	1.1
6	383178.45	3428109.98	1.3
7	367845.853	3426894.642	1.7
8	373666.697	3420756.296	4.5
9	389347.287	3444600.25	1.0
10	431748.147	3422223.149	33.6
11	431906.897	3430001.914	44.1
12	429313.975	3437706.597	61.7
13	432289.768	3441232.301	53.9
14	432065.648	3444892.694	62.2
15	428057.753	3447788.568	82.2
16	432827.649	3452269.292	67.3
17	394862.645	3426167.023	1.5
18	407268.692	3431530.949	3.4
19	417809.713	3416925.92	4.9
20	359719.878	3444449.78	2.5

Source: The analysis is carried out at the Faculty of Agriculture, Zagazig University, 2020

The analysis of the soil salinity table Table (2), based on Appendix (1), and indicates that salinity can be classified into the following categories:

- Non-saline and low saline lands:

They are the lands that have a normal or very low percentage of dissolved salts. That is, the degree of EC does not exceed 4 dsm/m. The lands of this category are spread over 8 samples, and they represent 40% of the total number of samples. The vast majority of these lands are located in the middle and west of the study area.

- Moderately saline lands:

They are the lands that have an average percentage of dissolved salts. That is, the degree of EC ranges from 4 to 8dsm/m. These lands are spread in the areas adjacent to the lands that have a normal percentage of dissolved salts. They are shown in 4 samples, representing 20% of the total number of samples.

- Extremely saline lands:

The degree of EC exceeds 16 dsm/m, shown in 8 samples and representing 40% of the total number of samples. The lands of this section cover scattered areas of the study area, particularly in the east and northeast. The high degree of electrical conductivity is owing to the leakage of the Suez Canal water.

3. Visual Investigation

In order to capture images indicative of soil salinity and its impact on vegetation, it is relied on the field review (field study) of the northeastern Nile Delta. This is mainly for the sake of supporting the accuracy of the spectral resolution for accurate mapping of salinity.

This is done based on the idea that extremely saline areas can be detected with all kinds of soil salinity indices, along with the indication of the bright reflection of the salt crust, and consequently there is no need to apply any of the indices (Awad, 2018). On the other hand, non-saline and low saline soils are indirectly investigated through capturing images of vegetation, which is inversely correlated with the degree of salinity. In this case, the low density vegetation indicates high salinity, and vice versa.

The following images confirm the variation in salinity degrees in the northeastern Nile Delta region, whether directly (Picture 1) or indirectly (Picture 2)

4. Factors Impacting Soil Salinity

Soil salinity in the northeast of the Nile Delta is impacted by many variables; the most important of which are as follows: geological, hydrogeological, topographical, and climatic characteristics.

a. Geological and hydrogeological characteristics:

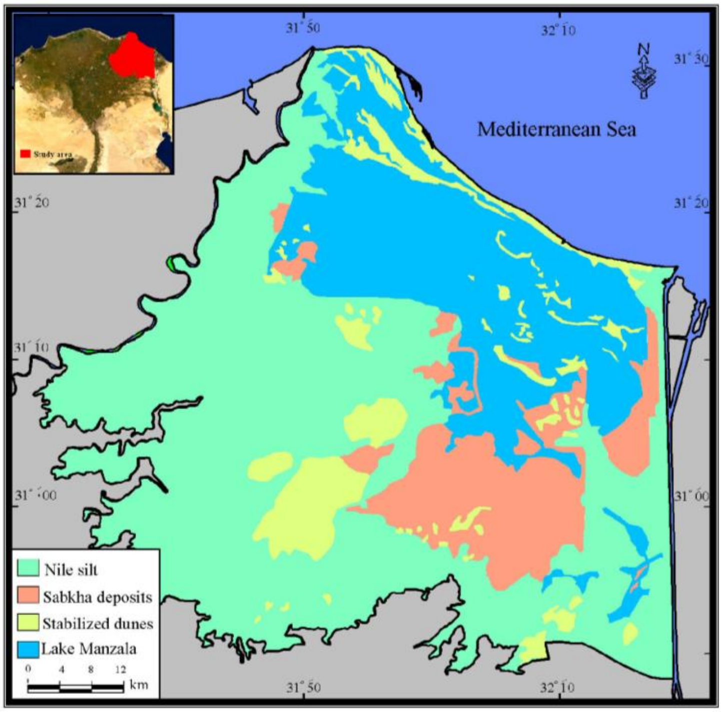
The development of the northeastern Nile River Delta region is reflected in its geological formations, along with the prevalence of the Nile deposits figure (3), as it belongs to one time, which is the Quaternary. It reaches an area of 2128 km^2, forming 53.8% of the total study area, followed by Sabkha deposits with an area of 494 km^2, making up 12.5%, and then the stable dunes that are spread over the low areas, making up 8.9%.

Source: Field Study, 2020

Picture (1) Highly Saline Areas and Sabkha in the Northeastern Nile River Delta

Source: Field Study, 2020

Picture (2) Variation in Vegetation Density (Extremely Low to Moderate) in the Northeastern Nile River Delta



Source: Geological maps (CONCO) 1: 500.000 in 1987, using ArcMap10.5

Figure (3): Geology of the Northeastern Nile River Delta

Table (3): Geology of the Study Area

No.	Geological deposits	Geological symbol	Area (km²)	%
1	Nile silt	Qns	2128	53.8
2	Sabkha deposits	Qb	494	12.5
3	Stabilized dunes	Qds	353	8.9
4	Lake Manzala	-	980	24.8
Total area	----------------------------		3955	100

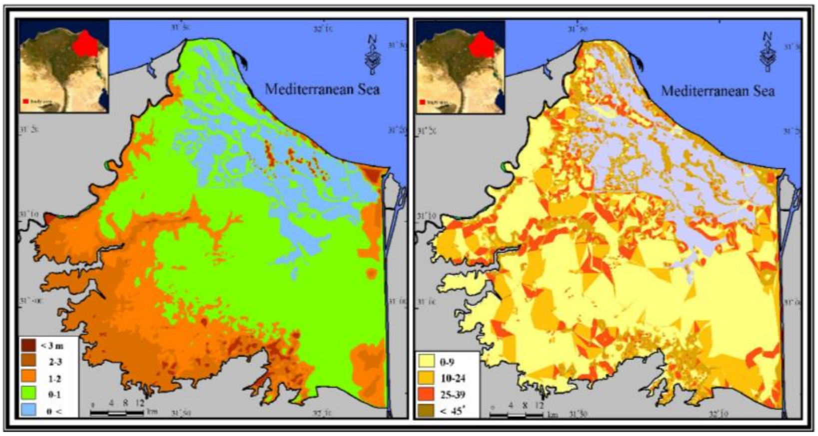
Source: It is based on Figure (3).

These deposits are characterized by being loose, and highly porous and permeable, which helps to establish a hydraulic connection between the groundwater and surface water represented by the Suez Canal, Lake Manzala, Damietta Branch, canals and drains. This, in turn, has impacted the properties of the groundwater, particularly its quality. In addition, the environmental conditions of deposition led to the formation of a clay layer, ranging from cohesive to extremely cohesive, with Holocene deposits (Saber, 2012), that helped to conserve water, and prevented its leakage to the bottom to a large extent (semi-permeable). This had a great impact on the high salinity of the soil, especially on the eastern side adjacent to the Suez Canal area.

b. Topographical characteristics:

The study of the topographic characteristics is useful in determining the extent of their impact on the water leakage process and the increase in the rates of soil salts in the study area. The analysis of these topographical characteristics in Table (4) and Figure (4) shows the following:

- **The elevations in the study area range between 0 and 4 meters above sea level, where the category of 0-1 meter above sea level prevails, with an area of 1941 km^2 and a rate of 49% of the total area of elevations in the study area. It is followed by the category of 1-2 meters above sea level, with an area of 734 km^2 and a rate of 19% of the total area of elevations in the study area. Then, the category of 3-4 meters above sea level comes last, with an area of 65km^2 and a rate of 2%.**
- **Gentle slopes (1-9°) prevail in the study area with a rate of 53%, followed by moderate slopes (10-24°) that come in the second place with a rate of 18% of the total study area. Then, steep slopes (25-39°) come last, with a rate of 13% of the total study area (Figure 4).**



Source: Topographical maps with a scale of 1: 50.000 in 2003, using ArcMap10.5

Figure (4): The Topographical Characteristics of the Study Area

Table (4): Topographical Characteristics in the Northeastern Nile River Delta

DEM (m)			Slope (°)		
Categories	**Area km²**	٪	**Categories**	**Area km²**	٪
0-1	1941	49.1	0-9	1778	45
1-2	734	18.6	10-24	607	15.3
2-3	622	15.7	25-39	445	11.3
3-4	65	1.6	< 40	532	13.5
Bodies of water	593	15	Bodies of water	593	15
Total	3955	100	Total	3955	100

Source: It is based on Figure 4, using ArcMap10.5.

It is evident from the analysis of the topographical characteristics of the northeastern delta that it is characterized by the prevalence of low-lying areas—which approximate 50% of the total study area and do not exceed one meter above sea level—along with the degree of gentle sloping and level. This helped the water to remain for a long period on the surface, led to the accumulation of salts in the study area mainly owing to the high degree of evaporation, and helped to increase water infiltration that raised the level of groundwater. Due to the capillary property, the water evaporates and the salts accumulate, particularly in the eastern part of the study area. On the other hand, the decrease in salinity, especially in some areas and in the west in particular, is a result of the spread of canals and the Damietta Branch (low saline water).

c. Climatic characteristics:

The study area is located in the area overlooking the Mediterranean Sea, which had a direct impact on the climatic characteristics. The annual average temperature in Port Said station reached 20.6°C, Damietta station 20.15°C, Ismailia station 21.8°C, and Sirw station 20.9°C. Moreover, evaporation rates are especially high in June. They converge in Damietta and Port Said stations by 5.6 mm and 5.8 mm respectively, whereas they are about 6.1 mm in Sirw and 6.7 mm in Ismailia (Meteorology, 2017).

There is no doubt that this temperature change in the northeastern Nile River Delta directly impacts the salt activity in the soil as their effect and effectiveness increase in the summer season. This is mainly due to the fact that the high temperature is associated with the high degree of evaporation, especially towards the south. Furthermore, as the temperature rises during daylight hours, especially in the summer, the salt solutions rise to the surface due to the capillary property to be exposed to evaporation at or near the surface, depositing salts.

Second: Results and Discussions:

1- The Best Soil Salinity Index:

The previous studies indicate that there is a variation in the values of the spectral reflectance of the surface of the earth, and salinity plays a major role in these changes. Consequently, this result has to be exploited in the study of salinity dynamics, which is the most important basis for monitoring soil degradation. These studies have relied on many of the aforementioned indices, and each index, in turn, relies on different variables of spectral reflectance. Accordingly, the current study identifies the best of these indices to rely on in studying the dynamics of soil salinity northeast of the Nile Delta.

The soil salinity indices were applied to the satellite image Landsat 8-2020 OLI, and compared with the field data to verify the accuracy of the results by establishing a correlation between the salinity values resulting from each index of salinity and the measured values in the field. Then, the most accurate index is chosen and applied in other years to study the development of soil salinization in the study area.

The best indices have been selected by determining the highest degree of correlation between the results of the indices and the results of the chemical analysis of soil samples. It is noted that the correlation has been established between the locations of the field samples and the indices, and not between areas to reach the highest possible accuracy. In addition, visual field investigation of many areas is sought, particularly of the highly saline ones to confirm their status.

By applying the eight indices to the study area, Salinity Index 1 was found to be the best in determining soil salinity as the value of the correlation coefficient reached 0.91. In terms of preference, it was followed directly by the second and fifth indices as the correlation coefficient reached 0.84 for both of them equally. The fourth, sixth and seventh indices are equal with a correlation coefficient of 0.83, while the value of the third index's correlation coefficient is 0.66. The eighth index comes in the fourth and last place in the ranking of indices, reaching 0.42 (Figure 5).

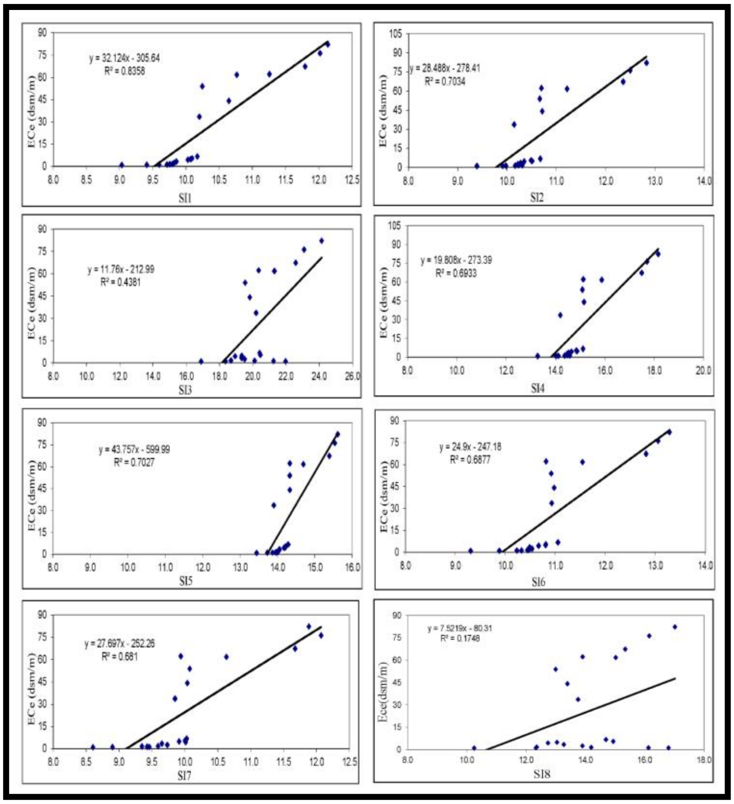


Figure (5) Correlation between Soil Salinity and Measured Field Values (EC)

This is consistent with the study of Awad (2018) in which the degree of correlation for the first index was 0.99, the study of Asfaw, et al. (2016), with a correlation degree for the first index of 0.78, and the study of Abdelaty and Aboukila (2017) with a correlation degree of 0.50.

2. Spatial and Temporal Dynamics of Soil Salinity:

The study of the development of soil salinity relies on the first index, which is the best, and most appropriate and effective index for monitoring the assessment of salinity spatially and temporally. This is done by relying on the satellite images Landsat 5 in the years of 1984, 2000 and 2010 along with Landsat 8 OLI 2020**.**

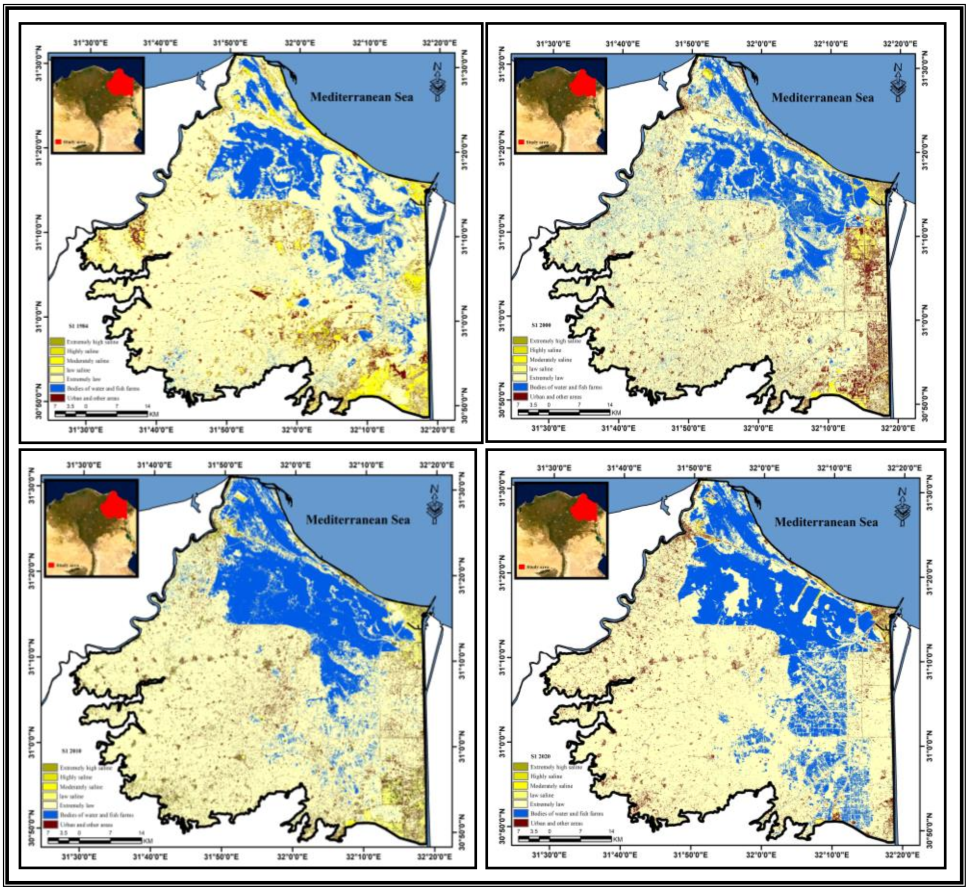
Figure (6) and Table (5) show the development of soil salinity from 1984 to 2020:

- Extremely low saline lands:

The lands of this category are spread in the vast majority of the lands of the study area. They increased from 1984 to 2010, reaching 39.8% and 45.42% respectively; however, their area decreased to 42.17% in 2020. The reason behind such decrease is not their high salinity, but it is due to cutting off parts from them, and turning them into fish farms. They are spread in the middle, the west and in some areas in the east of the study area.

- Low saline lands:

The area of land with a low percentage of salts increased significantly, reaching 9.8% in 1984, compared to 11.39% in 2020. These lands are spread in small areas near the areas of the first type, and in some areas in the east, which was a reflection of the government's policy of reclamation in the southern part of Port Said governorate, especially after the establishment of Al-Salam Canal.



Source: Satellite images for the years 1984, 2000, 2010, 2020, using ERDAS IMAGINE 2014 & EVVI 5 & Arc GIS 10.5

Figure (6): Development of Soil Salinity according to (SI 1) in the Northeast of the Nile Delta from 1984 to2020

Table (5): Development of the proportions of Soil Salinity Areas in the Northeast of the Nile Delta

Categories	1984 %	2000 %	2010 %	2020 %
Extremely low saline	39.8	44.78	45.42	42.17
Low saline	9.8	9.97	10.18	11.39
Moderately saline	3.8	3.7	3.05	3.15
Highly saline	1.4	1.1	0.9	0.47
Extremely high saline	0.4	0.35	0.2	0.1
Bodies of water and fish farms	34.7	26.2	23.65	25.45
Urban and other areas	10.1	13.9	16.6	17.27
Total	100	100	100	100

Source: It is based on Figure 6.

- Moderately saline lands:

These lands are spread in the areas adjacent to the lands that have a low percentage of salts. In general, these lands do not exceed 3.15% of the total study area during the comparison period.

- Highly saline lands:

The lands of this category are located in very small areas, especially in the east of the study area, with a significant decrease from 1.4% in 1984 to 0.47% in 2020. The reason for its existence is the dependence on the water of some drains to irrigate agricultural lands—which are characterized by high salts such as the Bahr El-Baqar drain—and the leakage of the Suez Canal water to those areas.

- Extremely high saline lands:

Lands that have a very high percentage of dissolved salts cover very small areas that do not exceed 0.4% of the total study area. The reason for the high degree of electrical conductivity in them, especially in the east and northeast of the study area, is due to several reasons; the most important of which are the following: being affected by salt water, especially El-Qabouti channel in the north and the Suez Canal in the east, and not leach the soil periodically, especially the lowlands.

It is concluded from the previous measurements that the general trend of extremely high and highly saline lands in the study area is heading towards a decrease, particularly in the eastern regions, in favor of an increase in the area of moderately saline and low saline lands.

3- The Impact of Soil Salinity on Vegetation:

The study relies on EVI (Enhanced Vegetation Index) to obtain the vegetation density and its development in the northeast of the Nile Delta during the period from 1984 to 2020.

It is an 'optimized' index designed to enhance the vegetation signal, improve sensitivity in high biomass regions, and improve vegetation monitoring through a de-coupling of the canopy background signal and a reduction in atmosphere influences. It can be applied through the following equation:

$$EVI = 2.5 * [(NIR - RED) / (NIR + 6 * RED - 7.5 * Blue + 1)]$$

(Liu and Huete, 1995)

This index is considered the best index in determining vegetation due to its ability to eliminate background and air noise.

The vegetation is one of the uses of land that is most sensitive to salts, taking into account that the impact varies from one plant to another. The harmful impact of salts in the soil is due to the fact that every part or salt granule attracts and holds moisture around itself, and thus the energy of the roots of plants is expended in order to tighten and absorb the water held around the salts. Moreover, the roots of plants allow the easiness of water movement through them, but they do not allow the movement of solutes or solutions, and therefore the osmotic pressure of the salts reduces the flow of water by free diffusion within the roots of plants (Abdulaziz, 1998). The impact of this is reflected on the rate of plant absorption of water, and thus on the rate of plant growth and crop productivity.

The lands of the study area are classified, according to the vegetation density (Figure 7 and Table 6) and the field study, into the following:

a. Lands of extremely high vegetation density:

They are highly productive lands, where most crops are available, and soil salinity is extremely low. Their area has increased significantly from 0.88% in 1984 to 5.97% of the total study area, and the lands of this category are located in the middle and west of the study area.

b. Lands of high vegetation density:

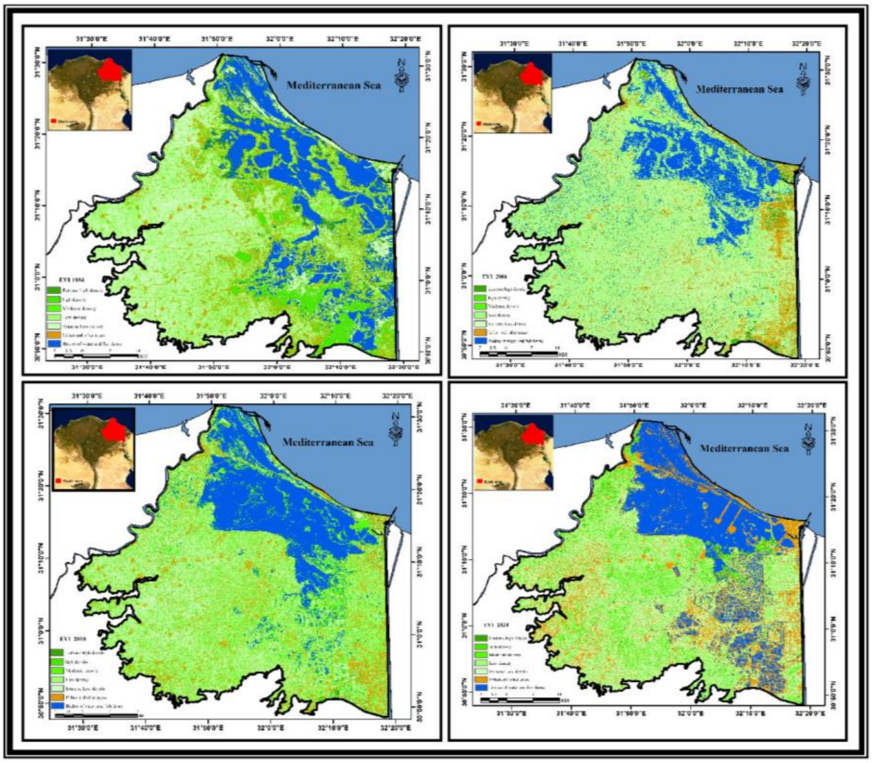
They are the well-productive farmlands, and their soil salinity is normal. They are similar to the previous category in the sense that their area increased from 3.03 to 12.52% in 1984 and 2020 respectively. Moreover, the lands of this section are spread in the areas adjacent to the aforementioned areas.

c. Lands of Moderate vegetation density:

They are medium-productive lands that yield crops. The acre productivity of these lands is within the limits of the general average per acre production in the Republic. They often have a normal or moderate percentage of salts, and this percentage reached 8.09% in 1984, and increased to 12.74% of the total study area in 2020.

d. Lands of low and extremely low vegetation density:

They are lands of low production; that is, their production is less than the general average for the production of an acre of crops in the Republic. They are either saline or extremely high saline lands. Therefore, the area of these lands together exceeded 25% of the total study area, with a clear decrease during the comparison period. This category is spread in the areas near the Suez Canal in the east and the low-lying areas south of Lake Manzala.



Source: Satellite images of the years 1984, 2000, 2010 and 2020, using ERDAS IMAGINE 2014 & EVVI 5 & Arc GIS 10.5

Figure (7) Application of the EVI Index to the Study Area

Table (6): The Percentage of Vegetation Density in the Northeastern Nile River Delta

Categories	1984 %	2000 %	2010 %	2020 %
Extremely low vegetation density	26.09	25.49	19.65	14.85
Low vegetation density	17.11	16.08	15.1	11.2
Moderate vegetation density	8.09	10.1	11.5	12.74
High vegetation density	3.03	7.13	10.6	12.52
Extremely high vegetation density	0.88	1.1	2.9	5.97
Bodies of water and fish farms	34.7	26.2	23.65	25.45
Urban and other areas	10.1	13.9	16.6	17.27
Total	100	100	100	100

Source: It is based on Figure 7.

The previous analysis shows an increase in the area of highly dense and extremely dense vegetation, and an evident decrease in the area of low and extremely low dense vegetation. This is due to several reasons; the most important of which is the change in soil salinity percentage. Table (7) indicates the correlation between the area ratios of soil salinity classes and the proportions of areas of vegetation density.

Table (7) The Correlation between Soil Salinity and Vegetation Density

Categories		Soil salinity (Ece)				
		Extremely low	Low	Moderate	High	Extremely high
Vegetation Density	Extremely low	-0.17	-0.93	0.88	0.96	0.99
	Low	-0.08	-0.99	0.71	0.97	0.93
	Moderate	0.50	0.85	-0.88	-0.98	-0.96
	High	0.53	0.81	-0.91	-0.96	-0.96
	Extremely high	0.40	0.74	-0.78	-0.96	-0.96

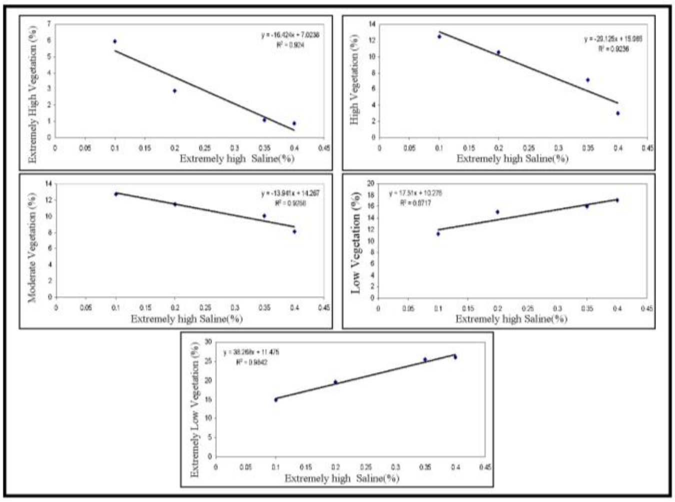
Source: It is based on Table 5 and Table 6, using SPSS.

The analysis of Table (7) and Figures (8, 9, 10, 11, and 12) indicates the following:

- **There is an extremely strong inverse correlation between the area of extremely high saline lands, and the moderate, high and extremely high vegetation density categories, reaching -0.96. Such correlation is logical because of the decrease in the area of extremely high saline areas, which took place during the comparison period from 1984 to 2020. As a result, the area of high vegetation density increased.**
- **The lowest degree of correlation recorded is between the area of extremely low saline lands and the vegetation**

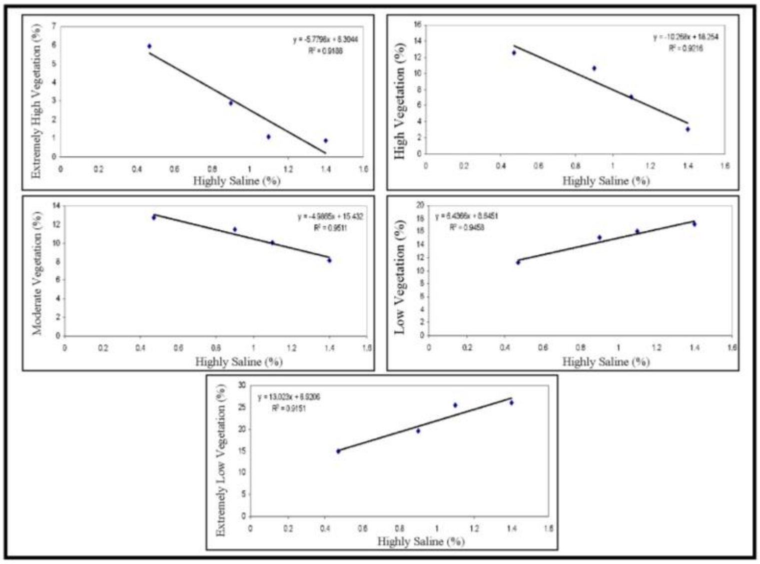
density categories. An extremely weak inverse relation is recorded with the low and extremely low categories, reaching - 0.08 and -0.17 respectively. In addition, a medium direct relation is recorded with the moderate, high and extremely high categories, ranging between 0.40 and 0.53. The reason for the decrease in the degree of correlation is due to a decrease in the area of low saline lands in 2020, contrary to what is expected, and this, as previously mentioned, is due to cutting off parts of them and converting them to fish farms.

- **It is worth noting that there are some illogical correlations between soil salinity and vegetation density. This is perhaps because of the small correlation sample (only 4 categories).**



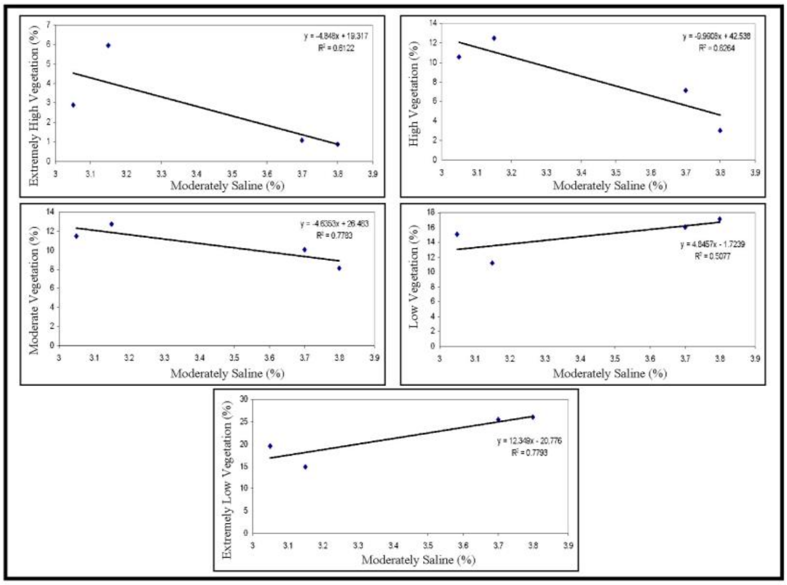
Source: It is based on Table 7, using SPSS.

Figure (8) Correlation between Extremely High Saline Soils and Vegetation Density



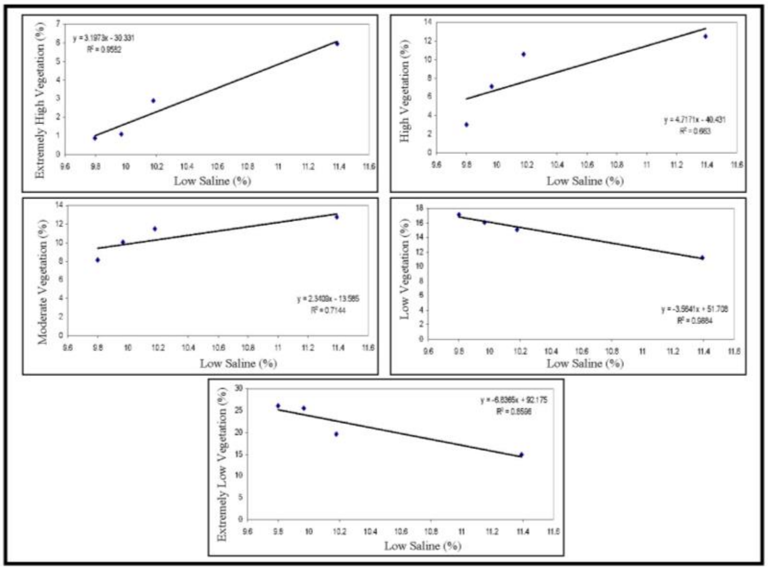
Source: It is based on Table 7, using SPSS.

Figure (9) Correlation between Highly Saline Soils and Vegetation Density



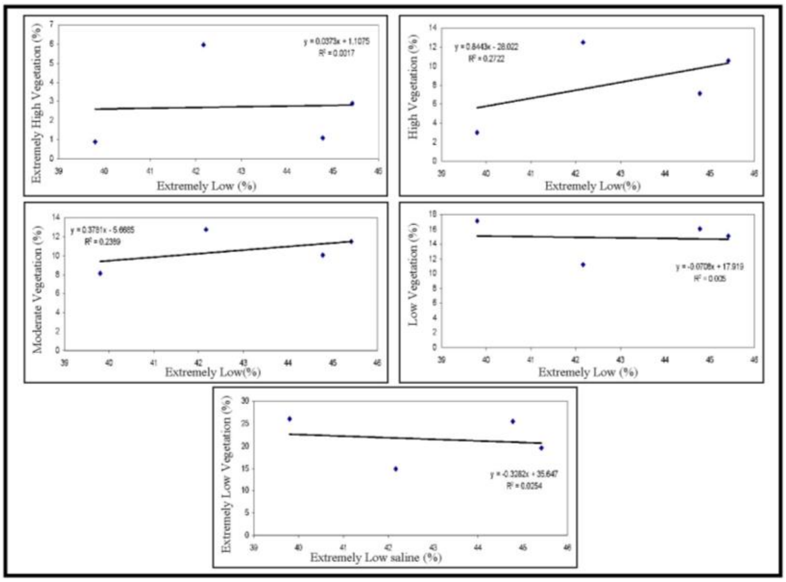
Source: It is based on Table 7, using SPSS.

Figure (10) Correlation between Moderately Saline Soils and Vegetation Density



Source: It is based on Table 7, using SPSS.

Figure (11) Correlation between low Saline Soils and Vegetation Density



Source: It is based on Table 7, using SPSS.

Figure (12) Correlation between Extremely Low saline Soils and Vegetation Density

Results:

1. The ability of geoinformatics techniques to create accurate maps of the dynamics of soil salinity, spatially and temporally, which is an integrated approach between field data, geographic information systems and remote sensing.
2. The ability of remote sensing techniques to Spectral Resolution resulting from differences in soil salinity as the study shows the efficiency of the satellite images Landsat 5 in the years of 1984, 2000 and 2010 along with Landsat 8 OLI 2020, in obtaining spatial accuracy and illustrative power.
3. The salinity index (SI) is one of the important spectral criteria in monitoring soil salinity, and it was applied to the study area to find out the spatial and temporal changes in soil salinity values.
4. There is a difference in the values of the salinity index SI1 (the best index) spatially and temporally due to the change in the natural and human environmental conditions that the northeastern Nile River delta went through. The general characteristics of the study area—which are represented in the prevalence of deposits that are loose, and highly porous and permeable; the prevalence of low-lying areas; the degree of sloping, whether gentle or level; salty water infiltration (the Suez Canal); and the high degree of evaporation—led to the accumulation of salts in some areas of the study, particularly in the east.
5. There is an extremely strong inverse correlation between the area of extremely high saline lands, and the moderate, high and extremely high vegetation density categories, reaching -0.96. Such correlation is logical because of the decrease in the area of extremely high saline areas, which took place during

the comparison period from 1984 to 2020. As a result, the area of high vegetation density increased. This is because vegetation is one of the land uses that is most vulnerable to soil salinity.

Recommendations:

1. The use of geoinformatics techniques is recommended—particularly multi-spectral image analysis, in the study of soil salinity, whether temporally or spatially—because of its constant updating of data and monitoring the changes that occur within the environment. This method is also one of the least expensive methods, especially in large areas.
2. The saline lands in the study area, particularly those in the east, are in need of digging a complete network of field drains, with a depth ranging from 80 to 100 cm from the surface of the earth, along with improving the condition of field drainage, and providing abundant amounts of irrigation water so as to leach away the highly excess salts.
3. Due to the utmost importance of this topic to ensure the accuracy of the indices used in assessing soil salinity, it is recommended to carry out many researches that deal with this topic. Accordingly, accurate results are to be obtained; on the basis of which real and realistic proposals and recommendations can be made, with the aim of reaching ways to avoid this problem in many areas that suffer from soil salinity.

Appendix (1): Categories of Soil Salinity and Its Impact on Crops according to Electrical Conductivity

Categories	ECe (dsm/m)	Salinity Impact on Crops
Non-saline	0-2	Small or marginal impact
Low saline	2-4	It impacts highly vulnerable crops.
Moderately saline	4-8	It impacts many crops, and their yields are limited.
Highly saline	8-16	It is tolerated by crops that tolerate salinity.
Extremely saline	<16	Some crops tolerate salinity.

Source: (Gorji, 2016) After USDA, 1954

Appendix (2) Usage of spectral bands in the 8 Landsat

Band No.	Wavelength (μm)	Spaial Resolution	Wavelength range
1	0.43−0.45	28.5	VNIR
2 BLUE	0.45−0.51		
3 GREEN	0.53−0.59		
4 RED	0.64−0.67		
5 NEAR INFRARED (NIR)	0.85−0.88		
8	0.50−0.68	14.25	
6	1.57−1.65	28.5	SWIR
7	2.11−2.29		
9	1.36−1.38		
10	10.6−11.19	(28.5)	TIRS
11	11.5−12.51		

Source: Pour and Hashim, 2015.

Appendix (3): Usage of Spectral Bands in ETM & TM Landsat Images

Band	Approximate Wavelength (µm)		Usage	ETM & TM Landsat
Blue	**0.45**	**0.52**	**It creates maps of coastal water areas, studying mud puddle of dams, and distinguishes between soil and vegetation, in addition to urban studies**	**1**
Green	**0.50**	**0.60**	**This band matches the green reflection of healthy vegetation, and is also useful for mapping water bodies and studying mud puddle of dams.**	**2**
Red	**0.60**	**0.70**	**It is the band of chlorophyll absorption of vegetation. It is considered one of the most important bands for distinguishing vegetation, and it is also useful for determining boundaries of soil types along with the geological boundaries. It is also used in urban studies.**	**3**
Near Infrared	**0.76**	**0.90**	**It helps to distinguish between types of vegetation due to its sensitivity to chlorophyll, and it is useful in distinguishing crops, enhancing the contrast between soil and crop as well as distinguishing between water and materials other than water.**	**4**
Mid Infrared	**1.55**	**1.74**	**It is sensitive to plant moisture, as it can study crop dryness and analyze plant safety. In addition, it is one of the few bands that distinguish between clouds, snow and ice.**	**5**
Mid Infrared	**2.08**	**2.35**	**It is used to distinguish between types of rocks and soil boundaries, in addition to determining the moisture of vegetation and soil. It is also useful in detecting fires.**	**7**
Thermal Infrared	**10.4**	**12.5**	**It detects stress exerted on vegetation and crops, heat intensity applications, and pest control. It is also useful in determining thermal pollution sites as well as sites for geothermal activities.**	**6**

https://sites.google.com/site/chaaouanjamal/teledetection/remote_sensing

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