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ADVANCES IN SOIL SALINITY DETECTION IN ARID AND SEMI-ARID REGIONS USING SALINITY AND VEGETATION INDICES

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ABSTRACT: *Soil salinization as a result of natural or of human-induces processes is a serious global-scale problem. Salinization is a major reason for soil resources degradation and declining of soil fertility. From an ecological and economic point of view it is extremely important to follow the occurrence and distribution of soil salinity as well as the intensity of the process. Several studies and efforts in assessing and controlling soil salinity have been made. Remote sensing techniques are widely used to detect and map the salt-affected areas. The indices used in this research are the normalized differential vegetation index (NDVI), normalized difference salinity index (NDSI) and modified soil adjust vegetation Index (MSAVI). MSAVI was found to be effective in discriminating the plants under severe and moderate conditions of soil salinity as well as under non-saline conditions. Temporal trend analysis technique was carried out to detect significant changes in the soil verses vegetation conditions. The obtained results showed that the studied area is mostly covered by field crops where, NDVI values were ranging between 0 and 0.82 and MSAVI ranging from 0.02 to 0.70. The NDSI values, however, showed the land salinity classes, as they were fluctuated from 0.01 to 0.89.*

Key words: *NDSI, NDVI, MSAVI, LAND SAT 8 image.*

INTRODUCTION.

Salinization is a major reason for degradation of the soil resources and declining of soil fertility. From an ecological and economic point of view it is extremely important to establish the occurrence and distribution of soil salinization as well as the intensity of the process. The magnitude and extent of soil salinity are affected climate change, soil parent material, inadequate irrigation and drainage systems and intensification of agricultural land use. To counteract deterioration of agricultural lands, the methods of managing and monitoring of soil resources must be improved. Today the world faces unprecedented set of environmental problems many of which are related to ecosystem depletion and destruction.

At present, conservation of natural resources is a fundamental and crucial ecological issue all over the planet. Soil cover is an essential component of the natural environment. It resembles the relationships between the other environmental components (rocks, water, climate, vegetation, human activities) and is an indicator of the ecological status of the landscape. Soil salinization is nowadays a world-wide problem relevant to the global concern of natural resources preservation. Based on the statistics concluded in 2008, more than 77 million hectares (5% of cultivated lands) in the world are affected by excess salt. Increased salinization of arable land will cause 50% land loss by the middle of 21st salt-spoiled soils constitute more than half of all irrigated lands. Every day for more than 20 years, an average of 2000 hectares of irrigated land in arid and semi-arid areas across 75 countries have been degraded by salt century (Sheng *et al.,* 2008; Rumiana *et* *al.,* 2015).Soil salinity is one of the most common soil-degradation processes, particularly prevalent in both arid and semi-arid areas (Ceuppens *et al*., 1997).

Salinity is a natural characteristic of the soil but salinization is caused by some anthropogenic activities. Salinity is defined as the salt accumulation in the soil (Katawatin and Kotrapat, 2005; Metternicht and Zinck, 2008). Soil salinization occurs when the weathered soil minerals and salts from irrigation water are not washed away by rain or by irrigation and instead they form excess amounts of Na^+, K^+, Ca^{2+}, Mg^{2+} and Cl^- ions (Fernandez-Buces *et al*., 2006). Under natural conditions, this phenomenon characterizes areas of low or decreasing precipitation, where there is poor drainage and rising water table level. Globally, salinization of agricultural soils is estimated at 45 Mha, and is growing at between 200000 and 500000 ha./ year (UNEP, 2007; Narmada *et al.,* 2015).

Remote sensing has been advocated as a powerful tool to play an important role in identifying, mapping, and monitoring soil salinity and salinization. The integration of remote sensing technologies in salinity studies is an expanding field of research and publication, taking advantage of steadily improving technology for remote and proximal sensing of land features at the terrain surface as well as in subsurface layers. Over the last two decades, several review papers have described the usefulness of remote sensing for salinity mapping and hazard assessment (Mougenot *et al*., 1993; Metternicht and Zinck, 2003; Farifteh *et al*., 2006). Now it might be the appropriate time to offer a comprehensive volume on the subject along with a large spectrum of recent and ongoing research using technological developments in sensors and platforms and new methodological approaches. The approach to the problem of delineating saline soils using remote sensing data and GIS techniques has been proved in many recent studies to be most efficient (Sadia and Nikos, 2005). The review is devoted to studying approaches used on the remotely sensed data to delineate the salt affected areas worldwide.

Implementation of remote sensing data in soil salinity mapping is firm to employ since salinization is not a static process. Therefore, a number of derivatives and alternatives to normalized difference vegetation index have been anticipated to discourse soils salinization monitoring and mapping (Montandon and Small, 2008; Yang *et al.,* 2011). Different remote sensing indices such as the salinity index (SI), the normalized difference salinity index (NDSI),and the brightness index (BI) in addition to normalized difference vegetation index (NDVI) were implemented to investigate the means by which these indices work for soil salinity mapping in the arid environment (Douaoui *et al.,* 2006 and Jiapaer *et al.,* 2011). The salinity index (SI), which combines the blue and red bands, is sensitive to the surface reflectance of salt-affected land with sparse vegetation cover (Douaoui *et al.,* 2006). The perspective of using remote sensing data and GIS practices has been demonstrated in several scholarly works to be the most resourceful (Roa *et al.,* 1991; Elhag and Bahrawi, 2014). The comprehensive use of satellite remote sensing and GIS has been recognized to be a cost-effective method for monitoring soils salinization poorly drained basins (Goossens *et al.,* 1993 and Casas, 1995). However, state of the art outcome specifies that there is no ideal combination of datatype and questioning method which can be functional with identical realization across approximately several environmental conditions (Wardlow and Egbert, 2008; Douaoui *et al.,* 2006). The aim of current research project is to differentiate the salinized soils from non-salinized soils implementing different approaches of digital image classification and band math techniques. To reach this objective, several soil salinity indices were applied to the Landsat 8 data.

Description of study area:

1. Location:

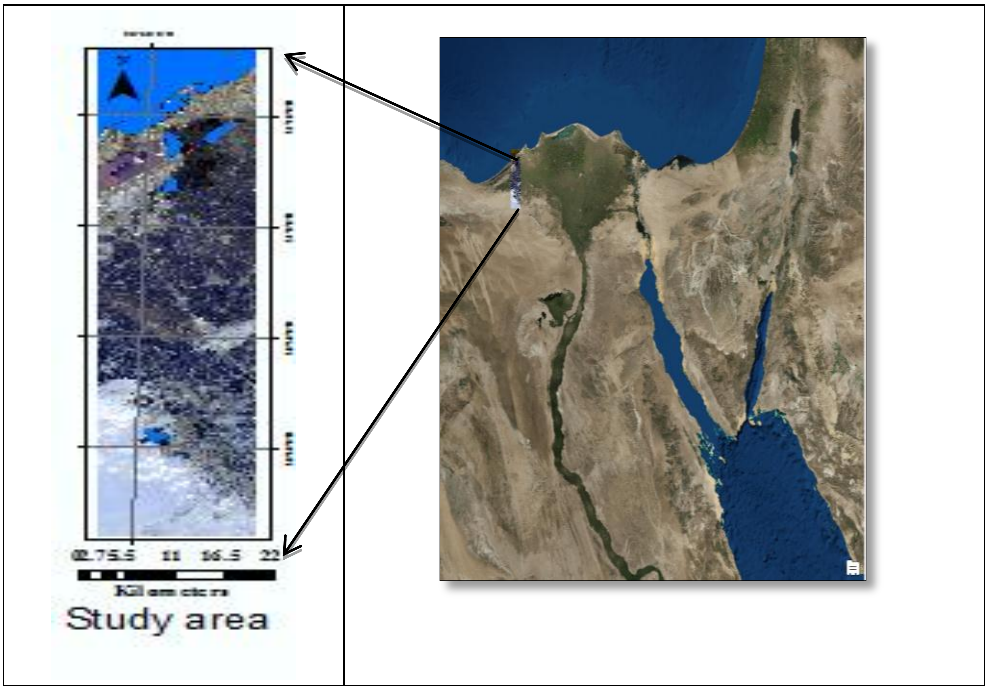
El Beheira Governorate occupies the main part of the western region of the Nile Delta. It lies on the western side of Rossetta Branch and is bounded to the north by Idku and Maryut lakes, It lies between longitudes 30^{o} $40^{'}$ and 29^{o} $50^{'}$ E and latitudes 31^{o} $30^{'}$ and 30^{o} $40^{'}$N, (Map 1).

2. Climate

The climatic condition of the study area are typically arid to semi-arid. It characterized by a long hot dry summer, mild winter with little rainfall, high evaporation with moderately to high relative humidity. With such high annual evapotranspiration condition both irrigation water and energy costs required for irrigation would be very high. The meteorological data and climate diagram of the study area are presented in Table (1) and Figure (1).

3. Geomorphology

The Nile Delta region covers an area of about 39000 square km. It extends 250 km from Lake Manzala on the east to El-Max, Alexandria on the west and 175 km in distance from Cairo in the south to Lake Burullus (North). The ancient Nile activity would be responsible for the macro- relief and the general slope from south to north towards the sea while the recent Nile activity would lead to the formation of the micro- relief. Surface level of the soil at the main branches or the secondary canals has been higher than valley between them. Within the studied area different geomorphological features have been distinguished (FAO, 1964; El Nahal *et al*., 1977; Shata *et al*., 1978). According to these authors three geomorphic units can be distinguished namely; Alluvial Plain (Recent Nile alluvium); Fluvial- marine Plain and Desert Plain.



Map (1): Location map of the study area.

Table (1): Climatological data of the studied area (2009-2014), (of Alexandria meteorological station).

Month	Temperature (°C)		Relative Humidity(%)	Wind speed 2m (m/ sec)	Rainfall (mm)	Sun shine duration (hr)	ET_o (mm/day)
	Max.	Min.					
Jan.	23.40	10.00	68.00	2.40	17.70	11.10	20.10
Feb.	22.00	10.19	65.00	2.70	6.50	11.00	22.30
Mar.	24.11	14.00	64.00	3.20	0.00	11.80	45.60
Apr.	25.00	13.91	62.00	2.80	0.00	12.80	74.30
May	29.90	17.50	66.00	2.90	0.00	13.60	95.70
Jun.	32.00	22.10	68.00	2.90	0.00	14.00	112.20
Jul.	34.00	24.00	67.00	2.90	0.00	14.00	120.60
Aug.	34.50	26.00	72.00	3.10	0.00	13.20	128.00
Sep.	34.50	25.50	65.00	2.70	0.00	12.20	117.40
Oct.	31.61	23.00	64.00	2.50	6.00	11.30	99.10
Nov.	27.50	15.80	72.00	1.80	1.00	10.40	65.00
Dec.	21.90	11.80	69.00	2.40	26.30	10.00	24.50

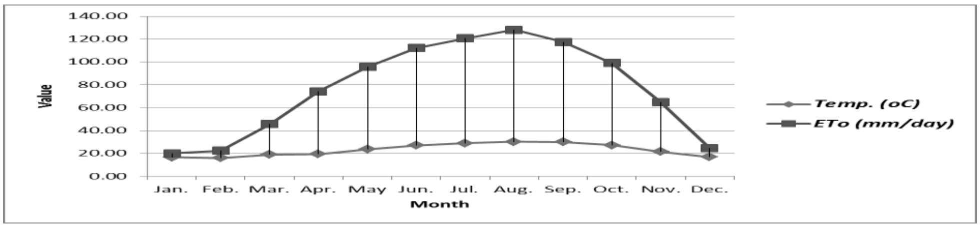


Figure (1): Climate diagram of the studied area.

4. Hydrological conditions

Groundwater (mostly recharged by the Nile water) is of relatively limited use in the Valley but is specially used in the desert fringes. Regional data on the hydrological conditions of the northwestern coastal zone of Egypt can be found in several publications such as (Guindy, 1989; Awad *et al.*, 1994; Shaaban, 2001). The studied area is characterized by extremely low rainfall with high evaporation and evapotranspiration rates. The scanty rainfall is confined to the winter season and rain usually occurs as thunderstorms and showers. Fresh groundwater in the region is believed to originate mainly from Nile delta to east of the investigated area; seepage of the fresh water from the Nile delta may also reach to the west of the studied area, similar results (Sharaky *et al*., 2007).

MATERIALS AND METHODS

The remotely sensed data of Landsat 8 image path 177 and raw 38 acquired on 2015-01-20 were the main source of information. Arc GIS 10.3 and ENVI 5.1 software's used to identify the boundaried and land features of the studied are based on the bands values to the top of Atmosphere (TOA) radians at the satellite image. This is applied after band wise conversion of the quantized and calibrated scaled Digital Numbers (DN). These software's are used to define and differentiate the saline from the non-saline soils of the studies area. Different indices namely; NDVI, NDSI and MSAVI were applied to the image of the study area (Huete, 1988). NDVI was calculated to differentiate between the areas of high from those of low vegetation cover. MSAVI was also calculated to identify the extent of healthy vegetation cover in the area. Additionally, in order to enhance the differentiation of saline areas, suppressing the vegetation, other index namely Normalized Difference Salinity Index (NDSI) have been employed depending on the spectral response of salt-affected soils (Odeh *et al.,*1995).

RESULTS AND DISCUSSION

Remote sensing applied to salinity and vegetation delineation:

1. Normalized difference salinity index (NDSI):

The use of NDSI index gives the differential preferences to achieve adequate soil salinity estimation on a large scale using remote sensing data. The dynamicity of the soil salinization process added further complications to designating salt-affected soils in a systematic uniform perspective. The use of different algorithms based on implementing different combinations and/or ratios of OLI-8 bands in the form of soil salinity index evidenced to be more efficient to overcome soil dynamicity problems (Lei *et al*., 2014; Zhang *et al*., 2015).The selection of the sensitive bands adequate for proper soil salinity mapping is not systematically generalized (Zhang *et al*., 2013; Zhang *et al*., 2015). Land salinity classes of the studied area are shown in Figure (2).The evaluation of different soil salinity indices was based on the regression model fit, effect significance, and model parameters. The NDSI is computed following the equation (Major *et al*., 1990):

$$\mathrm{NDSI} = \frac{\mathrm{R} - \mathrm{NIR}}{\mathrm{R} + \mathrm{NIR}}$$

Which: NIR and R are infrared red and red bands, respectively.

For this application, the NDSI dataset contained four training areas representing highly saline (mean value of 0.44 – 0.89), saline (mean value of 0.13 – 0.43), moderately saline (mean value of 0.08 – 0.12) and slightly saline (mean value of (0.01 – 0.07) areas were chosen, figure 2 and the supervised classification method was applied and the classification result is given in figure 2. As can be seen, the pale pink areas represent the slightly saline to low saline areas, orange areas represent the moderately saline areas, yellow areas represent saline areas and the brown areas represent the very high saline areas.

2. Normalized difference vegetation index (NDVI):

The NDVI was used to assess, monitor, and compare landscapes and it can be used to understand the various characteristics of vegetation community Elhag, (2016). Wesis *et al.,* (2004) concluded that NDVI is an appropriate tool for describing the vegetation variability in arid and semi-arid regions. It allows long time-scale investigations of Near-infrared energy which is highly reflected by the cell wall/air interface that is part of the internal structure of plants. The first vegetative indices were simple ratios of these spectral bands, mainly using the red band and the near-infrared (NIR) band. The NDVI is a normalized difference measure comparing the near infrared (NIR) and visible red bands using the formula (Rouse *et al*., 1973):

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{RED}}{\mathrm{NIR} + \mathrm{RED}}$$

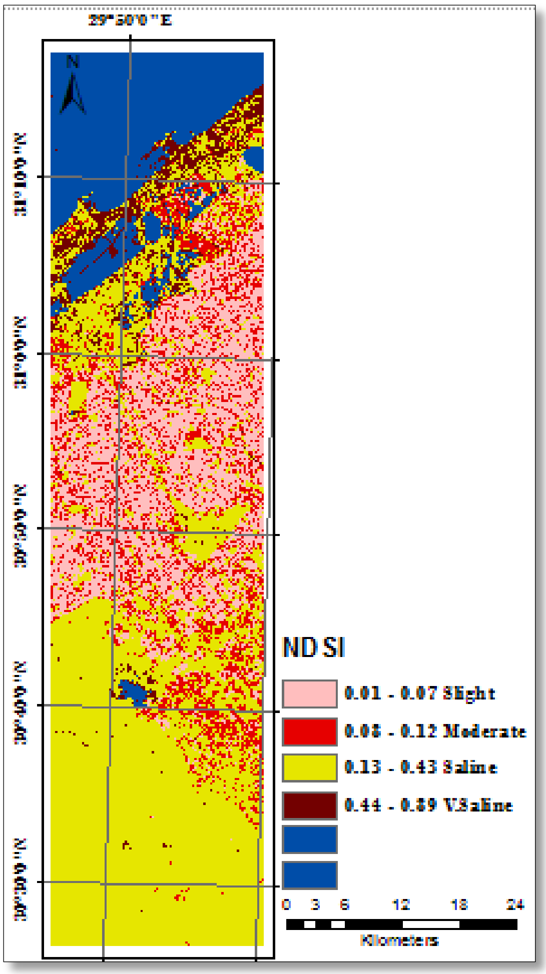


Figure (2): Classified LANDSAT 8 image using NDSI equation.

Training areas representing highly vegetated (mean value of 0.60 – 0.82), moderately vegetated (mean value of 0.4 – 0.59), and slightly vegetated (mean value of 0.21 - 0.39) and non- vegetated (mean value was smaller than 0.20) areas were chosen and the supervised classification method was applied. The classification result is given in Figure 3a where, the dark green areas represent the highly vegetated areas, yellow areas represent the non-vegetated areas and the pale green areas represent the low-vegetated areas. Accordingly, it could be concluded that the area is mainly highly vegetated area.

3. Modified soil adjust vegetation index (MSAVI):

The SAVI was developed to minimize soil influences on canopy spectra by incorporating a soil adjustment factor (L) into the denominator of NDVI equation. For optimal adjustment of the soil effect, however, the (L) factor should vary inversely with the amount of vegetation present. (L) is a soil fudge factor that varies from 0 to 1 depending on the soil, often set to 1. SAVI was also calculated to understand the extent of healthy vegetation cover in the area.The modified soil adjusted vegetation index has been shown to increase the dynamic range of the vegetation signal while further minimizing the soil background influences, resulting in greater vegetation sensitivity as defined by a 'vegetation signal' to 'soil noise' ratio. The MSAVI is a type of soil adjust vegetation index SAVI. As the study area is considered an arid and semi-arid area, it is expected that indices which consider soil reflectance can estimate vegetation fraction more accurately than other indices. Results showed that only MSAVI has acceptable outputs (Figure 3b). Qi *et al*., (1994b) developed the MSAVI2 to more reliably and simply calculate a soil brightness correction factor (Jiang *et al*., 2007; Qi *et al*., 1994a; Qi *et al*., 1994b; Ray, 2011). The MSAVI2 is computed following the equation:

$$\text{MSAVI2} = \frac{(2 * \text{NIR} + 1 - \sqrt{(2 * \text{NIR} + 1)^2 - 8 * (\text{NIR} - \text{RED})}}{2}$$

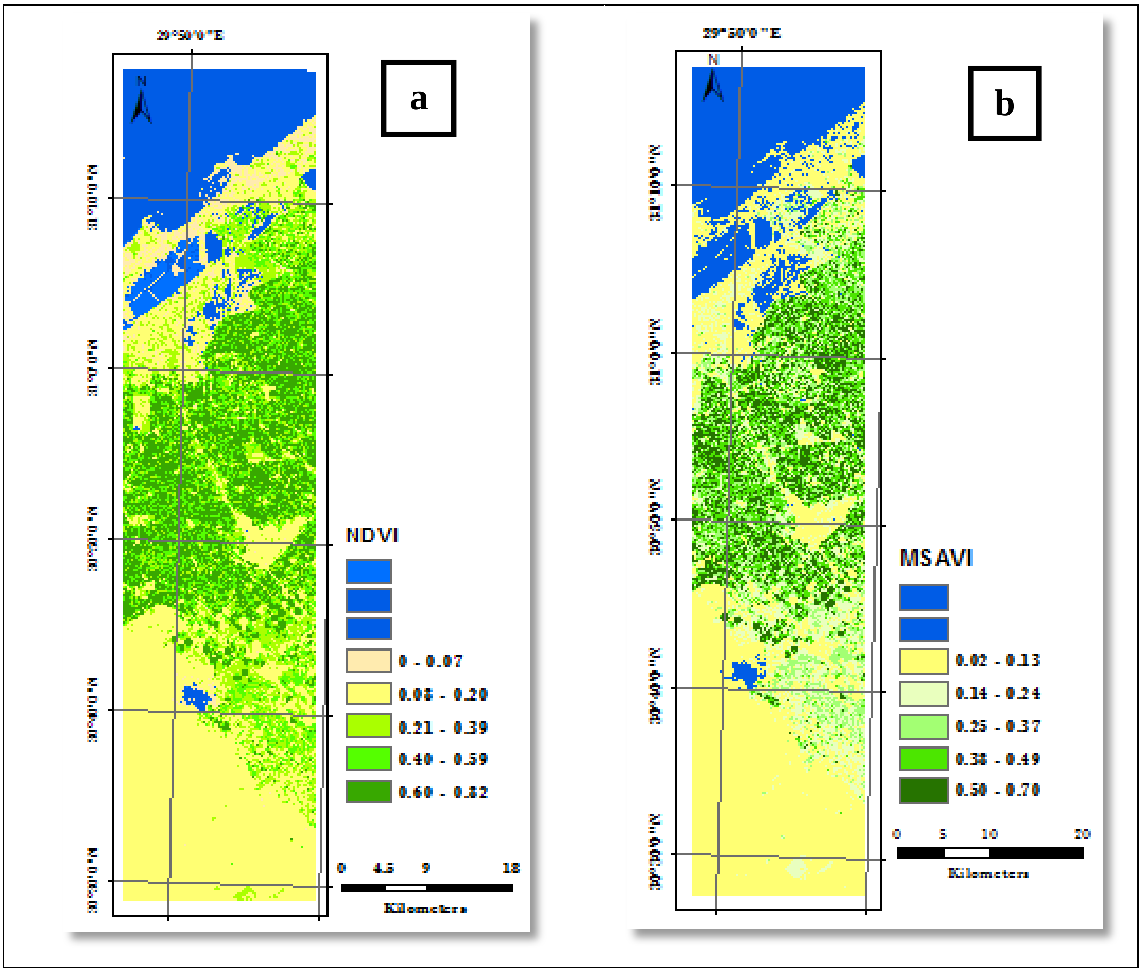


Figure (3): Classified LANDSAT 8 image using NDVI and MSAVI equations.

MSAVI image in Figure 3b give much importance to the information of internal difference of the vegetation as they expand the extracted spatial information of the vegetation to a certain extent. So they can provide major references for the information extraction of different vegetation type. The chosen training sets were representing highly healthy vegetated type (0.5– 0.7), moderately healthy vegetated type (0.38 – 0.49) and low healthy vegetated type (0.14 – 0.37). The classification results is given in figure 3b, where, the dark green color refers to the highly healthy vegetated areas, the olive green color refers to moderate healthy vegetated areas. While, the pale green shows the low to healthy vegetated areas.

CONCLUSIONS

The results of the current study revealed that the area under investigation is mostly of cultivated land. Monitoring soil salinity of such an area is very crucial as salinity may occur and extent in a way that the soil could lose its productivity. Using remotely sensed data and salinity and vegetation indices has proved to be effective as quick and accurate in monitoring soil salinity. NDSI and MSAVI were employed and showed different salinity classes ranging from non- saline to highly saline. NDVI index differentiates between the highly, low and non- vegetated areas. These results may contribute in managing the soils and take the appropriate measures to control salinity.

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التقدم في رصد ملوحة التربة في المناطق الجافة وشبه الجافة باستخدام مؤشرات الملوحة والغطاء النباتى

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الملخص العربى

تملح التربة هو نتيجة لعمليات طبيعية أو بفعل الإنسان وهى مشكلة خطيرة على المستوى العالمي، حيث أن التملح هو السبب الرئيسي لتدهور الموارد الأرضية وانخفاض خصوبة التربة. ومن وجهة النظر البيئية والاقتصادية فإنه من المهم للغاية تتبع حدوث وشدة وتوزيع ملوحة التربة. ولقد بذلت الجهود وأجريت العديد من الدراسات لإيجاد طرق سريعة لتقييم ومراقبة ملوحة التربة. واستخدمت تقنيات الاستشعار عن بعد على نطاق واسع للكشف عن وإعداد خرائط المناطق المتأثرة بتملح التربة. والمؤشرات المستخدمة في هذا البحث هي تطبيع مؤشر التفاضلية الغطاء النباتي (NDVI)، مؤشر تطبيع الفرق الملوحة (NDSI) ومؤشر التربة لضبط الغطاء النباتي المعدل (MSAVI)، ولقد وجد أن مؤشر MSAVI هو الأكثر فاعلية في تمييز النباتات تحت ظروف عالية ومتوسطة من ملوحة التربة وكذلك في ظل ظروف التربة غير المالحة. وقد استخدمت تقنية تحليل الاتجاه الزمني للكشف عن التغييرات المعنوية في التربة في مقابل ظروف الغطاء النباتي. وأظهرت النتائج المتحصل عليها أن منطقة الدراسة مكسوه معظمها بالمحاصيل الحقلية حيث كانت قيم NDVI تتراوح بين صفر و 0,82، و MSAVI من 0,02 إلى 0,70 وأيضا قيم NDSI أظهرت أراضي ذات درجات ملوحة مختلفة حيث تراوحت قيمها بين 0,01 و0,89.