Detection of Soil Salinity for Bare and Cultivated Lands Using Landsat ETM+ Imagery Data: A Case Study from El-Beheira Governorate, Egypt

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ABSTRACT

Soil salinization is a standout amongst the most basic environmental universal issues due to its adverse effects on agricultural productivity and sustainable development. Remote sensing is an important tool for investigating soil characteristics such as soil salinity. In saline soils, the spectral reflectance of salt at the surface or of vegetation execution that was adversely influenced by salt varies with different salinity levels. So, many salinity and vegetation indices have been developed and used. This study used ground data and Landsat Enhanced Thematic Mapper Plus (ETM+) satellite images (visible and near-infrared reflectance) to compare between eleven spectral indices, which encompassed soil salinity and vegetation indices, to determine the best index to the estimations of soil salinity for bare and cultivated soil. Soil samples were gathered from two locations in El-Beheira governorate in Egypt; 24 samples from Wadi-El-Natroun (bare soil) and 22 samples from El-Bostan (cultivated soil) and the soil samples locations were overlaid on ETM+ satellite image to extract the exact index values. The electrical conductivity (EC) measured in saturated soil-paste extract. Among those spectral indices, SI3 showed the highest correlation coefficient with EC (R^2 = 0.77) according to linear regression analysis and S6 according to Polynomial regression (R^2 = 0.83), followed by S3 for bare soil. NDVI and SAVI get the best result for assessing the soil salinity of cultivated soil (R^2 = 0.83 and 0.76) according to Polynomial and linear regression, respectively, followed by RVI.

Keywords: Soil salinity, salinity indices, vegetation indices, remote sensing.

INTRODUCTION

Soil salinization, either naturally occurring (primary soil salinization) or human-induced (secondary soil salinization) is a global vital issue, like climate change, global warming, desertification, and other environmental issues (Rowel, 1994). According to Farifteh (2007) soil salinization, as a term, that refers to the accumulation of salts on the surface or/and at the root zone of the soil and causes harmful effects on both of plants and soil. It hurtfully influences the soil productivity, therefore undermining the sustainability of agricultural production (Rowel, 1994) and if it increases in the future with its present rate, a lot of nations will confront a big problem of producing enough food for their population (Gorji et al., 2017). It reduces the area of cultivated land from 1 to 2% per year and continues to increase (FAO, 2002). Therefore, the monitoring and predicting of soil salinity are essential to take protective measures against further degradation of the soil (Gorji et al., 2015).

In some countries such as Argentina, Egypt, India, Iraq, Pakistan, Syria and Iran, the land salinization is a serious issue due to its harmful effects on the national economy (Rhoads, 1990). The saline soils are common in regions under semi-arid and arid climate conditions, but it may occur in any region and under every climate condition in the world (Al-Khair, 2003).

The saline soils represent about 397 million hectares of land around the world, according to the Food and Agriculture Organization (Koohafkan, 2012). The Egyptian government has an increasing demand for self-sufficiency of agricultural products, so it is working hard to reclaim new lands (Varallyay, 1987) for providing sufficient food for its rapidly increasing population (Gorji et al., 2017). Soil salinization in such lands hinders the governments' plans for agriculture expansion (Varallyay, 1987).

According to Gehad (2003), nearly 55.44 % of the Egyptian soil is non- saline, 5.34 % moderately saline, 7.23 % high saline, 5.1 % very high saline, 0.32 % towns, 26.47 % water bodies and 0.1 % could be considered as swamps.

Traditionally, soil salinization is measured and monitored by wet chemistry laboratory method, this method needs more time and has a high cost and unsuited for large areas. Therefore, in recent times, remote sensing and GIS are among cheaper and faster methods, also covers large areas (Mashimbye, 2013). Those Modern technologies such remote sensing and

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GIS make the measuring and monitoring of soil salinity quite controllable and manageable (Gorji et al., 2015), but they require skilled people in field observation techniques (Soil Science), geographic information systems (GIS), remote sensing and geostatistical techniques (Mashimbye, 2013).

Soil salinity can be detected from remote sensing data through two approaches; directly by analyzing the spectral reflectance of soils on bare soil, with salt efflorescence and crust (salinity indices), or indirectly through analyzing the spectral reflectance of a growing vegetation on affected soils (vegetation indices) (Al-Khair, 2003; Aldakheel, 2011; Mashimbye, 2013; Matinfar, 2013).

Many researchers (Katawatin and Kotrapat, 2004; Mehrjardi et al., 2008; Yu et al., 2010; Mulder et al., 2011) have investigated the utility and effectiveness of ETM+ data for soil salinity mapping and monitoring. The aim of this research is to study how the different remote sensing indices (salinity and vegetation indices), which are derived from Landsat ETM+ satellite image, work on soil salinity prediction of both bare and cultivated lands in the study area compared to laboratory measurements of electrical conductivity.

MATERIALS AND METHODS

Study Area

In this research two study areas, Wadi-El-Natroun (Location 1) and El-Bostan farm (Location 2), were chosen; all of them are located in north Egypt (El-Beheira Governorate): Location 1 presents bare lands and lies between longitude 222083 to 223433 E and latitude 3362575 to 3363798 N. Whereas location 2 presents cultivated lands (wheat and clover**)** and lies between longitude 258991 to 259639 E and latitude 3404715 to 3405468 N (Fig. 1)

El-Beheira Governorate is located under arid conditions; the mean annual precipitation ranges from 9.6 to 24.8 mm month^{-1} falling in the months of November through February. The values of mean annual temperature and relative humidity are 21 °C, and 57% respectively (Ebaid et al., 2016).

Remote Sensing and GIS

Landsat 7 images have three visible bands (blue, green, and red), 1 near infrared band (NIR), and 2 shortwave infrared bands (MIR-1, MIR-2) at 30m resolution; a thermal infrared band (TIR) at 60m resolution; and a panchromatic (PAN) band with 15m resolution. The Landsat 7 image was acquired in March 2017 and was also resampled to 30 m resolution (Fig. 2). The coordinate system has UTM projection, WGS 1984 datum, and The UTM zone is 36 northern. The image indices have been derived and tested by using ERDAS (10.1) and ENVI (5.3) software. All the created image indices have been registered and loaded as input data to ArcGIS 10.2 software as an information layer.

Field Work and Laboratory Analysis

A hard and soft copy of ETM+ image, which was taken on March 2017, was used for choosing the location of sampling points. The exact position of sampling points in latitude and longitude was identified by GPS (Global Positioning System) (Table 1).

The positions of soil samples were chosen according to a systematic random method for location 1 (Wadi-El-Natroun) and according to the homogeneity of crop growth in location 2 (El-Bostan farm) (Fig. 1). Forty-six samples were collected from the upper layer (0-30 cm) by an auger. Of the 46 soil samples collected, 24 were collected from location 1 and 22 were collected from location 2. Each sample was air dried, ground, sieved with a 2-mm sieve and stored in a plastic bag until analysis. The EC of the saturated paste of each sample was determined using the methods outlined by Jackson (1973).

Remote Sensing Spectral Indices

Eleven spectral indices were generated from two different remote sensing indicators, salinity and vegetation (Table 2). Four vegetation and seven soil salinity indices that were derived from the ETM+ images were examined based on their potential for assessing soil salinity. Both soil samples and remote sensing data were acquired during March 2017. Forty-six soil samples were then overlaid on ETM+ images to extract the exact index values related to the soil samples

Statistical Analysis

Two different approaches; namely, linear regression analysis and polynomial regression analysis have been conducted to establish a relationship between EC laboratory measurements and satellite image-derived indices using the SPSS software (SPSS, 2007).

RERSULTS AND DISCUSSION

Laboratory Electrical Conductivity (EC)

The salinity was classified into five classes using EC values according to the Food and Agriculture Organization (FAO) soil salinity classification system (Abrol et al., 1988) as shown in Table 3. The EC values of the study area ranged from non-saline to strongly saline (1.11 - 9.50 dS m^{-1}) at location 1, and ranged from non-saline to moderately saline (1.00 - at 6.38 dS m^{-1}) at location 2 (Table 4).

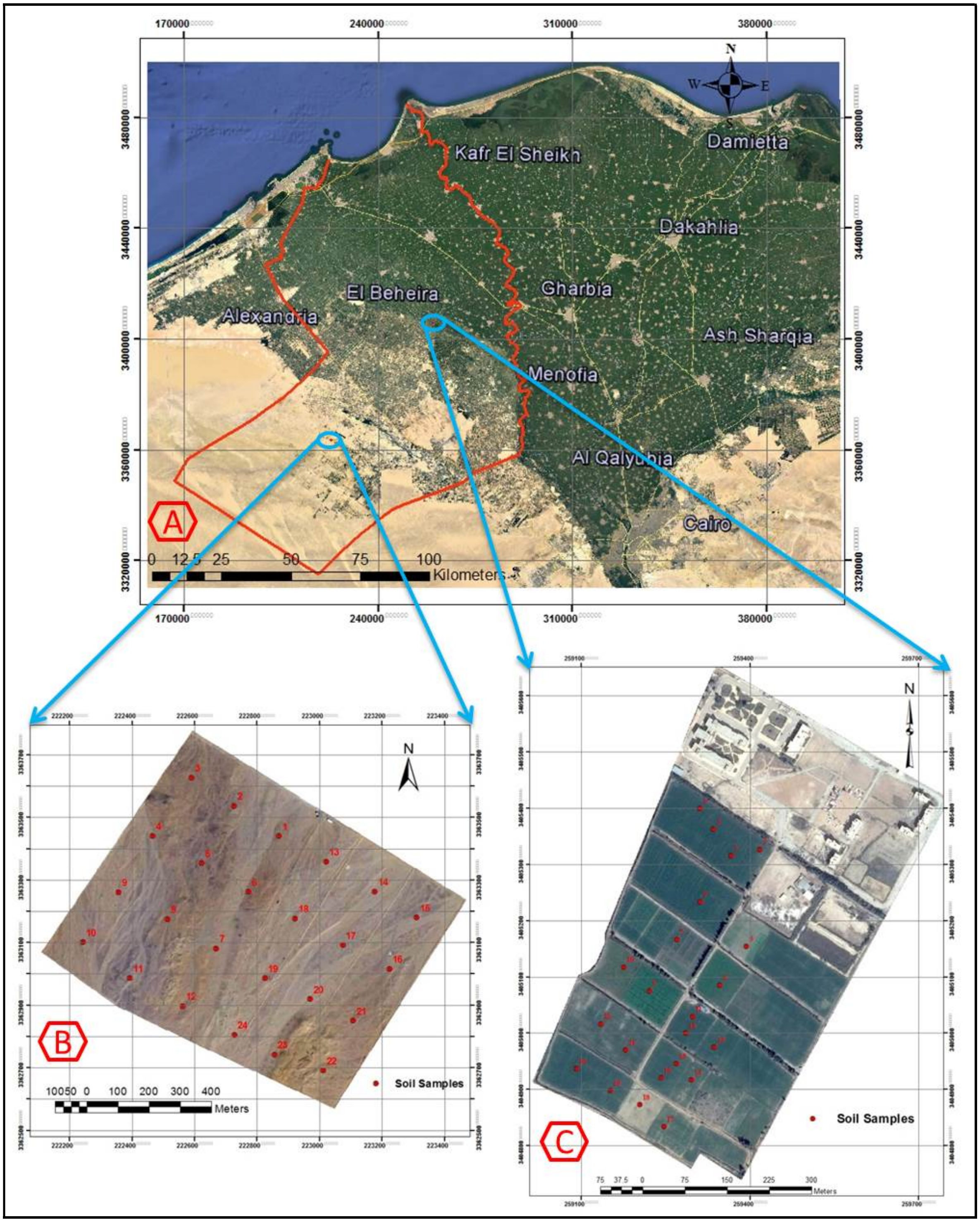

Fig. 1. The distribution of the sample points over the two locations in the study area: A) El-Beheira governorate; B) Wadi-El-Natroun (bare soil); C) El-Bostan (cultivated soil)

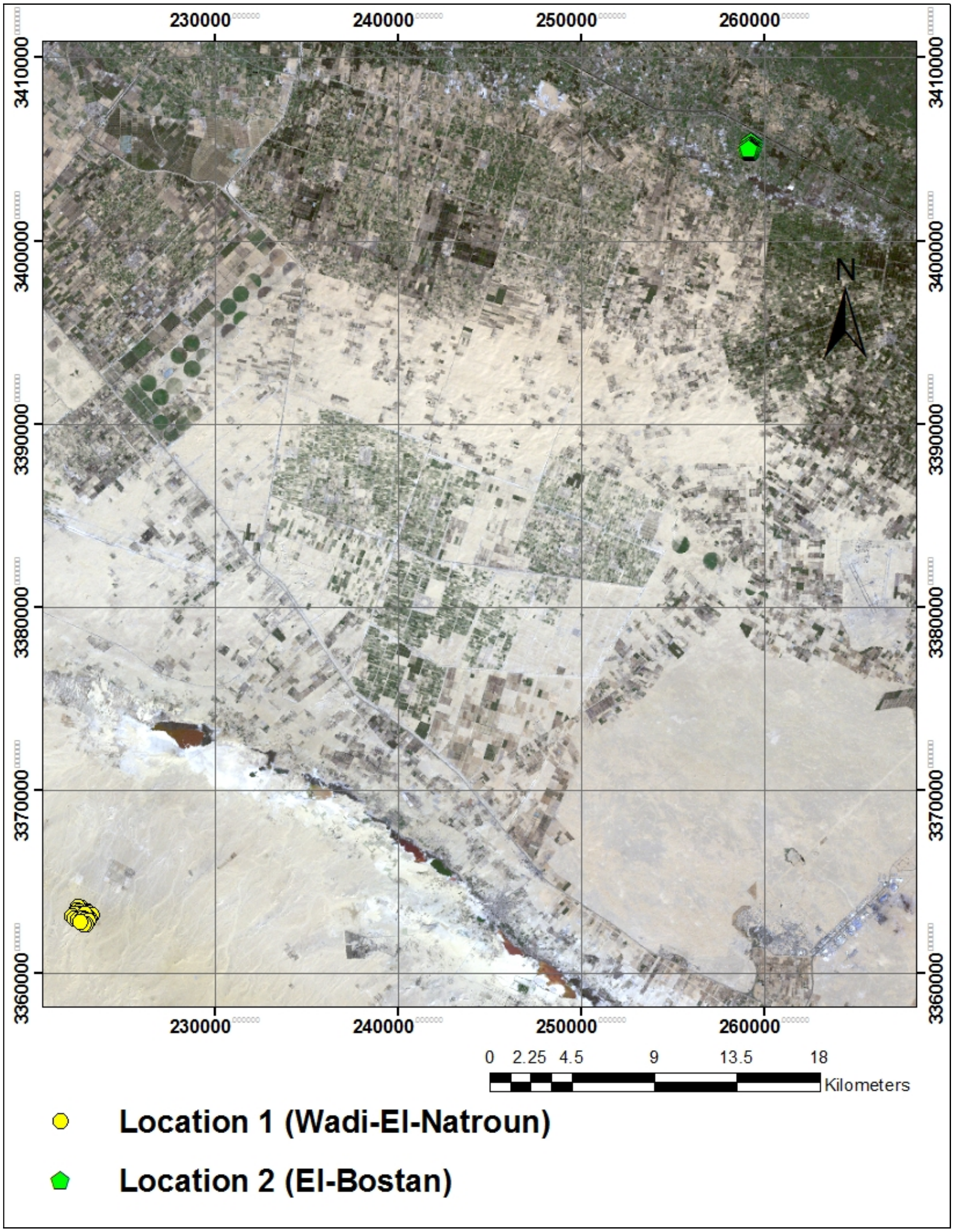

Fig. 2. RGB Landsat 7 (ETM+) image of the study area.

Table 1. The coordinates of soil samples

Sample No.	Location 1		Location 2	
	Coordinates		Coordinates	
	E	N	E	N
1	222879	3363440	259368	3405316
2	222738	3363529	259419	3405327
3	222583	3363628	259337	3405363
4	222479	3363445	259312	3405400
5	222623	3363348	259312	3405234
6	222780	3363258	259395	3405155
7	222675	3363081	259271	3405167
8	222521	3363172	259348	3405086
9	222356	3363266	259222	3405076
10	222245	3363094	259177	3405118
11	222405	3362989	259299	3405030
12	222573	3362897	259287	3405000
13	223077	3363384	259338	3404975
14	223127	3363275	259297	3404917
15	223324	3363175	259270	3404946
16	223228	3363016	259243	3404921
17	223055	3363067	259248	3404834
18	222930	3363240	259205	3404873
19	222834	3362991	259153	3404898
20	222971	3362955	259092	3404937
21	223113	3362847	259180	3404970
22	223011	3362662	259136	3405017
23	222871	3362697		
24	222728	3362810		

Table 2. Applied spectral indices on the investigated area

No.	Index	Equation	Reference
1	Normalized Differential Vegetation Index	NDVI=(NIR-R)/(NIR+R)	Deering and Rouse, 1975
2	Enhanced Vegetation Index	EVI=2.5(NIR-R)/(NIR+6R-7.5B+1)	Liu and Huete, 1995
3	Soil Adjusted Vegetation Index	SAVI=(NIR-R)/(NIR+R+L)*(1+L)	Huete, 1988
4	Ratio Vegetation Index	RVI=NIR/R	Major et al., 1990
5	Salinity Index	SI=√(B *R)	Khan et al., 2005
6	Salinity Index 1	SI1=√(G *R)	Khan et al., 2005
7	Salinity Index 3	SI3=√((G^2+R^2))	Douaoui et al., 2006
8	Salinity Index	S1=B/R	Bannari et al., 2008
9	Salinity Index	S2=(B-R)/(B+R)	Bannari et al., 2008
10	Salinity Index	S3=(G*R)/B	Bannari et al., 2008
11	Salinity Index	S6=(R*NIR)/G	Abbas and Khan, 2007

* B, G, R, NIR: reflectance in the blue, green, red and near-infrared bands; L is a constant equal to 0.5.

Table 3. Food and Agriculture Organization (FAO) soil salinity classification system.

EC value	0 - 2	2 - 4	4 - 8	8 - 16	> 16
Salinity class	non-saline	slightly saline	moderately saline	strongly saline	very strongly saline

Table 4. The laboratory values of EC in the study area.

Location 1				**Location 2**			
Sample No.	**EC dS m^{-1}**	**Sample No.**	**EC dS m^{-1}**	**Sample No.**	**EC dS m^{-1}**	**Sample No.**	**EC dS m^{-1}**
1	2.42	13	1.36	1	1.00	13	3.36
2	2.91	14	1.39	2	5.23	14	1.74
3	2.84	15	3.64	3	2.96	15	2.03
4	3.26	16	8.50	4	4.32	16	3.27
5	1.85	17	3.38	5	3.60	17	3.00
6	2.83	18	3.96	6	2.73	18	2.46
7	2.68	19	1.70	7	4.40	19	2.35
8	3.96	20	1.11	8	3.86	20	3.19
9	1.43	21	1.51	9	3.42	21	4.19
10	3.52	22	9.50	10	3.57	22	6.38
11	4.11	23	4.00	11	5.48		
12	4.94	24	3.58	12	3.80		

Soil spectral reflectance

In this part of the research we discuss the soil spectral behavior of different levels of soil salinity depending on the spectral regions provided by the ETM+ data (visible and near-infrared).

There is a high correlation between soil spectral reflectance and its properties such as soil salinity. The spectral reflectance of soil samples was investigated over the visible and NIR wavelength ranges. Spectral reflectance increased as soil salinity increased in bare soil (location 1), whereas, the strongly saline soil evidences higher reflectance than moderately saline soil and the last one reflects a higher amount of radiation than non-saline soil as shown in Fig. 3 and as the studies of Rao et al. (1995); Karavanova et al. (2001) and Metternicht and Zinck (2003) revealed. On the other hand, at the cultivated soils (location 2), Spectral reflectance decreased as soil salinity increased except over the blue band (Fig. 3).

However, the visible and NIR reflectance is a good indicator for soil salinity, whereas it is displaying more sensitivity to its levels. Those findings agree with those of Schmid et al. (2008) and Bouaziz et al. (2011). According to the results in this study area and as shown in Fig. 3, high EC value gives a relatively higher spectral response in the NIR than in the visible spectrum.

Remote sensing spectral indices

Essentially, we use two approaches to detect soil salinity by remote sensing; the first approach is direct by analyzing the spectral reflectance of soils (bare soils) and the second one is indirect through analyzing the spectral reflectance of growing vegetation on soils (Mashimbye, 2013).

There was a good relationship between EC and all of salinity indices in location 1, but the best relationship was found with SI3, S6 and S3 indices, respectively (Table 5). However, all vegetation indices were not significant and the SAVI was the poorest predictor of soil salinity at this location.

This finding concurs with the results acquired by Bouaziz et al. (2011) and Fan et al. (2012) who found that the vegetation indices were weakly correlated with EC values, while the soil salinity indices were more strongly correlated with bare soil.

We could use the vegetation performance in the cultivated soil as an indirect indicator to soil salinity (Wang et al., 2013), whereas we assume that a large vegetation amount means more successful crop growth and less harmful salts in the soil. There was a good relationship between EC and all of vegetation indices at location 2 except EVI index. The best relationship was with NDVI and SAVI indices (the same values), followed by RVI (Table 5). However, all salinity indices were not significant. Among all of the assessed indices, EVI yielded poor findings for assessing soil salinity at this location.

Polynomial and linear regression results for different spectral indices are presented in Fig. 4 and Fig. 5. Salinity index (SI3) indicated the best result with R^2 value 0.77 for the linear regression analysis, and (S6) for the polynomial regression with R^2 value 0.83 for location 1.

On the other hand, the NDVI and SAVI were the best indices with R^2 value 0.83 and 0.76 for the polynomial and linear regression analysis, respectively, for location 2. Our results are similar to those of Alhammadi and Glenn (2008) and Allbed et al. (2014) who reported that the SAVI index gave very good results with assessing soil salinity of cultivated soils. The equations shown in Fig. 4 and Fig. 5 could be used to predict soil salinity by using spectral indices without direct EC measurements.

Table 5. The relationships between the selected spectral indices and the EC

No.	Spectral Indices	Location 1		Location 2	
		R^2 (Linear Regression)	R^2 (Polynomial Regression)	R^2 (Linear Regression)	R^2 (Polynomial Regression)
1	NDVI	0.24	0.32	0.76	0.83
2	EVI	0.28	0.41	0.00	0.01
3	RVI	0.24	0.33	0.68	0.82
4	SAVI	0.24	0.32	0.76	0.83
5	SI	0.61	0.67	0.05	0.50
6	SI1	0.64	0.71	0.14	0.52
7	SI3	0.77	0.82	0.01	0.44
8	S1	0.52	0.64	0.47	0.58
9	S2	0.53	0.64	0.48	0.58
10	S3	0.74	0.82	0.00	0.25
11	S6	0.76	0.83	0.23	0.57

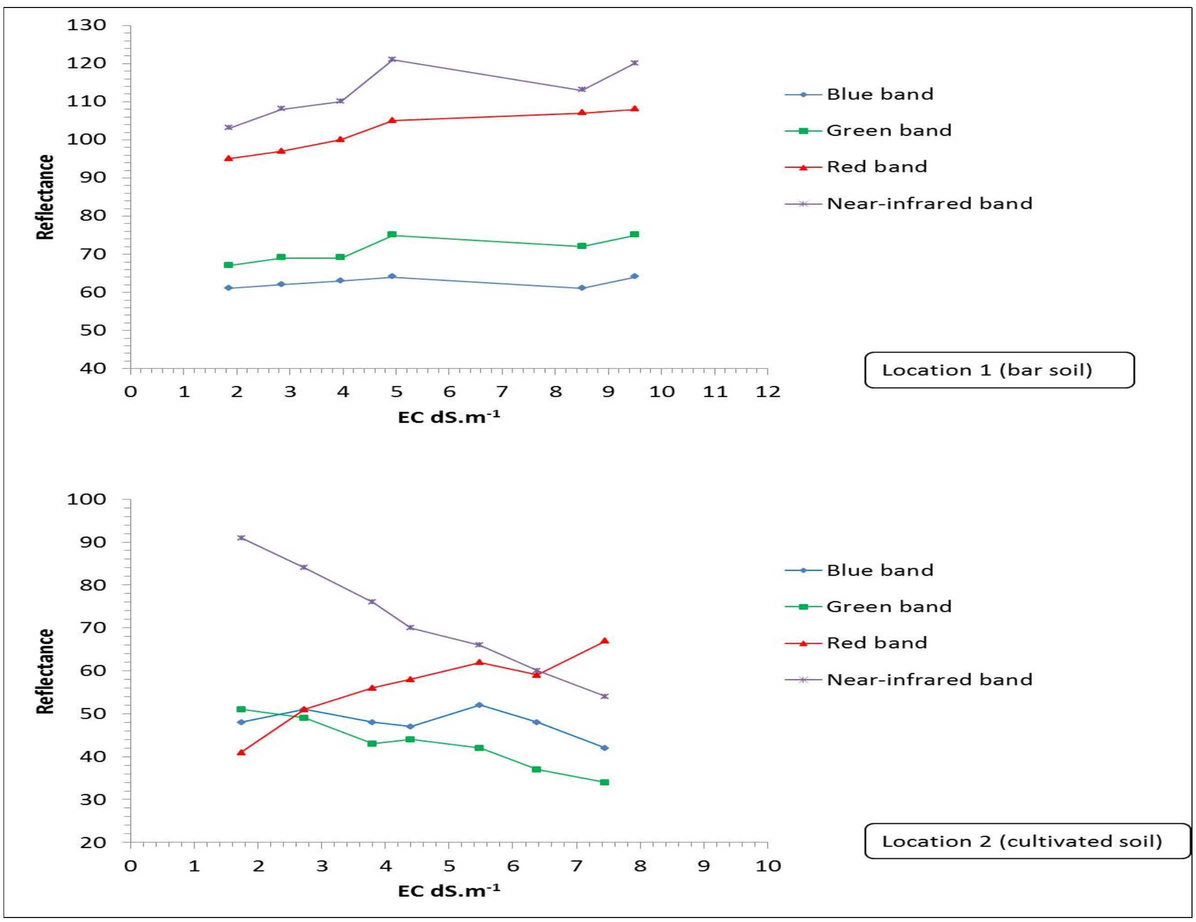

Fig. 3. Spectral signature variation of different soil surface features due to differences in electrical conductivity

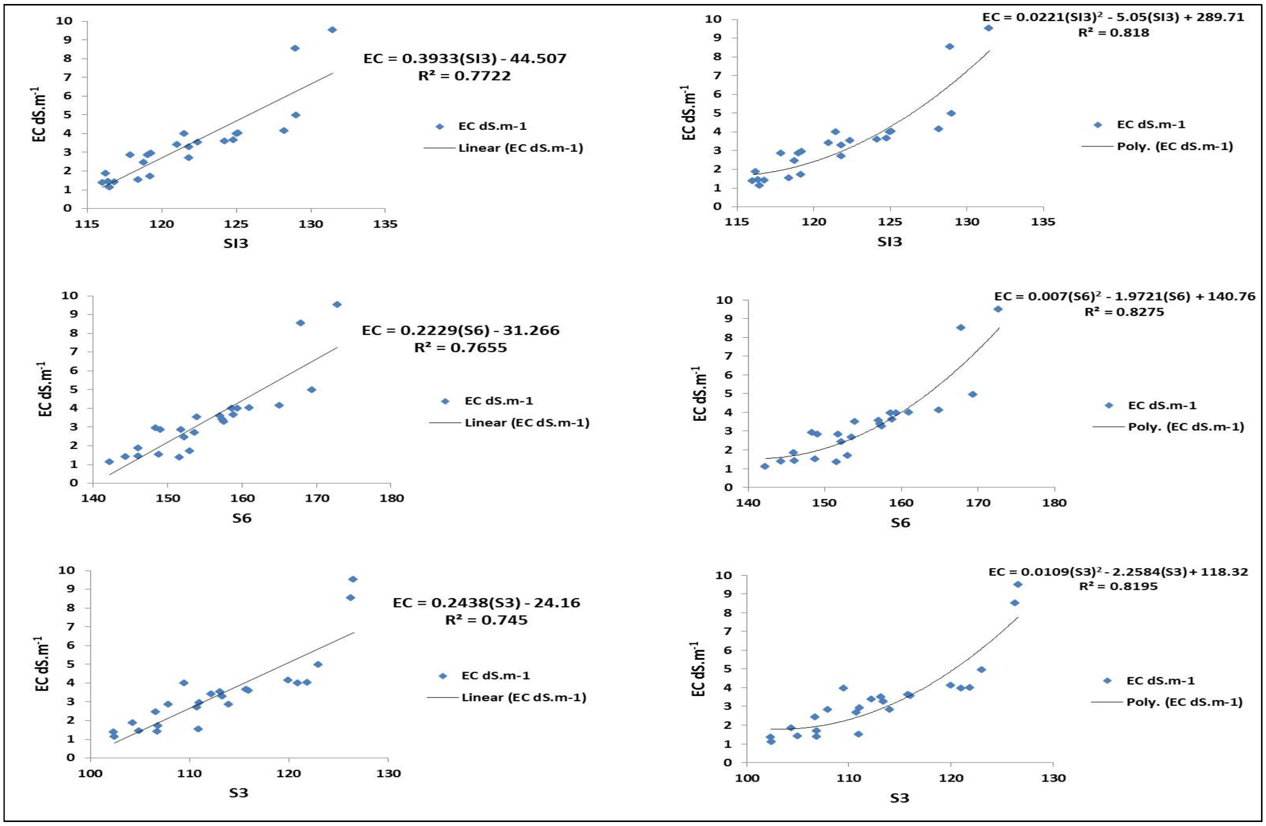

Fig. 4. Regression equation relating EC and some salinity indices at location 1.

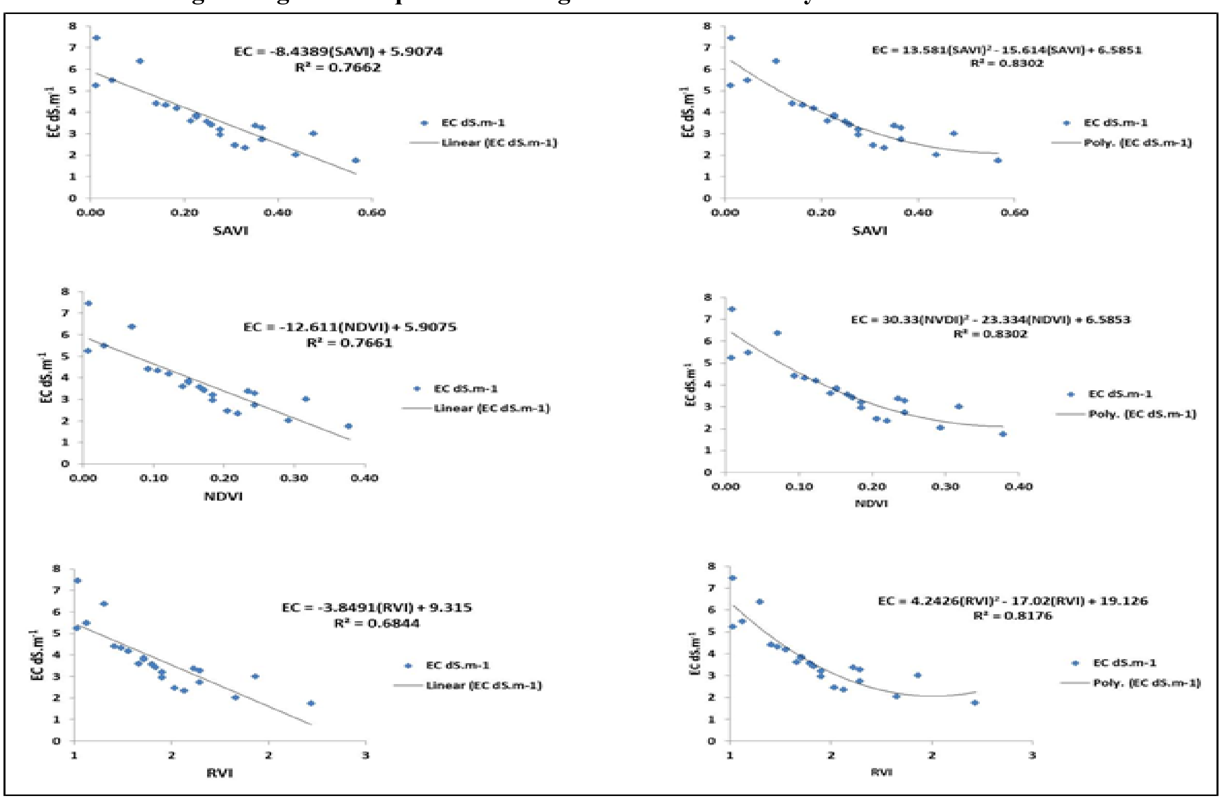

Fig. 5. Regression equation relating EC and some vegetation indices at location 2

CONCLUSION

In arid and semi-arid regions of the world, soil salinization is a major factor that affects agricultural productivity and sustainable development. The monitoring and predicting of soil salinity are very important to take protective measures against further soil degradation. Remote sensing considered as a particularly valuable tool for achieving this task. This research focused on the spectral indices (salinity and vegetation indices) for the prediction of soil salinity in bare and cultivated lands in El-Beheira governorate, Egypt. The results show that: Overall, the salinity indices that were extracted from the ETM+ satellite images were the most useful for assessing the soil salinity in bare areas and the vegetation indices for cultivated areas.

The results of this study showed that the SI3, S6 and S3indices were the most useful for assessing soil salinity in the bare areas. Whereas NDVI, SAVI and RVI yield better outcomes for the cultivated areas, respectively. Those indices are useful indicators for soil salinity prediction in the study area. However, it may be unsuited for other regions as their performance varies with different environmental conditions, soil, and vegetation cover, etc. Those indices may help decision-makers and land planners to face the salinity issue at a regional level and avoid further adverse environmental effects.

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الملخص العربي

الكشف عن ملوحة التربة للأراضي الغير مزروعة والمزروعة باستخدام بيانات صور القمر الصناعي الامريكي لاندسات (+ETM): دراسة حالة من محافظة البحيرة، مصر

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تعتبر ملوحة التربة من أبرز القضايا البيئية العالمية وذلك بسبب آثارها السلبية على الإنتاجية الزراعية والتنمية المستدامة، وكذلك يعتبر الاستشعار عن بعد أداة هامة لاستكشاف خصائص التربة مثل الملوحة. يتفاوت الانعكاس الطيفي للأملاح على سطح التربة وكذلك بالنسبة لانعكاسات الغطاء النباتي والذي يتأثر سلبا بالمستويات المختلفة من الملوحه. لذلك، تم تطوير واستخدام العديد من دلائل الملوحة والغطاء النباتي حيث استخدمت في هذه الدراسة بيانات أرضية والانعكاسات الطيفية في مدى الضوء المرئي والضوء القريب من الأشعة تحت الحمراء للقمر الصناعي الأمريكي لاندسات (+ETM) بغرض المقارنة بين ١١ مؤشرا طيفيا، والتي اشتملت على دلائل الملوحة ودلائل الغطاء النباتي لتحديد أفضل مؤشر للتنبؤ بملوحة التربة الغير مزروعة والتربة المزروعة. تم جمع عينات التربة (٤٦ عينة) من موقعين في محافظة البحيرة في مصر، ٢٤ عينة من وادي النطرون (التربة الغير مزروعة) و٢٢ عينة من البستان (التربة المزروعة) وتم توقيع أماكن عينات التربة على صورة القمر الصناعي لاستخراج قيم الأدلة بدقة. تم قياس التوصيل الكهربي للتربة في مستخلص عجينة التربة المشبعة للطبقة السطحية بعمق ٣٠ سم، وأظهرت النتائج أن مؤشر الملوحة (SI3) أعطى أعلي قيمة انحدار مع التوصيل الكهربائي مع تحليل الانحدار المتعدد (Polynomial) يليه تحليل الانحدار الخطي(linear)، حيث كان معامل الانحدار لهذا الدليل (R^2) هو ٠,٨٥ و٠,٧٧ على التوالي بالنسبة للتربة الغير مزروعة. اما بالنسبة للتربة المزروعة فقد أعطي دليل الغطاء النباتي (SAVI) أعلى قيمه لمعامل الانحدار مع التوصيل الكهربي ٠,٨٣ و٠,٧٦ وفقا لتحليل الانحدار المتعدد والخطي على التوالي.