SOIL SALINITY FORCASTING USIG SPECTRUM REFLECTIVITY DATA*

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ABSTRACT

This study was conducted to assess soil salinity forecasting using spectral soil reflectivity. Artificial salinization was carried out on silty clay loam soil. Collected soil sample was handy crushed, sieved through a 4 mm sieve and backed in plastic columns. The columns were closed from the bottom with a perforated plastic lids with the presence of sand-gravel filter. Columns placed vertically at plastic basins contain saline ground water and left for salinization by capillary rise. At the desired salinity level, soil reflectivity was measured using spectroradiometer and wave length between 350-2500 nm, and band width 1 nm. Soil salinity and moisture were determined soon after spectral measurements. Data processed and converted to digital data using ViewSpecPro software. MS Excel 2010 was used to calculate reflectivity data for bands equivalent to those used with the sensor OLI used at LandSat-8. SPSS V.23 statistic program was used to formulate mathematics models (Multiple linear, Quadratic and Cubic) that describe the relationship between soil salinity and spectral reflectivity at three soil moisture levels i.e. 8, 18 and 24%. Results confirmed the efficiency of the three models to forecast soil salinity at 19 dS m^{-1} or higher and at soil moisture of 24%. The quadratic and cubic models also gave good results at soil salinity of 9 dS m^{-1} or more and at 8% soil moisture level. At soil moisture of 18%, the Quadratic and Cubic models showed behavior similar to their behavior at the lower moisture level, while the linear model was efficient at salinity level of 40 dS m^{-1} and higher.

Key words: soil salinity, soil spectral reflectivity.

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استشراف ملوحة التربة باستخدام بيانات الانعكاسية الطيفية*

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المستخلص:

نفذت هذه الدراسة لتحري إمكانية استشراف ملوحة التربة باستخدام بيانات الانعكاسية الطيفية. اجريت عملية تمليح لتربة رسوبية ذات نسجة مزيجة طينية غرينية بعد ان كسرت كتلها يدويا ومررت من منخل قطر فتحاته 4 ملم، وعبئت في اعمدة بلاستيكية، وأغلقت الاعمدة من نهايتها السفلى بغطاء مثقب مع وجود مرشح من الحصى والرمل، ثم وضعت عمودياً في احواض تحوي مياه مالحة، وتركت لتتملح بفعل الخاصية الشعرية، وبعد وصول الملوحة الى المستوى المطلوب قيست الانعكاسية الطيفية للعينات باستخدام مقياس الانعكاس الطيفي في الاطوال الموجية الممتدة بين 350–2500 نانومتراً وبحزمة عرضها 1 نانومتراً، وجمعت عينات تربة مباشرة بعد قياس انعكاسيتها لتقدير رطوبتها وايصاليتها الكهربائية. عولجت البيانات وحولت الى بيانات رقمية باستخدام برنامج ViewSpectroPro، واستخدم البرنامج ME 2010 لحساب قيم الانعكاسية الطيفية للحزم المكافئة لتلك المستخدمة في المتحسس OLI على متن القمر LandSat-8، واستخدم البرنامج SPSS V.23 لصياغة الإنموذجات الرياضية (الخطي المتعدد والتربيعي والتكعيبي) التي تصف العلاقة بين ملوحة التربة وانعكاسيتها الطيفية عند ثلاثة مستويات رطوبية هي 8 و 18 و 24 %. أكدت النتائج كفاءة الإنموذجات الثلاثة لاستشراف ملوحة التربة عند مستوى 19 ديسيسمنز م$^{-1}$ أو أعلى من ذلك وعند مستوى رطوبة تربة 24 %، وأعطى الإنموذجان التربيعي والتكعيبي نتائج جيدة أيضا لاستشراف ملوحة التربة في المستويات التي تساوي أو تزيد عن 9 ديسيسمنز م$^{-1}$ ومستوى رطوبة تربة 8 %، أما عند مستوى رطوبة 18% فقد أظهر الإنموذجان التربيعي والتكعيبي سلوكا مشابهاً لسلوكهما في مستوى الرطوبة 8 %، بينما كان الإنموذج الخطي كفوءاً في مستوى الملوحة 40 ديسيسمنز م$^{-1}$ فأكثر.

كلمات مفتاحية: ملوحة التربة، الانعكاسية الطيفية للتربة.

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INTRODUCTION

Salt-affected soils are widely separated in the world. It is area estimated at 1 billion hectares. This equal to 7 % of the area of Earth land (9). In the Near East, salt affected soils is estimated at 105.6 million hectares, or 5.9% of the area of that region (5). In Iraq, salinization process is concentrated mainly in Mesopotamian plain (8). Land degradation as a result of soil salinization reduce the area of productive land by about 30% (10). Although salinization process are well known in Iraqi soils since many centuries, but it increased significantly in the years 2002-2013 (10). This was due to the repeated dry seasons and poor management of soil and irrigation. Monitoring and follow-up natural resources and processes, including land salinization using suitable developed means commensurate with the size of the problem and its rapid separation, has become an urgent necessity to achieve sustainable development. Many countries found their aims in the technology of remote sensing. This technology is fast in performance and reduces efforts and costs, as well as being a historical record that can be consulted whenever needed (11). Lillesand and Kiefer (14) mentioned that remote sensing is one of the modern technologies which can be used to diagnose and predict many soil characteristics. This was because of the availability of data for large areas in many spectrum at a short time. Also, Al-Heity and Al-Wehishi (1) reported that the data provided by remote sensing technology has an important role in different studies. All parts of electromagnetic spectrum can be used to increase the understanding and interpretation of most phenomena studied by these technology. The development of spectroscopy equipment analysis and accessories, and the means of aviation and computers has opened up a huge sources of data about atmosphere and natural resources. In the past, access to such as these data was carried out by primitive ways accompanied with many palaces, as well as waste of time, effort and money (3). Salts in arid and semiarid regions are more precipitated and crystallized in the surface of the soils (12). Increasing salt concentration increases the spectral reflectivity of the soil surface (12). These findings were also noticed by other workers (13 and 16). They explained that the reflectivity of the soil in the visible and reflected infra-red (IR) electromagnetic spectrum increases with increasing soil salinity. Sadiq and Howari (15) explained that the best part of electromagnetic spectrum to identify saline soils is the band between 660 to 2200 nm. Other workers (8) recorded that salts increase soil reflectivity at middle IR (WL=1300-3000), except water absorption band. Due to the high benefit of using remote sensing in soil studies, and to the high correlation between soil salinity and its spectral reflectivity, so this work was conducted to assess predicting of soil salinity from soil reflectivity data at different soil moisture levels.

MATERIALS AND METHODS

Non-Saline silt clay loam soil classified as Typic Torrifluvent was used in this study. Soil material was sampled from the surface layer (0-30 cm) of a field at the college of Agriculture, in Abu-Ghraib. Collected soil material was handy broken up, air dried, sieved through a 4 mm sieve and then packed in polyvinyl chloride columns 40 cm in height and 7.5 in diameter. The columns were closed from the bottom with a perforated plastic lids. Table 1 explained some physical and chemical properties of the soil sample under field condition.

Table 1. Some properties of the soil used in the study

Soil Properties	Unit	Value
EC_e	$dS\ m^{-1}$	3
pH	-	7.38
Organic matter	$g\ kg^{-1}$	8
Bulk Density	$Mg\ m^{-3}$	1.4
Sand	$g\ kg^{-1}$	144
Silt	$g\ kg^{-1}$	460
Clay	$g\ kg^{-1}$	396
Soil Texture	Silty Clay Loam	

Filter of 5 cm in height, consisted from two layers of gravels (2 cm thickness for each), and one layer of sand and filter paper was placed at the end of each column. Gravels diameters of the lower layer and the layer above it were 9-4 and 4-2 mm, respectively. The diameters of sand were 2-1 mm. Soil packed in each columns for 33 cm in height, to achieve bulk density as it is in the field. Columns placed in plastic containers which connected to each other by plastic pipes to achieve water at one level. Containers joined to large tank filled with saline ground water. Table 2 explained some properties of used water.

Table 2. Some chemical properties of ground water used in soil salinization

Property	Unit	Value
EC	dS m^{-1}	10
pH	-	7.91
Na^{+}	mg l^{-1}	1056
Ca^{2+}		803
Mg^{2+}		360
K^{+}		92
Cl^{-}		2181
SO_4^{2-}		2199
HCO_3^{-}		680

Water level in containers maintained constant by using a raft placed in the first container. Total number of columns were 200, each 10 columns were placed in one container. When soil salinity reached the desired level, as set of columns taken, while the rest stay at the container to achieve progress salinization. Desired salinity levels have been checked using additional soil columns.

Soil Spectral Reflectivity

Soil spectral reflectivity were measured at 8 salinity levels and 4 moisture levels, measuring was done at 5 replicatios for each treatment. Table 3 summarize these treatments. Each set of columns, representing 1 soil salinity level × 4 soil moisture × 5 replications) was divided into 4 groups randomly, each group represent one moisture level. Soil reflectivity was measured by spectroradiationmeter using narrow bands (1 nm), have a length between 350 to 2500 nm. After that, soil samples were collected from the upper 5 cm of soil in each column to determine EC and soluble ions. Each group of columns were left to the next day or the next to reach the required less moisture level. Then, its reflectivity was measured at the required moisture. Reflectivity measuring and soil sampling was repeated with each group of columns.

Laboratory Work

Mechanical analysis, bulk density and soil moisture were determined using pipette method, cylinder method and gravimetrically respectively, as was described by Black et al. (6). Electrical conductivity for soil sample collected from the field and those collected from columns was carried out at 1:1 soil: water extracts. Results then converted to soil paste extract using conversion factor between EC_e and $EC_{1:1}$ for the studied soil which was 2.1. Organic matter was determined using modified method proposed by Walkley-Black. All chemical analysis was carried out as was described by Al-Tamimi (4).

Table 3. Salinity and moisture levels of the soil during reflectivity measuring

EC_e	Gravimetric Soil Moisture, %			
3	n.d	8	18	24
7	8	11	15	25
14	9	14	19	24
21	7	11	17	26
30	8	11	18	24
39	7	11	17	23
60	8	11	17	23
78	9	11	19	23

n.d= reflectivity not determined

Reflectivity Data Processing

Viewspecpro software program was used to convert spectral reflectivity data to digital files that can be manipulated by using Microsoft Excel 2010 program. Also, the last program was used to calculate spectral reflectivity values of the equivalent band used on OLI sensor, which used by LandSat-8 satellite. To predict soil salinity quantitatively, SPSS V.23 software program was used to formulate mathematical models, at three moisture levels (i.e. 8, 18 and 24 %). These models were: multiple linear, quadratic cubic quartic and exponential models. Soil salinity was assumed as dependent variables, while soil reflectivity assumed as independent variable. Standard error (S.E) and determination factor were used to accept or reject mathematical model. Absolute Relative Error (A.R.E) was used to demonstrate the efficiency of these used models to predict soil salinity. A.R.E. can be calculated by using this equation (2):

$$A.R.E. = \frac{measured\ value - \ forcasted\ value}{measured\ value} \times 100$$

Digital Data for spectral Bands

Spectral reflectivity data, for bands equivalent to those used with the sensor OLI on the satellite LandSat-8, at different levels of soil salinity and three soil moisture levels illustrated in tables 4. Generally low reflectivity values were recorded at higher moisture. Data in table 3 shows that spectral reflectivity values of the used bands at moisture level 24 %, did not have a given curve with salinity levels. It decreased and increased randomly.

RESULT AND DISCUSSION

Table 4. Spectral reflectivity data at different moisture and salinity levels for bands equivalent to those used in OLI sensor

Soil moisture	EC	B1	B2	B3	B4	B5	B6	B7	B9
8 %	3	0.136	0.152	0.211	0.262	0.321	0.379	0.356	0.370
	7	0.135	0.156	0.216	0.269	0.331	0.393	0.364.	0.383
	14	0.136	0.159	0.222	0.277	0.342	0.407	0.373	396
	21	0.144	0.167	0.233	0.292	0.363	0.435	0.390	0.422
	30	0.168	0.191	0.2.58	0.315	0.384	0.456	0.419	0.443
	39	0.181	0.205	0.273	0.329	0.395	0.466	0.439	0.454
	60	0.204	0.220	0.297	0.355	0.423	0.492	0.457	0.480
	78	0.206	0.229	0.295	0.352	0.426	0.508	0.463	0.494

Soil moisture	EC	B1	B2	B3	B4	B5	B6	B7	B9
18 %	3	0.100	0.115	0.162	0.203	0.252	0.289	0.255	0.285
	7	0.102	0.117	0.165	0.208	0.258	0.298	0.262	0.293
	14	0.103	0.119	0.168	0.212	0.265	0.308	0.270	0.302
	21	0.108	0.124	0175	0.221	0.277	0.321	0.275	0.315
	30	0.119	0.136	0.187	0.233	0.288	0.334	0.295	0.328
	39	0.125	0.143	0.195	0.240	0.293	0.341	0.309	0.335
	60	0.136	0.153	0.203	0.247	0.306	0.360	0.322	0.352
	78	0.135	0.153	0.205	0.252	0.313	0.372	0.320	0.362

Soil moisture	EC	B1	B2	B3	B4	B5	B6	B7	B9
24 %	3	0.068	0.078	0.113	0.145	083.1	0.199	0.154	0.200
	7	0.068	0.078	0.114	0.146	0.185	0.204	0.161	0.204
	14	0.069	0.079	0.115	0.148	0.187	0.208	0.167	0.208
	21	0.071	0.081	0.118	0.151	0.191	0.208	0.161	0.208
	30	0.070	0.080	0.117	0.151	0.191	0.212	0.170	0.212
	39	0.069	0.080	0.117	0.151	0.192	0.217	0.180	0.216
	60	0.068	0.077	0.109	0.140	0.190	0.228	0.187	0.223
	78	0.065	0.076	0.115	0.151	0.200	0.236	0.177	0.231

Table 4 shows spectral reflectivity values at different salinity levels and at three soil moisture levels, i.e. 8, 18 and 24 %. Results indicate that at 8 and 8% soil moisture levels and high salinity levels (60 and 78 dS m^{-1}), the spectral reflectivity values in the first four bands (i.e. B1, B2, B3, and B4) were nearly equal to each other. Also, highest differences in reflectivity values were recorded with B6 band, followed by the band B9 and then B7 at all moisture levels. Whereas the differences decreased with increasing soil moisture level.

In the first five bands (B1 to B5), and at all soil salinity levels, the differences between soil reflectivity increased with increasing band wave length at soil moisture levels 8 and 18%. While at 24% soil moisture level, the differences between the reflectivity of these five bands differed randomly and did not correlate with their length (Table 3). This may be due to the effect of high moisture level in this soil.

Forecasting Soil Salinity

Results indicated that all used mathematical models were suitable and can be used to predict soil salinity from reflectivity data, for equivalent spectrum bands which used in OLI sensor. Three of these models are shown in table 5. These models were multiple linear, Quadratic and Cubic. The rest two models (quartic and exponential) were neglected because their results were similar to those obtained by the linear, quadratic and cubic models which are simpler for application. The multiple linear model explained that soil salinity positively correlated with the band B9 at soil moisture level of 8%. The determination factor (R^2) and S.E values were 0.94 and 7.1, respectively. At 18% soil moisture level, soil salinity positively correlated with the recorded reflectivity in the band B6 and negatively with the recorded reflectivity in the band B9. The values of R^2 and S.E were 0.99 and 3.1, respectively. Using Quadratic model at 8 and 24% soil moisture level, a negative correlation was noticed between recorded reflectivity and soil salinity in the band B9, while positive correlation was noticed between squares of reflectivity value and soil salinity in this band. The values of R^2 and S.E were 0.99 and 2.6, respectively at 8% soil moisture level, and 0.98 and 3.3, respectively at 24% soil moisture level (Table 5). At moisture levels of 18%, Quadratic model showed that soil salinity negatively correlated with reflectivity and positively correlated with the squares of reflectivity value in B6 band. The values of R^2 and S.E were 0.99 and 1.3, respectively. Cubic model confirmed that soil salinity negatively correlated with square value of reflectivity at B6 band and positively correlated with reflectivity cubic value at the same band, and at both soil moisture level, 8 and 18%. The values of R^2 and S.E were 0.99 and 2.1, respectively at soil moisture of 8%. Whereas, these values were 0.99 and 1.2 at soil moisture of 18%. At soil moisture of 24%, Cubic model explained that soil salinity had a negative correlation with reflectivity data and a significant positive correlation with cubic value of reflectivity recorded at B9 band. The values of R^2 and S.E were 0.98 and 3.3 respectively (Table 5).

Table 5. Mathematical models to forecast soil salinity quantitatively

Soil moisture, %	Mathematical Models	R^2	S.E
	Linear		
8	EC = - 209.810 + 560.056 (B9)	0.94	7.1
18	EC = - 173.982 + 8048.276 (B6) - 7569.163 (B9)	0.99	3.1
24	EC = - 420.618 + 2108.589 (B6)	0.99	3.1
	Quadratic		
8	EC = 521.259 - 2859.563 (B9) + 3959.884 ($B9^2$)	0.99	2.6
18	EC = 516.373 - 3835.481 (B6) + 7133.215 ($B6^2$)	0.99	1.3
24	EC = 159.864 - 3722.198 (B9) + 14596.840 ($B9^2$)	0.98	3.3
	Qubic		
8	EC = 115.495 - 2587.290 ($B6^2$) + 4794.506 ($B6^3$)	0.99	2.1
18	EC = 97.803 - 4534.871 ($B6^2$) + 11784.329 ($B6^3$)	0.99	1.2
24	EC = -73.429 - 523.475 (B9) + 22169.376 ($B9^3$)	0.98	3.3

To examine suitability and successfulness of the mathematics models in forecasting soil salinity levels, the three used models were tested using new soil samples have different salinity levels and did not participate in creation these models. Absolute relative error percentage was used as a criteria to assess viability and goodness of fit of each model (Table 6). Model was accepted when A.R.E percentage equal or less than 10% (2). Results in table 4 pointed out that the three used models were effective in forecasting soil salinity at the levels equal to 19 dSm^{-1} or more at moisture level of 24%. At soil moisture of 8%, linear model did not gave a clear results to forecast soil salinity. The quadratic and cubic models both show similar acceptable results. Apart from soil salinity of 13 and 27, the two models can be used to forecast soil salinity of 9 dSm^{-1} and more (A.R.E <10). At soil moisture of 18%, the linear model was effective in forecasting the last three studied salinity levels i.e. 40, 60 and 80 dS m^{-1}, while the results with the quadratic and cubic models were similar to those recorded with these two models at 8% soil moisture (Table 6).]

Table 6. Measured and forecasted soil salinity using bands equivalent to those used in OLI sensor

Measured vale	Linear model		Quadratic model		Qubic model	
	Forecasted vlue	S.E	Forecasted vlue	S.E	Forecasted vlue	S.E
Soil Moisture, 8%						
3	2.58	14	5.32	77	4.96	45
4	1.12	72	5.97	49	5.86	46
6	4.83	19	6.96	16	7.05	17
9	8.54	5*	8.30	7*	8.54	5*
13	12.25	5*	9.98	23	10.33	20
19	27.08	42	20.19	6*	20.75	9*
27	38.78	43	32.16	19	32.12	18
40	44.87	12	39.76	0.6*	39.27	2*
60	59.52	0.8*	61.88	3*	60.48	0.8*
80	67.25	15	75.73	5*	77.02	3*
Soil Moisture, 18%						
3	0.26	91	3.93	31	3.77	25
4	3.57	10*	5.45.	36	5.44	36
6	7.41	23	7.26	21	7.36	22
9	11.25	25	9.36	4*	9.53	6*
13	15.08	16	11.77	9*	11.96	8*
19	24.54	29	20.76	9*	20.86	9*
27	31.42	16	31.39	16	31.30	16
40	35.91	10*	38.89	2*	38.70	3*
60	62.47	4*	60.75	1*	60.58	0.9
80	75.40	5*	77.22	3*	77.44	3*
Soil Moisture, 24%						
3	0.66	78	0.26	91	0.20	93
4	5.26	31	4.71	17	4.69	17
6	9.85	64	9.28	54	9.28	54
9	14.45	60	13.98	55	14.00	55
13	19.04	46	18.80	44	18.83	44
19	18.22	4*	19.07	0.3*	19.09	0.4*
27	27.82	3*	28.97	7*	28.98	7*
40	37.42	6*	39.33	1*	39.34	1*
60	61.74.	3*	56.57	5*	56.56	5*
80	77.21	3*	77.44	3*	79.70	0.4*

REFRENCES

1. Al-Heity, E. A. and A. A. Al-Wehishi. 2005. Remote Sensing – Fundamentals and Applications. Dar Al-Rewad, Benghazi, Libya.1st ed. (*in Arbic*). pp: 286

2. Al-Kubiasi, A. M. 1997. Spatial Modeling of Some Soil Properties Using Digital Data of Landsat-5 Satellite. Ph.D. Dissertation, College of Agric., Baghdad Univ. (*In Arabic with English summary*). pp: 140

3. Al-Meshhedani, A. S. and A. M. Al-Kubiasi 2014. Remote Sensing Science. Al-Dar Al-Jameyeia for Printing, Publishing and Translation. Baghdad, Iraq. 1st ed. (*in Arbic*). pp. 339.

4. Al-Tamimi, R. A. 2016. Chemical Analysis of Soil, Water and Plant. Fundamentals and Applications. Al-Anbar Univ., Iraq. 1st ed. (*in Arabic*). pp. 542.

5. Aringhieri, R. 2010. The Salt Problem in Soil: An Overview. Environmental Quality, 5:15-22

6. Black, C. A. 1965. Methods of Soil Analysis. Am. Soc. Agron., Inc., Soil Sci. Soc. Am. Inc., Madison, Wisconsin, USA. pp: 1956

7. FAO (Food and Agriculture Organization of the United Nations). 2012. Water Resources, Development and Management Service. pp: 182

8. Farifteh, J., F. van der Meer, M. van der Meijde and C. Atzberger. 2008. Spectral characteristics of salt-affected soils: A laboratory experiment. Geoderma, 145:196-206

9. Ghassemi, F., A. J. Jakeman and H. A. Nix. 1995. Salinization of Land and Water Resources: Human Causes, Extent, Management and Case Studies. The Australian Univ., Canberra, Australia and CAB International, Wallingford, Oxon, UK. pp: 526

10. Hassan, Z. D. 2016. Geomorphology of Alluvial Sahil Sabakh Using Remote Sensing and GSI. Ph.D. Dissertation, Women Education College, Univ. of Baghdad. (*in Arabic*). pp: 294

11. Ibrahim, M. 2016. Modelling soil salinity and mapping using spectral remote sensing data in arid and semi-arid region. Intern. J. Remote Sensing Applica. 6:76-83

12. Karavanova, E. I., D.P. Shrestha and D. S. Orlove. 2000. Application of remote sensing techniques for the study of soil salinity in semi-arid Uzbekistan. *In*: Bridges, I. H., L. R. Oldeman, F. Penning de Vries, S. Scherr and S. Sombatpaint (eds.). Responses to Land Degradation. Oxford and IBH Publishing Co. Pvt. Ltd, p: 261-273

13. Levy, J., A. Nolin, A. Fountain and J. Head. 2014. Hyperspectral measurement of wet, dry and saline soils from the McMurdo dry valleys: Soil moisture properties from remote sensing. Antarctic Sci. 26 (5):565-572.

14. Lillesand, T. M. and R. W. Kiefer. 2000. Remote Sensing and Image Interpretation. John Wiley and Sons Inc., New York. PP: 725

15. Sadiq, A. and F. Howari. 2009. Remote sensing and spectral characteristic of desert sand from Qatar peninsula, Arabian Gulf. Remote Sens.1: 915-933

16. Xu, C., W. Zeng, J. Huang, J. Wu and J. D. Willem. 2016. Prediction of soil moisture content and soil salt concentration from hyperspectral laboratory and field data. Remote Sens. 8: 42-62.