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Research Article

Modeling of Exchangeable Sodium Ratio on the Saline Soil

[1]Zahra Shirmohammadi-aliakbarkhani and [2]Somayeh Heydari

[1]Department of Water Engineering, Faculty of Agriculture and Animal Science, University of Torbat-e Jam, Khorasan Razavi, Iran
[2]Department of Chemistry, Faculty of Agriculture and Animal Science, University of Torbat-e Jam, Khorasan Razavi, Iran

Abstract

Background and Objective: Despite the expansion of salinity in arid and semiarid regions, the measurement of exchangeable cations concentrations such as exchangeable sodium ratio in saline soils remains difficult. Exchangeable sodium ratio (ESR) often measured by using the time-consuming laboratory tests. The correlation between ESR and sodium adsorption ratio (SAR) has documented in many studies. However, no studies have undertaken to model soil ESR in the Sarakhs Plain, Northeast Iran. The aim of this study was to evaluate a linear regression model between soluble and exchangeable cations in this area. **Materials and Methods:** In this study, 124 soil samples randomly taken from surface and subsurface the experimental site. The soil samples collected using a soil auger at 0-30 cm and 30-60 cm depth. Then the linear regression model was used for predicting soil (ESR) on saline soil. The soil ESR values measured in soil samples compared to the soil ESR values predicted using the soil ESR-SAR model. **Results:** The statistical results indicate that in surface soil (0-30 cm) and subsurface soil (30-60 cm), to predict soil ESR from soil SAR, the linear regression model ESR = 0.0182SAR-0.027 with (R^2 = 0.92, p<0.001) and ESR = 0.0157SAR-0.020 with (R^2 = 0.83, p<0.001) can be recommended, respectively. **Conclusion:** In conclusion, the soil ESR-SAR model recommended for the prediction of soil ESR to its significant importance reducing in time and field checking.

Key words: Soil salinity, sodium adsorption ratio, exchangeable sodium ratio, sarakhs plain

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Corresponding Author: Zahra Shirmohammadi-aliakbarkhani, Department of Water Engineering, Faculty of Agriculture and Animal Science, University of Torbat-e Jam, Khorasan Razavi, Iran Tel: +989153258570 Fax: +985152547045

Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Salinity is one of the main problems that resulted in limiting plant growth and yield. The application of fertilizers and using the inappropriate quality of irrigation water and saline water may increase the salinity of the soil[1]. When the accumulation of salts increases in the root zone, it reduces the ability of crops to take up water. Increasing salt in the soil is a big problem, lead to reduce the product[2,3].

Seilsepour *et al.*[4] illustrated that 2 different criteria as indices of salinity, soil sodium adsorption ratio (SAR) and exchangeable sodium percentage (ESP) that defined by Eq. 1 and 2:

$$SAR = Na^{+} / [(Ca^{2+}+Mg^{2+})/2]^{0.5} \quad (1)$$

where, Na^+, Ca^{2+}, Mg^{2+} are soluble cations in soil solution (meq L^{-1})

$$ESP = \frac{Ex.Na}{CEC} \times 100 \quad (2)$$

where, ESP is exchangeable sodium percentage (%), EX. Na^+ is measured exchangeable Na^+ (meq/100 g) and CEC is cation exchange capacity (meq/100 g).

The following equations are used to describe the soil ESR from exchangeable Na and CEC:

$$ESR = \frac{Ex.Na^{+}}{CEC- EX.Na^{+}} \quad (3)$$

In this equation, ESR is exchangeable sodium ratio (%), EX. Na^+ is measured exchangeable Na^+ (meq/100 g) and CEC is cation exchange capacity (meq/100 g).

However, The ESR of a soil can be calculated from ESP using the expression:

$$ESR = \frac{ESP}{100\text{-}ESP} \quad (4)$$

Musslewhite and Jin[5] reported that indirectly predictions soil ESP using a soil salinity index such as SAR, may be more appropriate and economical. Previous researches reported association between soil ESP and SAR[2,6-8].

Therefore, to estimate soil ESP can using soil SAR. The United States Council Laboratory (USES) found the linear relationship between SAR and ESR as ESR = -0.0126+0.01475 SAR for the United States[9]. Many of these methods, however, have variations, for reasons of local adjustments, raising further uncertainties, requiring thus regional checks and other research result showed that the prevalent model between soil ESR and SAR to changed significantly with both the dominant clay mineral and solution ionic strength available in the soil and is not constant[4,10-13]. Therefore, the regression model between ESR and SAR must be considered directly in the different region's soil. The objective of the present study was to evaluate a linear regression model between soluble and exchangeable cations in some soils of Sarakhs plain, Iran.

MATERIALS AND METHODS

Experimental procedure: In this study, 124 soil samples randomly taken from surface and subsurface the experimental site of Sarakhs, Iran (latitude-36° 19', longitude-61° 6' and altitude-235 m) (Fig. 1). The soil samples collected using a soil auger at 0-30 cm and 30-60 cm depth. The study was carried out in 2017. The soil physical properties in the study area showed in Table 1.

The soil chemical and physical properties, i.e., soil texture and EC, pH, Ca^{2+}, Mg^{2+}, Na^+, CEC, SAR and ESR of the soil samples were measured by using laboratory tests as demonstrated by United States Salinity Laboratory Staff[2].

Also, 20 soil samples from each layer at random were taken to verify the model by comparing its results with those of the laboratory tests. Chemical properties of soil samples from 2 layers have shown in Table 2.

Statistical analysis: A paired sample t-test analysis (the standard deviation of difference, the mean difference confidence interval, standard error of mean (SEM) and p-value) used to evaluate the soil ESR values predicted using the soil ESR-SAR model with the soil ESR values measured by laboratory tests. The statistical analyses were performed by using Microsoft Excel Software (Version 2010).

Table 1: Some physical properties of the experimental site

	Particle size distribution (%)						
Soil depth (cm)	Sand	Silt	Clay	Soil texture	Field capacity (%)	Wilting point (%)	Bulk density (g cm^{-3})
0-30	34	40	26	Loam	31	14	1.4
30-60	20	48	32	Clay loam	36	18	1.35

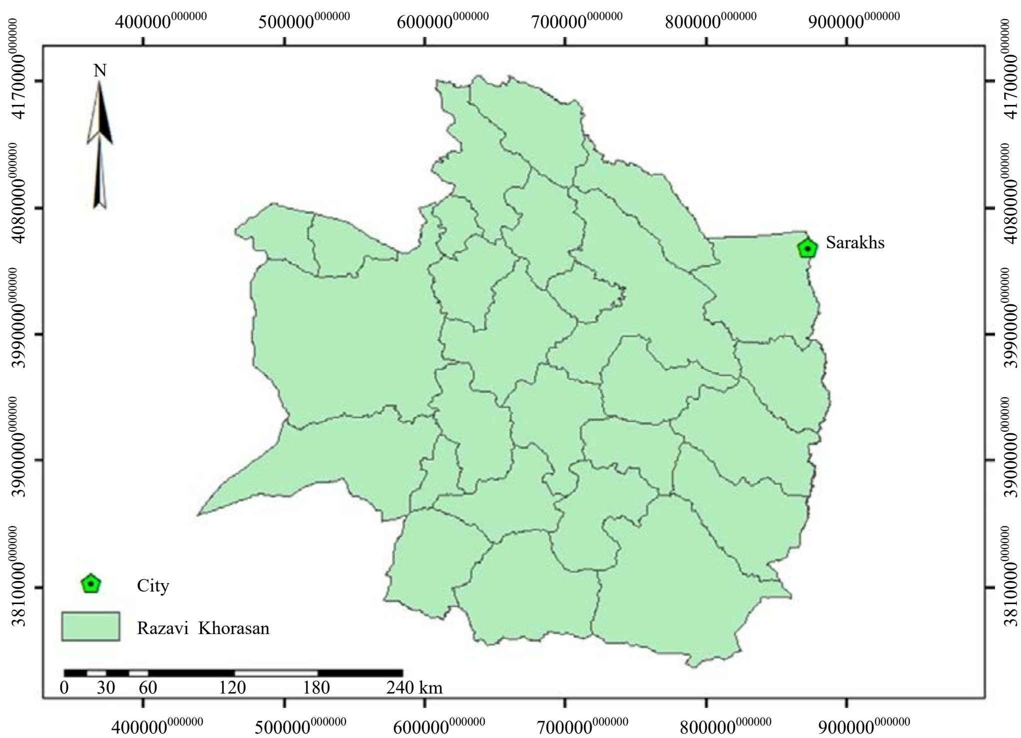

Fig. 1: Layout of the study area in Razavi Khorasan province, Northeast Iran (ArcGIS 10.3)

Table 2: Chemical properties of the experimental site and the mean values, standard deviation (SD) and coefficient of variation (CV) of soil chemical properties of the 62 soil samples from 2 layers

Depth (cm)	Parameters	Minimum	Maximum	Mean	SD	CV (%)
0-30	PH	7.56	8.01	7.79	0.10	1.26
	EC (dS m^{-1})	3.67	9.67	6.40	1.46	22.75
	Na^+ (meq/100 g)	24.81	64.96	41.00	9.44	23.03
	Ca^{2+} (meq/100 g)	6.50	20.15	12.86	3.64	28.30
	Mg^{2+} (meq/100 g)	7.25	23.90	15.58	3.90	25.07
	SAR $(meq/100\ g)^{0.5}$	8.48	14.75	10.92	1.82	16.64
	CEC (meq/100 g)	10.64	28.29	16.92	3.77	22.30
	EX.Na^+ (meq/100 g)	1.95	2.86	2.25	0.23	10.44
	ESR	0.10	0.23	0.16	0.03	20.91
30-60	PH	7.59	7.96	7.80	0.09	1.19
	EC (dS m^{-1})	3.02	7.84	5.14	1.19	23.19
	Na^+ (meq/100 g)	17.25	54.09	33.22	7.73	23.26
	$Ca2^+$ (meq/100 g)	5.55	17.80	10.33	2.74	26.47
	Mg^{2+} (meq/100 g)	6.35	21.85	12.78	3.66	28.64
	SAR $(meq/100\ g)^{0.5}$	5.96	13.65	9.79	1.63	16.67
	CEC (meq/100 g)	13.22	31.57	19.91	4.32	21.68
	EX.Na^+ (meq/100 g)	1.90	3.23	2.30	0.29	12.62

EC: Soil electrical conductivities of saturated pasted extract, SAR: Sodium adsorption ratio of saturated pasted extract, CEC: Cation exchange capacity of saturated pasted extract, EX.Na^+: Measured exchangeable Na^+, ESR: Exchangeable sodium ratio

Regression model: A linear regression model to explain the relationship between the soil SAR and soil ESR values shown in Eq. 5:

$$Y = \alpha + \beta X \tag{5}$$

where, Y is a dependent variable (in this study ESR of soil), X is an independent variable (in this study SAR of soil) and α, β is regression coefficients[2,4].

RESULTS

The coefficient of variation (CV.), coefficient of determination (R^2) and regression equations of ESR-SAR are shown in Table 3. Highly significant regression model ($p<0.001$) were found between ESR and SAR.

The result of a paired sample t-test analyses of the soil ESR-SAR model are shown in Table 4. The t-test results in both layers of soil showed that the soil ESR values predicted by

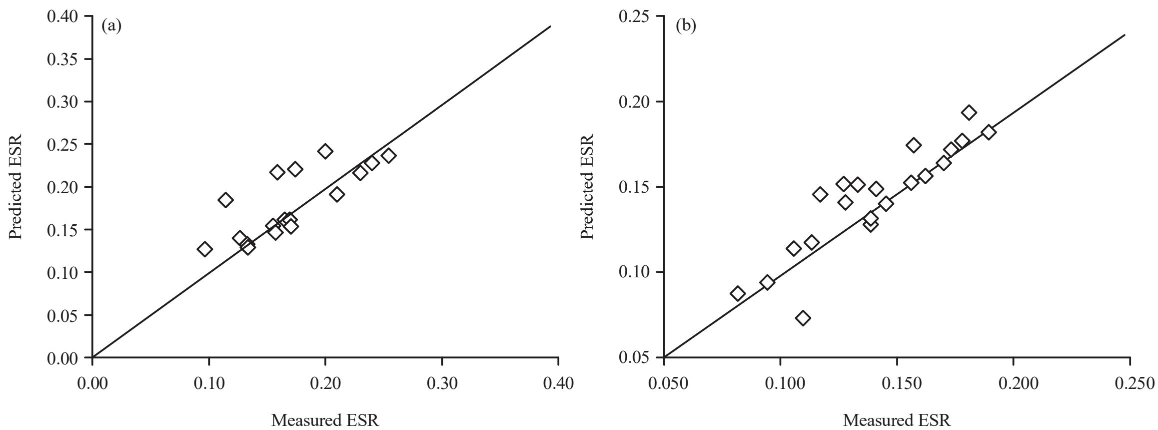

Fig. 2(a-b): Relationships between measured and predicted soil exchangeable sodium ratio (ESR) with the line of equality (1.0:1.0) for (a) 0-30 cm soil and (b) 30-60 cm soil

Table 3: The p-value of independent variable, coefficient of determination (R^2) and coefficient of variation (CV) of the soil ESR-SAR model

Layers	Model	Independent variable	p-value	R^2	CV (%)
0-30 cm	ESR = 0.0182SAR-0.027	SAR	1.34E-23	0.918	18.5
30-60 cm	ESR = 0.0157SAR-0.020	SAR	4.28E-15	0.833	17.2

Table 4: Paired samples t-test analysis on comparing soil ESR determination methods on soil samples

Layers	Determination methods	Average difference (%)	Standard deviation of difference (%)	Standard error of mean (SEM)	p-value	95% confidence intervals for the difference in means
0-30 cm	ESR-SAR model and laboratory test	-0.007	0.0288	0.0064	0.259^{ns}	-0.0209 to 0.0060
30-60 cm	ESR-SAR model and laboratory test	-0.004	0.0144	0.00321	0.280^{ns}	-0.0103 to 0.0032

ns: Non significant, ESR: Exchangeable sodium ratio, SAR: Sodium adsorption ratio of saturated pasted extract

Table 5: ESR-SAR relationships of various soil

soil	ESR-SAR model	R^2	References
Surface (0-30 cm)	ESR = 0.0182SAR-0.027	0.918	This study
Subsurface (30-60 cm)	ESR = 0.0157SAR-0.020	0.833	This study
A horizon	ESR = 0.0058SAR+0.0076	0.902	Harron *et al.*[14]
B horizon	ESR = 0.0173SAR-0.0180	0.902	Harron *et al.*[14]
59 soils from Western USA	ESR = 0.01475SAR-0.0126	0.852	United states salinity laboratory staff[2]
LS	ESR = 0.0074SAR+0.1593	0.839	Paliwal and Gandhi[15]
SCL	ESR = 0.0109SAR+0.1324	0.834	Paliwal and Gandhi[15]
CL	ESR = 0.0109SAR+0.1320	0.918	Paliwal and Gandhi[15]

these 2 regression equations were not significantly different ($p>0.05$) from the actual soil ESR measured by laboratory tests.

Figure 2a, b showed the predicted ESR using the ESR = 0.0182SAR-0.027 and ESR = 0.0157SAR-0.020 models and measured ESR with the line of equality (1.0:1.0) for 2 soil layers. In both layers, a paired samples t-test approach was used to compare the soil ESR values measured and predicted.

Figure 3a, b show the Bland-Altman plot for evaluating the agreement between the soil ESR values measured by laboratory tests and the soil ESR values predicted using this the model for 2 soil layers.

The results of previous studies presented in Table 5 and Fig. 4.

DISCUSSION

In this study, for both soil layers, a highly significant correlation for the ESR with the SAR obtained. Also in previous studies, the linear regression between the soil ESR and the soil SAR has been recognized[2,14,15].

For soil samples of 0-30 cm depth, the regression model of ESR = 0.0182SAR-0.027 and for soil samples of 30-60 cm depth, the regression model ESR = 0.0157SAR-0.020 were established to predict soil ESR in the Sarakhs Plain. The Bland-Altman approach[16] in both layers of soil was also used to plot the agreement between the soil ESR values measured and predicted. The comparison between measured and

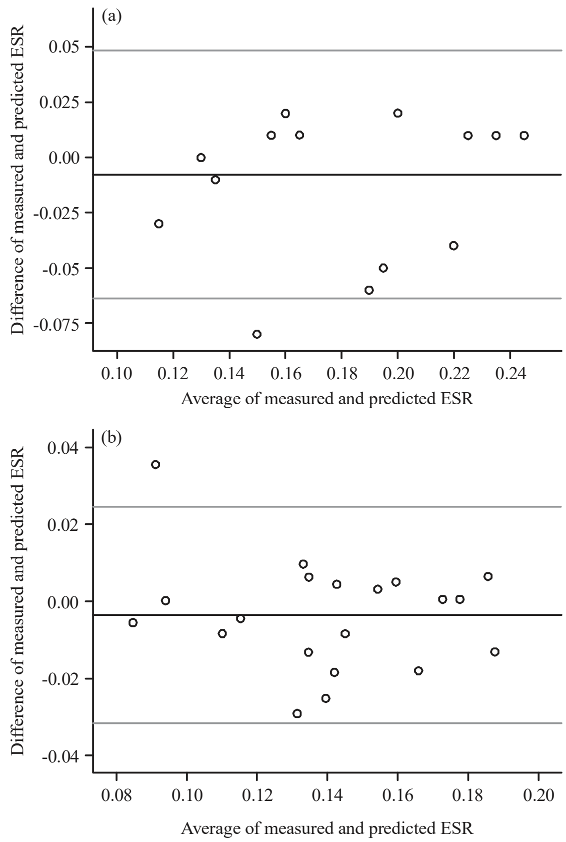

Fig. 3a-b: Bland-Altman plot for the comparison of measured and predicted soil exchangeable sodium ratio (ESR) for (a) 0-30 cm, outer lines indicate the 95% limit of agreement (-0.063, 0.049), center line shows the average difference (-0.007) and (b) 30-60 cm, outer lines indicate the 95% limit of agreement (-0.032, 0.025), center line shows the average difference (-0.004)

predicted data obtained from the mentioned models in both layers of soil has been depicted that indicates good match (Fig. 3a,b).

For soil samples of 0-30 cm depth, the 95% limits of agreement for comparison of the actual soil ESR determined with laboratory test and the soil ESR-SAR model were calculated at -0.063 and 0.049% (Fig. 3a). Thus, soil ESR predicted by the soil ESR-SAR model may be 0.063% lower or 0.049% higher than soil ESR measured by laboratory test.

For soil samples of 30-60 cm depth, the 95% limits of agreement for comparison of the actual soil ESR determined with laboratory test and the soil ESR-SAR model were calculated at -0.032 and 0.025% (Fig. 3b). Thus, soil ESR predicted by the soil ESR-SAR model may be -0.032% lower or 0.025% higher than soil ESR measured by laboratory test.

The results of paired samples t-test in both layers of soil indicated that the soil ESR values predicted with the soil ESR-SAR models were not significantly different ($p>0.05$) than the actual soil ESR measured with laboratory tests (Table 4). For soil samples of 0-30 cm depth, the mean soil ESR difference between 2 methods was -0.007% (95% confidence interval: -0.0209 and 0.0060%, $p = 0.259$). The standard deviation of the soil ESR differences was 0.0288%. For soil samples of 30-60 cm depth, the mean soil ESR difference between 2 methods was -0.004% (95% confidence interval: -0.0103 and 0.0032%, $p = 0.280$). The standard deviation of the soil ESR differences was 0.0144%.

For soil samples of 0-30 cm depth, The regression models of ESR = 0.0182SAR-0.027 is close to the regression models of ESR = 0.0173SAR-0.0180 from Harron *et al.*[14] in the B horizon. But this model is different from the other model[2,4,15].

For soil samples of 30-60 cm depth, it's clear from Fig. 4 that the regression models of ESR = 0.0157SAR-0.020 in the Sarakhs Plain are different from the other model[2,4,14,15].

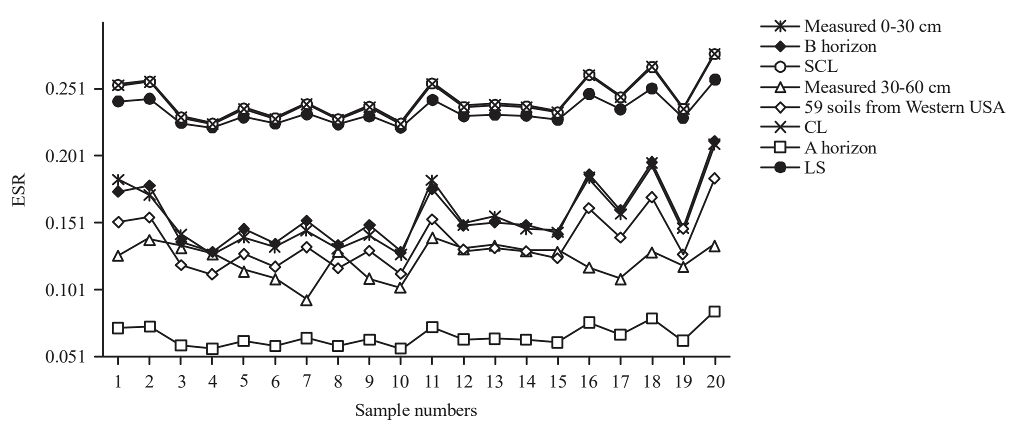

Fig. 4: Comparison of measured soil exchangeable sodium ratio (ESR) for soil samples of 0-30 and 30-60 cm depth and predicted soil exchangeable sodium ratio (ESR) by the other model on previous studies

This indicates that the ESR-SAR couple is not constant because it is influenced by numerous factors such as content solution ionic strength, organic matter content, soil salinity and clay minerals[10,14,17,18]. Thus, the relationship between soil ESR and SAR should be determined directly for the soil of interest[4,17].

In this study, Influence of all factors affecting on the ESR-SAR model has not studied. Future studies on the ESR-SAR relationship with consideration of all parameters will help the researcher in soil studies.

CONCLUSION

In this research, the linear regression model has used predict soil exchangeable sodium ratio (ESR) on saline soil. A new equation was established to from soil SAR to predict soil ESR. The soil ESR values measured in soil samples of 0-30 cm and 30-60 cm depth by laboratory tests compared to the soil ESR values predicted using the soil ESR-SAR model. The statistical results on both layers showed that there was no difference between the soil ESR values predicted by this the model and the soil ESR values measured by the laboratory tests ($p>0.05$). Therefore, instead of time-consuming and costly laboratory tests, the soil ESR-SAR model can be recommended for the prediction of soil ESR.

SIGNIFICANCE STATEMENT

This study discovered a new equation from soil SAR to predict soil ESR that can be beneficial for soil studies instead of time-consuming and costly laboratory tests. Other research result showed that the prevalent model between soil ESR and SAR to changed significantly with both the dominant clay mineral and solution ionic strength available in the soil and is not constant. Therefore, the regression model between ESR and SAR must be considered directly in the different region's soil. The results of this study would aid in determining the appropriate model for prediction of ESR from SAR on saline soils. This study will help the researchers to uncover the critical areas of the soil ESR-SAR relationship in some soils of Sarakhs plain in Iran that many researchers were not able to explore. Thus a new equation on determination exchangeable cations in soil studies may be arrived at.

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