EnvironmentAsia
The international journal by the Thai Society of Higher Education Institutes on Environment

EnvironmentAsia 18(2) 2025 121-130
DOI 10.14456/ea.2025.42
ISSN 1906-1714; ONLINE ISSN: 2586-8861

Soil ECe Prediction from Different EC Water Ratios and Sample Sizes in Salt-affected Soils

Koddam Rukadi, Porntip Phontusang*, and Anongnat Sriprachote

Department of Soil Science and Environment, Faculty of Agriculture, Khon Kaen University, Khon Kaen Province, 40002, Thailand

*Corresponding author: porntph@kku.ac.th
Received: January 23, 2025; Revised: March 20, 2025; Accepted: April 17, 2025

Abstract

Given the environmental hazards worldwide, salt-affected soils present an appealing topic for discussion. This study investigates (i) the correlation between the electrical conductivity of saturated paste extract (ECe) and the electrical conductivity (EC) of water ratios 1:2.5 and 1:5 and (ii) sample size (n = 25, 50, and 100) measurements for the model accuracy by using linear regression. In total, 300 topsoil samples (0 - 30 cm) were collected from three study sites in different classes (class 1, class 2, and class 3) of salt-affected soils in Muang Pia Subdistrict, Ban Phai District, Khon Kaen Province. The results showed there was the highest correlation intensity between ECe and EC water ratio 1:5 from sample size n = 25 ($R^2 = 0.392$), in contrast to weak correlation with the same sample size ($R^2 = 0.028$), and moderate correlation with an increased sample size n = 50 ($R^2 = 0.157$), for classes 2, 1, and 3, respectively. Finally, it can be concluded that the most effective approach to assessing the correlation between ECe and EC water ratios is by using EC water ratio 1:5 according to the highest correlation intensity, more diluted extract and technically used than EC 1:2.5. The findings of this study strongly recommend the improvement of soil ECe assessment from soil EC water ratios in the future by the incorporation of further point data and field area utilizing this approach.

Keywords: Soil salinization; Electrical conductivity; EC 1:2.5 and EC 1:5; Linear regression; Northeast Thailand

1. Introduction

Soil salinity is a critical component that significantly influences the suitability of soil for agricultural production. Generally crops are sensitive to excess soluble salt in the root zone due to salinity in the soil, this can inhibit plant growth and reduce crop yields (United States Salinity Laboratory Staff, 1954; Corwin and Yemoto, 2017). Therefore, measuring soil salinity is one of the most important tool in agricultural management, and applying a suitable and relatively simple method (Khorsandi and Yazdi, 2011).

Electrical conductivity (EC) is an accepted approach for measuring soil salinity were soil classified as saline when the EC of saturation extract (ECe) over than 4 dS/m (Bannari *et al.,* 2008; Sonmez *et al.,* 2008). ECe considered as the standard and the best method to measure soil salinity were directly related to plants (United States Salinity Laboratorys Staff, 1954; Rhoades, 1982). Therefore, the ECe method remains costly, labor-intensive, and time-consuming, requiring more knowledge for assessing the soil paste extract than soil water ratio methods (Khorsandi and Yazdi, 2007; Sonmez *et al.,* 2008; Kargas *et al.,* 2020).

Numerous studies from various soil salinity research globally have determined and demonstrated that measuring the ECe values derived from various soil EC water ratios (i.e., 1:1, 1:2, 1:2.5, 1:5, and 1:10) are easy to extract (Khorsandi and Yazdi, 2007) and highly significant correlations and convenient than measuring soil ECe. Therefore, these factors have led several laboratories and researchers to suggest this method in evaluating soil salinity by EC measurements of soil to water ratios of 1:2.5 and 1:5. The research has reported that the soil to water ratios extraction method were demonstrate a weak relationship with the real of natural soil conditions (Sonmez *et al.,* 2008; Matthees *et al.,* 2017).

Correlating ECe with EC 1:1, 1:2.5, and 1:5 was the primary focus of most studies conducted in other nations, in Russia were analyzed EC 1:5 (Smagin and Kacimov, 2023), Turkey were analyzed EC 1:1, 1:2.5, 1:5 (Gozukara *et al.,* 2022; Sonmez *et al.,* 2008), in Thailand were analyzed EC 1:5 (Leksungnoen *et al.,* 2018), in the USA were analyzed EC 1:1, 1:2, 1:5 (He *et al.,* 2013; Matthees *et al.,* 2017; Corwin and Yemoto, 2017), and China were analyzed EC 1:5 (Chi and Wang, 2010). All equations have demonstrated geographical variability, indicating the necessity for region-specific equations and it appears that EC 1:5 is the most intensively researched and high correlation (Leksungnoen *et al.,* 2018). Research indicates that ECe values typically exceed those obtained by soil water ratios methods such as 1:2.5 and 1:5 (Sonmez *et al.,* 2008; Kargas *et al.,* 2020).

Sample size is critical for the accuracy and reliability of predictive models (Or, 2010), particularly in estimating ECe. Larger samples reduce errors and enhance precision, improving pattern recognition. However, small samples can still provide valuable insights when resources are limited (Phontusang *et al.,* 2017). While larger samples are preferred for robustness, small samples, if managed effectively, can yield meaningful results, particularly in exploratory research. Careful consideration of sample size ensures reliable ECe predictions across diverse research and practical settings.

This study aims to analyze the correlation between soil ECe and soil EC water ratios of 1:2.5 and 1:5. Moreover, this study also explore the effect of sample size on model accuracy. As a methodology, simple linear regression models were used for this analysis.

2. Methodology

2.1 Background area and soil sampling

The background of soil sampling area is situated in Muang Pia Subdistrict, Ban Phai District, Khon Kaen Province, Thailand (Figure 1). Approximately, the study area around 73.40 km^2, were the elevation range between 150 - 200 m above mean sea level at latitude 16°01' - 16°11' N and longitude 102°37'- 102°42' E which lies in the inland of Northeast region. The eastern and southern area of Muang Pia Subdistrict regions, predominantly consist of land used for rice cultivation, but the northern region mainly consists of saline soil, which serves as a source for boiling rock salt for tribute and trade, also in this region there is land remains unoccupied as no vegetation can thrive in that area. The southern and western regions consist of hills interspersed with plains, while the hills are used for agriculture and horticulture.

The climate features of the area are tropical monsoon weather. The summer period is from February to April (35 – 37 °C), the rainy period start from May to September (20 – 25 °C), and the lowest monthly (winter period) occurred in October to January (14 - 15 °C) every year (Muang Pia Subdistrict Administrative Organization, 2022). The study site was selected on the findings of Phontusang *et al.* (2017) which can be categorized into 3 sites based on the percentage of surface salt crust in dry season (Wichaidit, 1995). Furthemore, the soil texture measurements are the general measurements as for the representative from each class of salt-affected soils salt crust surface percentages.

Class 1, as a loam soil texture, with sand comprising 44.96%, silt comprising 35.78%, and clay comprising 19.26%. Despite loam soil emerges as the optimal choice for plant growth due to its balanced water retention and higher nutrient retention capacity (Khanh *et al.,* 2024; Thanh *et al.,* 2022). Class 1 was categorized very severely salt-affected soils with covered areas by salt crust more than 50% of soil surface. On this salt-affected soils class only some tolerant grass species such as P*uccinellia tenuifloa, Acacia salicina,* *Sporobolus cryptandrus* are capable of growth (Figure 1).

Class 2 as a sandy loam soil texture, with sand making up 53.38% of the substance, silt making up 31.06%, and clay making up 15.56%. Despite the sandy loam soil with low clay content provides for fertility, structure stability, and good water retention (Daneshvar *et al.,* 2024), there are certain areas where plant growth is inhibited. Class 2 categorized severely salt-affected soils covered areas by salt crust between 10 - 50 % of soil surface. Mostly, in this class a wide variety of plant species are capable of growth (i.e., *oryza sativa, psidium guajava, capsicum annuum*). However, certain areas within the field remain unsuitable for plant growth due to the high salinity levels.

Lastly, class 3 as a clay loam soil, with sand comprising 40.88%, silt comprising 29.11%, and clay comprising 30.01%. Class 3 classified moderately salt-affected soils, supports healthy plant growth with high sand content make it higher adsorption capacity (Qi *et al.,* 2021). This area is also characterized by a salt crust covering 1 - 10% of the soil surface. It should be noted that this study exclusively conducted a comprehensive analysis of soil texture across all classifications of the study sites.

A total of 300 soil samples were collected for this study, with 100 samples representing each soil class. The samples were collected from a depth of 0 - 30 cm (topsoil). Subsequently, all samples were analyzed at the Department of Soil Science and Environment Laboratory, Faculty of Agriculture, Khon Kaen University.

2.2 Soil ECe and EC water ratios analysis

In this study, soil ECe values by using standard method (United States Salinity Laboratory Staff, 1954) were obtained from the findings of Phontusang *et al.* (2017). Phontusang *et al.* (2017) indicated that the field size for sampling measurements should be ≥ 40 × 40 m or equivalent to 25 samples, where this was particularly true for classes 1 and 3; meanwhile in class 2 it was relatively poor because of the high variation of soil ECe in this area. Furthermore, the salinity classification in the study areas (Figure 1), class 1 can be classified = very strongly saline, class 2 = non-saline to very strongly saline, and class 3 = non-saline (Table 3).

A total 300 soil samples were air dry, ground to pass sieve and analyzed soil EC water ratios 1:2.5 and 1:5 method by United States Salinity Laboratory Staff, (1954) method. The soil water suspension for EC water ratio 1:2.5 was obtained by adding 50 mL of distilled water with 20 g of air-dried soil into 100 mL glass beaker for stirring and

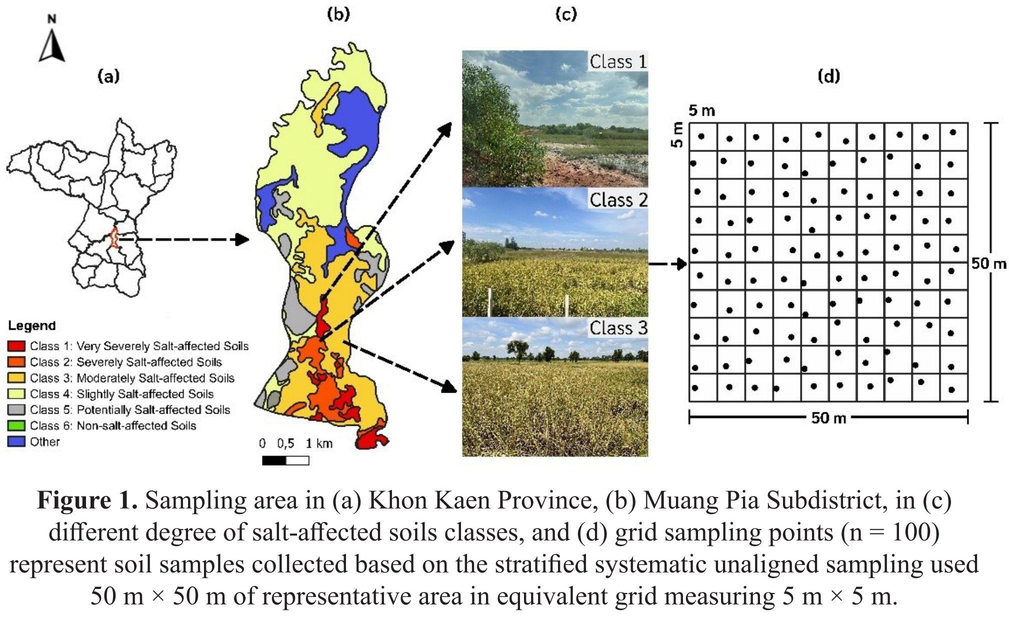

Figure 1. Sampling area in (a) Khon Kaen Province, (b) Muang Pia Subdistrict, in (c) different degree of salt-affected soils classes, and (d) grid sampling points (n = 100) represent soil samples collected based on the stratified systematic unaligned sampling used 50 m × 50 m of representative area in equivalent grid measuring 5 m × 5 m.

equilibrium method. The soil suspension was stirred by hand for 10 minutes, and the next step was a 30-minute waiting period to allow the soil-water EC ratio to reach equilibrium before measurement. The 30 minutes time was selected because most of soils were demonstrated to reach the equilibrium after this period (He *et al.,* 2013). The soil water suspension for EC water ratio 1:5 was stirred using beaker glass 150 mL (20 g soil and 100 mL distilled water) was stirred similarly to EC water ratios 1:2.5 step. All methods and EC readings of soil water suspension for measuring the EC water ratios (1:2.5 and 1:5) using EC meter were maintained at room temperature 25 °C.

2.3 Soil samples selection

The samples selection investigates the correlation between soil ECe and soil EC water ratio 1:2.5 and EC water ratio 1:5 and sample size measurement involving the building of simple linear regression. The comparison of ECe is conducted using sample sizes 25, 50, and 100. Similarly, the sample sizes for EC 1:2.5 and EC 1:5 include 25, 50, and 100 samples using systematic grid selection (Figure 2). In particular, 25 samples were reduced from 75 samples, with 3-point samples eliminated for every 4 squares. Fifty samples were reduced by fifty samples, and for every four squares, two-point samples were eliminated. Furthermore, 100 samples are filled to capacity.

Throughout all 3 classes, 18 datasets were created to compare the ECe to EC water ratios (EC 1:2.5 and EC 1:5) using a different number of samples in each class (Table 1).

2.4 Statistical analysis

To assess the possible and the best relationship between ECe and EC water ratios 1:2.5 and 1:5 and different sample sizes in each dataset, a simple linear regression model was used for this purpose. The analysis was conducted using GS+ 10.0 software version (Robertson, 2008). The linear regression model Eq. (1) is used to determine the correlation between primary (independent) variable and secondary (dependent) variable

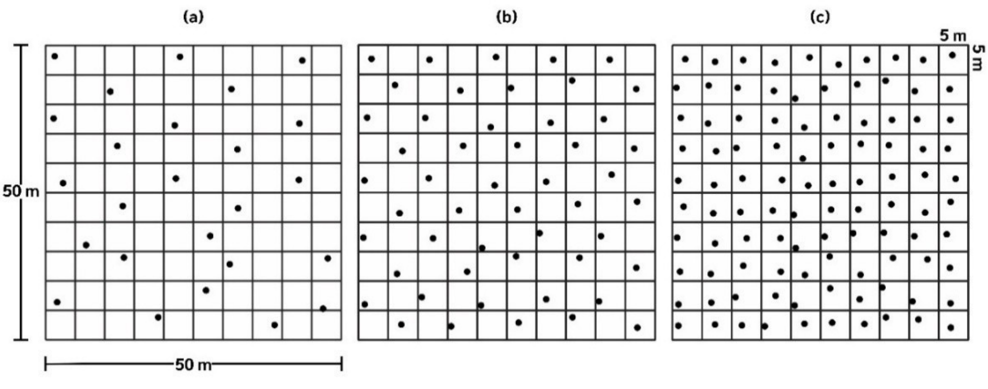

Figure 2. Soil samples selection, (a) 25 samples, (b) 50 samples, and (c) 100 samples

Table 1. Soil samples selection of ECe and EC water ratios

EC 1:2.5				EC 1:5			
Dataset	Class	ECe	Sample size	Dataset	Class	ECe	Sample size
1		25	25	10		25	25
2	1	50	50	11	1	50	50
3		100	100	12		100	100
4		25	25	13		25	25
5	2	50	50	14	2	50	50
6		100	100	15		100	100
7		25	25	16		25	25
8	3	50	50	17	3	50	50
9		100	100	18		100	100

(Almeida *et al.,* 2019; Hasibuan *et al.,* 2022; Rokde and Thosar, 2023). Where, the primary variable for this study is ECe and the secondary variable is EC water ratios 1:2.5 and 1:5 (Table 1).

$$Y = c + \beta X \tag{1}$$

In this context the dependent variable is Y, the variable constant is c, the regression coefficient is β, and the independent variable is X. The evaluation of these resulting equations is conducted based on the R^2 value. The R^2 value is a coefficient that indicates the strength of the correlation between the independent and dependent variables in the regression analysis (Almeida *et al.,* 2019). The indicates proportion of variance in the dependent variable explained by the model, helping to assess the model's validity and guide decisions on its acceptance or rejection (Table 2).

3. Results and Discussion

3.1 The variability of EC water ratios in different sample sizes

The detailed descriptive statistics for the EC water ratios of 1:2.5 and 1:5 is presented in Table 3. The coefficient of variation (CV) is a valuable statistical metric for measuring the spatial variability that indicates the regional heterogeneity of soil properties (Lv *et al.,* 2013). In general, the spatial variability of both EC water ratios methods ranges from weak to strong (CV = 0.02 - 3.81). In class 1, the CV values from EC water ratios 1:2.5 and 1:5 demonstrate notable heterogeneity between the three classes. Class 1 has considerable diversity, denoting significant distribution. Class 2 has a combination of weak to moderate variability in dataset of EC 1:2.5 method and moderate variability in the dataset of EC 1:5 method, indicating both stability and significant variations in the data. Class 3 has low variability from both 2 methods, indicating substantial consistency within the data. These data emphasize varying levels of dispersion between the classes, which may guide subsequent assessment and interpretation.

3.2 Correlation between ECe and EC water ratios

Table 4 shows the linear correlation between ECe and different EC water ratios and sample sizes, which is followed by Figure 3, which represents the best correlation results of EC water ratio 1:5. In general, R^2 indicates the strength of the correlation between ECe and EC water ratios in all 18 datasets and 3 classes. Based on Table 4, the R^2 values range from null to high correlation intensity ($R^2 = 0 – 0.392$).

In class 1, the correlation intensity between ECe and EC water ratio 1:2.5 in a different sample size indicated by R^2. The results showed weak correlation in every sample size in this class. The highest correlation intensity was found with sample size 25 ($R^2 = 0.014$). Similarly, the weak correlation intensity showed between ECe and EC water ratio 1:5 in every sample size, where the highest correlation intensity (Figure 3a) was found with the sample size 25 ($R^2 = 0.028$). The weak correlation intensity between ECe and EC water ratios 1:2.5 and 1:5 for class 1 in every sample size, this was due to the extremely high of ECe values (56.70 to 433 dS/m) and high CV values (Table 3). Both methods, using EC water ratios of 1:2.5 and 1:5, are applicable to assessing the ECe value.

Table 2. The Correlation intensity R^2

Correlation intensity	R^2 value
Null	0.00
Weak	0.01-0.09
Moderate	0.09-0.36
High	0.36-0.81
Very high	0.81-0.98
Perfect	1.00

Source: Almeida *et al.,* 2019

In class 2, it showed a very high variation of correlation intensity; this indicated null to high correlation between different methods of EC soil water ratios and different sample sizes. We found that the EC 1:5 method with the 25 samples showed the high correlation intensity $R^2 = 0.392$ (Figure 3b) and moderate correlation intensity in the 100 and 50 samples (R^2 = 0.273 and R^2 = 0.253, respectively). In contrast, the method of EC 1:2.5 had the highest correlation intensity ($R^2 = 0.048$) with the 25 samples, and there is no correlation intensity in 100 samples. The high variation of correlation intensity between ECe and both EC water ratios methods, was due to the high variation of ECe (non-saline to very strongly saline) values and CV values in class 2 (Table 3).

Furthermore, these results led to the lowered ECe value in class 2 compared to class 1 and different regional of salt-affected soils area. Based on these results, particularly from EC water ratio 1:5 with sample size 25, it can be interpreted that this sample size is highly recommended to be applied to assess the ECe value. Moreover, the other sample sizes, 50 and 100, can be interpreted that these sample sizes can be applied to assess the ECe value. However, both of this are not as strongly recommended as sample size 25. Similarly, in class 3 there were sample sizes 25 and 50 identified as moderate correlations; it can be interpreted that these sample sizes can be applied to assess the ECe value from EC water ratio 1:5.

In class 3, there was a weak to moderate correlation intensity in the methods of EC 1:2.5 and EC 1:5 with different sample sizes. The EC 1:2.5 with the 50 samples showed the highest correlation intensity ($R^2 = 0.138$). Meanwhile, the EC 1:5 with the 25 and 50 sample sizes showed the highest correlation intensity (R^2 = 0.136 and R^2 = 0.157). Furthermore, the best correlation intensity was shown in Figure 3(c) from sample size n = 50. Despite being identified as a weak to moderate correlation, its impact in this class was less meaningful owing to the lower ECe value, categorized as non-saline, which aligns with the weak CV values (Table 3). Lastly, despite a weak correlation between the two methods for almost all datasets, a correlation is likewise detectable. Alternative methods or data modifications are needed to be explored to enhance model resilience and soil types (Leksungnoen *et al.,* 2018).

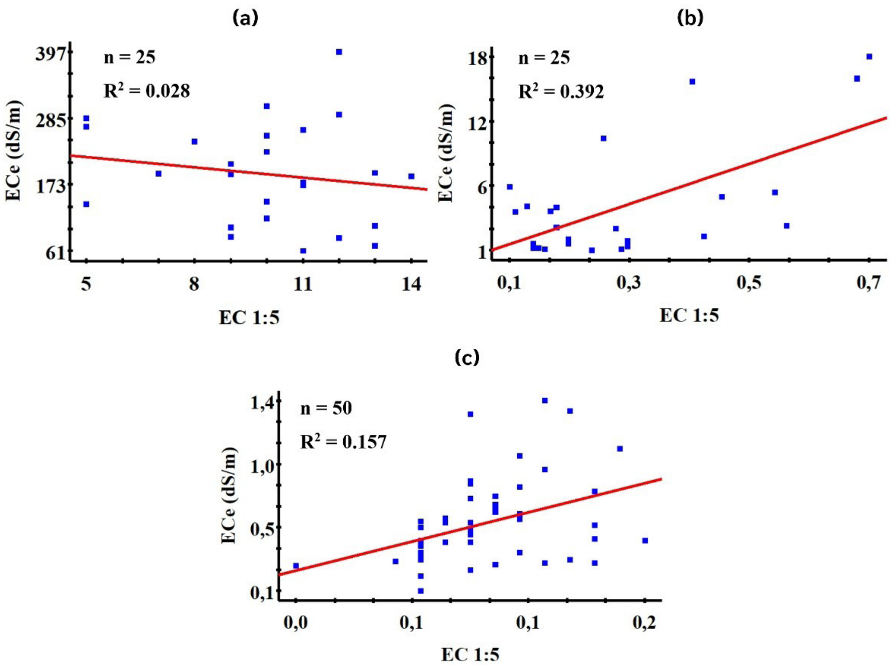

Figure 3. Best correlation between ECe and EC water ratio 1:5 from each class, (a) class 1, (b) class 2, and (c) class 3

Table 3. Basic statistics from EC water ratios 1:2.5 and 1:5 in different study sites of salt-affected soils classes

Class	Number of samples	ECe (dS/m)[a]				EC 1:2.5 (dS/m)					EC 1:5 (dS/m)				
		Min	Max	Mean	CV (%)	Min	Max	Mean	CV	Degree of coefficient variation[b]	Min	Max	Mean	CV	Degree of coefficient variation[b]
1	25	61.10	397	190.98	44.75	9.00	19.00	14.00	2.59	Strong	5.00	14.00	9.96	2.53	strong
	50	56.70	410	202.91	43.64	1.00	20.00	12.76	3.76	Strong	4.00	16.00	9.98	2.44	strong
	100	56.70	433	205.69	42.18	1.78	23.20	13.54	3.81	Strong	4.57	16.73	10.39	2.49	strong
2	25	0.79	17.88	4.74	105.52	0.10	0.42	0.29	0.06	Weak	0.05	0.66	0.24	0.18	moderate
	50	0.16	21.20	5.01	114.81	0.13	1.14	0.33	0.14	Moderate	0.01	0.75	0.25	0.18	moderate
	100	0.16	24.90	4.73	115.32	0.10	1.14	0.31	0.11	Moderate	0.01	0.75	0.24	0.17	moderate
3	25	0.17	1.12	0.50	46.07	0.07	0.32	0.13	0.02	Weak	0.01	0.24	0.08	0.04	weak
	50	0.11	1.39	0.56	50.64	0.07	0.26	0.12	0.04	Weak	0.01	0.15	0.08	0.02	weak
	100	0.11	1.39	0.55	49.57	0.07	0.32	0.12	0.04	Weak	0.01	0.24	0.08	0.03	Weak

[a]The ECe values based on Phontusang *et al*. (2017)
[b]Degree of coefficient of variation (CV) based on Lv *et al*. (2013): values < 0.10, 0.10-1.0, and >1 imply weak, moderate, and strong variability, respectively

Table 4. Correlation between ECe and EC water ratios in a different number of samples in each dataset

Class	ECe×EC 1:2.5	Intercept regression equation	R^2	ECe×EC 1:5	Intercept regression equation	R^2
1	25×25	ECe = 237.99 - 3.4 × EC 1:2.5	0.014	25×25	ECe = 247.94 - 5.7 × EC 1:5	0.028
	50×50	ECe = 223.03 - 1.6 × EC 1:2.5	0.005	50×50	ECe = 190.61 + 1.2 × EC 1:5	0.001
	100×100	ECe = 231.85 - 2.2 × EC 1:2.5	0.008	100×100	ECe = 178.39 + 2.7 × EC 1:5	0.006
2	25×25	ECe = -0.54 + 17.83 ×EC 1:2.5	0.048	25×25	ECe = 0.50 + 17.38 × EC 1:5	0.392
	50×50	ECe = 5.51 - 1.51 × EC 1:2.5	0.001	50×50	ECe = 1.04 + 15.57 × EC 1:5	0.253
	100×100	ECe = 4.57 + 0.47 × EC 1:2.5	0.000	100×100	ECe = 0.74 + 16.08 ×EC 1:5	0.273
3	25×25	ECe = 0.37 + 1.09 × EC 1:2.5	0.067	25×25	ECe = 0.33 + 2.16 × EC 1:5	0.136
	50×50	ECe = 0.22 + 2.61 × EC 1:2.5	0.138	50×50	ECe = 0.20 + 4.19 × EC 1:5	0.157
	100×100	ECe = 0.33 + 1.65 × EC 1:2.5	0.069	100×100	ECe = 0.33 + 2.49 × EC 1:5	0.077

Despite the research from Sonmez *et al.,* (2008) and Gozukara *et al.,* (2022) showed very high correlation between ECe and EC water ratios 1:2.5. However, this study was conducted in different regions and natural conditions, particularly with different classes and salt-affected soils. Furthermore, the previous studies from several countries have reported that highly correlation between ECe and EC water ratio 1:5 such as Sonmez *et al.* (2008) and Gozukara *et al.* (2022) from Turkey, Chi and Wang, (2010) from China, He *et al.* (2012) from USA, Smagin and Kacimov, (2023) from Russia, and Leksungnoen *et al.* (2018) from Thailand with study areas in Nong Khai and Nakhon Ratchasima Province. Closely, this study is particularly in class 2 with sample size 25 identified as high correlation intensity. Figure 3 showed the best correlation between ECe and EC water ratio 1:5 from each class (i.e., class 1, class 2, and class 3).

4. Conclusion

This research was conducted to study the linear regression between soil ECe and soil EC water ratios 1:2.5 and 1:5 and concluded that it can be predicted. The measurements in three study sites with different salt-affected soils successfully identified the significant correlation between soil ECe and EC water ratio 1:5 as the best prediction. Particularly in class 2, it was confirmed as a reasonable method to predict in this region with a small sample size of 25; this is highly recommended to apply. Further study should explore non-linear models, carry out more comparative sample sizes, multi-regional studies, and correlations with soil texture measurements to ensure its precision and accuracy. Furthermore, adaptive strategies, such as salt-tolerant crops and effective water management, are crucial to mitigating soil salinization's impact on agriculture, where the Ministry of Agriculture and the Land Development Department play a key role in promoting these solutions, particularly in the Northeast of Thailand.

Acknowledgement

The authors would like to acknowledge the ASEAN and GMS Countries Scholarship 2023 (Grant no: KKU ASEAN-GMS 027/2024), Khon Kaen University, Thailand for the support study master program.

References

Andrey Smagin, Anvar Kacimov NS. EC conversion for 1:5 extracts and standard saturated soil-water pastes in the assessment of arid land salinization: Classical methodologies revisited. J Saudi Soc Agric Sci. 2023; (December): 12. Available from: https://doi.org/10.1016/j.jssas.2023.12.005.

Almeida R, Leite JC, Silva JGS, Oliveira JPA, Valda LHC. Use of Simple Linear Regression Models to Analyze the Contribution of Non-linear Loads in the Harmonic Distortions of Voltage in an Electric System Bus: Case Study. Int J Adv Eng Res Sci. 2019; 6(7): 372–81.

Bannari A, Guedon AM, El-Harti A, Cherkaoui FZ, El-Ghmari A. Characterization of slightly and moderately saline and sodic soils in irrigated agricultural land using simulated data of advanced land imaging (EO-1) sensor. Commun Soil Sci Plant Anal. 2008; 39(19–20): 2795–811.

Chi CM, Wang ZC. Characterizing salt-affected soils of Songnen Plain using saturated paste and 1:5 soil-to-water extraction methods. Arid L Res Manag. 2010; 24(1): 1–11.

Daneshvar S, Mosaddeghi MR, Afyuni M. Effect of biochar and hydrochar of pistachio residues on physical quality indicators of a sandy loam soil. Geoderma Reg. 2024;36:e00740. Available from: https://doi.org/10.1016/j.geodrs.2023.e00740.

Dennis L. Corwin and Kevin Yemoto. Salinity: Electrical conductivity and total dissolved solids. Soil Sci Soc Am J. 2017; 84(5): 1442–61.

George Kargas, Paraskevi Londra AS. Comparison of soil EC values from methods based on 1:1 and 1:5 soil to water ratios and ECe from saturated paste extract based method. Water (Switzerland). 2020; 12(4): 1–12.

Gozukara G, Altunbas S, Dengiz O, Adak A. Assessing the effect of soil to water ratios and sampling strategies on the prediction of EC and pH using pXRF and Vis-NIR spectra. Comput Electron Agric. 2022;203(November):107459. Available from: https://doi.org/10.1016/j.compag.2022.107459.

Hasibuan A, Siregar WV, Isa M, Warman E, Finata R, Mursalin M. The Use of Regression Method on Simple E for Estimating Electrical Energy Consumption. HighTech Innov J. 2022; 3(3): 306–18.

Heather L. Matthees, Yangbo He, Rachel K. Owen, David Hopkins BD, John Lee, David E. Clay, Cheryl Reese, MDouglas D. alof and TMD. Predicting Soil Electrical Conductivity of the Saturation Extract from a 1:1 Soil to Water Ratio. Commun Soil Sci Plant Anal. 2017; 48(18): 2148–54.

He Y, De Sutter T, Hopkins D, Jia X, Wysocki DA. Predicting ECe of the saturated paste extract from value of EC1:5. Can J Soil Sci. 2013; 93(5): 585–94.

He Y, DeSutter T, Prunty L, Hopkins D, Jia X, Wysocki DA. Evaluation of 1:5 soil to water extract electrical conductivity methods. Geoderma. 2012;185–186:12–7. Available from: http://dx.doi.org/10.1016/j.geoderma.2012.03.022.

Khanh PT, Pramanik S, Ngoc TTH. Soil Permeability of Sandy Loam and Clay Loam Soil in the Paddy Fields in An Giang Province in Vietnam. Environ Challenges. 2024;15(January):100907. Available from: https://doi.org/10.1016/j.envc.2024.100907.

Khorsandi F, Yazdi FA. Estimation of saturated paste extracts' electrical conductivity from 1:5 soil/water suspension and gypsum. Commun Soil Sci Plant Anal. 2011; 42(3): 315–21.

Khorsandi F, Yazdi FA. Gypsum and texture effects on the estimation of saturated paste electrical conductivity by two extraction methods. Commun Soil Sci Plant Anal. 2007; 38(7–8): 1105–17.

Leksungnoen N, Andriyas T, Andriyas S. ECe prediction from EC1:5 in inland salt-affected soils collected from Khorat and Sakhon Nakhon basins, Thailand. Commun Soil Sci Plant Anal. 2018; 49(21): 2627–37.

Lv ZZ, Liu GM, Yang JS, Zhang MM, He HBS& SPY. Spatial variability of soil salinity in Bohai Sea coastal wetlands, China: Partition into four management zones. Plant Biosyst. 2013; 147(4): 1201–10.

Muang Pia Subdistrict Administrative Organization. Muang Pia Subdistrict Administrative Organization. 2022. Available from: https://www.muangpere.go.th/data.php?content_id=2. Accessed, 22 March 2024.

Or YM. A study in determining the sample size in Geostatistics. Dep Math Stat Sci Edmonton, Alberta, Canada. 2010;108. Available from: https://doi.org/10.7939/R3SC96.

Phontusang P, Katawatin R, Pannangpetch K, Lerdsuwansri SK. International Journal of Geoinformatics Vol. 13, No. 2, June. 2017. p. 14.

Qi W, Zhang Z, Wang C, Huang M. Prediction of infiltration behaviors and evaluation of irrigation efficiency in clay loam soil under Moistube® irrigation. Agric Water Manag. 2021;248(May 2020):106756. Available from: https://doi.org/10.1016/j.agwat.2021.106756.

Rhoades JD. Soluble Salts, In: Page, A.L (Ed.), Methods of Soil Analysis, Part 2, Second Edition. Chem Microbiol Prop. 1982; Agronomy M(9):167–79.

Robertson, G.P. GS+: Geostatistics for the Environmental Sciences. Gamma Design Software, Plainwell, Michigan USA. 2008.

Rokde JR, Thosar AG. Linear regression approach for performance evaluation of ES with load impedance variations of non-critical and critical load. e-Prime - Adv Electr Eng Electron Energy. 2023;6(August):100312. Available from: https://doi.org/10.1016/j.prime.2023.100312.

Sahriye Sonmez, Dursun Buyuktas, Filiz Okturen SC. Assessment of different soil to water ratios (1:1, 1:2.5, 1:5) in soil salinity studies. Geoderma. 2008; 144(1–2): 361–9.

Thanh NN, Chotpantarat S, Trung NH, Ngu NH, Muoi L Van. Mapping groundwater potential zones in Kanchanaburi Province, Thailand by integrating of analytic hierarchy process, frequency ratio, and random forest. Ecol Indic. 2022;145(November):109591. Available from: https://doi.org/10.1016/j.ecolind.2022.109591.

United States Salinity Laboratory Staff. Diagnosis and Improvement of Saline and Alkaline Soils. Agric. Handbook No. 60. USSL, Riverside, CA, USA. 1954.

Wichaidit P. Report on Survey and Studies of Salt-affected Soils: Khon Kaen Province (in Thai). Soil Survey and Classification Section, Land Development Department, Bangkok, Thailand, 1995, p. 1-20.