EVALUATION ON SALINITY LEVEL AND ELECTRICAL CONDUCTIVITY OF SALT-AFFECTED AREAS IN GROUND LEVEL THROUGH REMOTE SENSING TECHNIQUES

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ABSTRACT

This study aims to develop evaluation methods on salinity level and Electrical Conductivity (EC) of salt-affected areas at ground level through Remote Sensing Techniques. The research methodology was divided into 1) analyzing data obtained from Landsat-8 satellite along with 3 formats of spectral indices, i.e., Salinity Index (SI), Brightness Index (BI), and Normalized Difference Salinity Index (NDSI); 2) conducting field survey to measure Electrical Conductivity (EC) of salt-affected areas in ground level; and 3) conducting linear regression analysis with analyzed data obtained from Landsat-8 satellite and electrical conductivity of salt-affected areas in ground level. The results revealed that SI had a relationship with EC of saline soil at ground level at the highest level with a Confidence Interval of over 70% (R^2 = 0.758) and correlation coefficient over 80% (R= 0.870). From such a linear relationship, a map of the distribution of saline soil in the research area could be created. From the total research areas of 73.40 km^2, distribution of salt-affected areas in ground level could be divided into 5 levels (calculated to be % per area), i.e., highest level (>16 ds/m), high level (8-16 dS/m), moderate level (4-8 dS/m), low level (2-4 dS/m), and none (area with no effect from saline soil in ground level) (0-2 dS/m) with value of 0.01%, 0.01%, 40%, 59.71%, and 0.01%, respectively.

Keywords: remote sensing, electrical conductivity, soil salinity, salt-affected soils.

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INTRODUCTION

Saline soil is a kind of soil with a high level of soluble salt affecting to growth and productivity of plants. It could be noticed from salt stains, i.e., a cluster of salt stains could be seen, especially in drought season when plants often have blast disease and internode shortening due to dehydration and toxicity from Sodium (Na) and Chloride (CI) causing unbalance of nutrients. Saline salt had Electrical Conductivity (EC) of solution extracted from saturated soil from water higher than 2 dS/m at 25°C [1]. The problem of saline soil in Thailand could be found in coastal areas of the central region and northeastern region. It was found that the northeastern part has the highest level of problems with saline soil in Thailand, especially in lowlands like Nakhon Ratchasima, Chiyaphum, Khon Kaen, and Udon Thani [2-4]. Saline soil in the northeastern part is soil with an accumulation of salt from the dissolution of rock salt or underground water with a high amount of salt dissolved in water. Consequently, a rock layer with an accumulation of salt or salt stains on the ground is caused. Salinity levels are various in the same area and salinity is also different in each depth level of soil that can be changed based on seasons [5]. The appearance of saline soil that can be noticed is salt flakes shown on the ground of the land that is normally wasteland without farming or with salt-tolerant weeds like Carissa carandas Linn and Carissa spinarum L., etc. In 2017, it was found that there were 17.8 million rai in salt-affected areas in Thailand 2017 [6] causing some important problems and obstacles against area development that also affected the occupations of local people, especially agriculture on the lower level of growth, and productivity of plants. In addition, it also affected to overall economy, society, and environment of those areas [7].

Currently, Remote Sensing Technology is applied to the survey of natural resources in various dimensions, [8-18] especially salt-affected areas monitoring and test, salinity level test, and distribution of salt-affected areas at ground level, etc. [19-22]. Monitor and testing salinity level and distribution of salt-affected areas at ground level, could be performed through various methods, for example, 1) Using field survey technique in actual areas and collecting soil samples to analyze Electrical Conductivity in the laboratory; and 2) Use Remote Sensing Techniques to perceive the quantity of salt stains and evaluate salinity level [23-26]. However, there are many limitations of field survey technique in actual areas and collecting soil samples to analyze Electrical Conductivity in the laboratory, for example, high budget, long duration, inability to monitor or perform backward prediction on data of salt strains in the past as well as limitation on area size hindering operation in wide areas. Consequently, such monitoring is unable to be performed to be consistent with changes in actual salt-affected areas that are continuously increased based on factors on climate, plants, and rainfall of each region [27-29]. As a result, salinity level monitoring and testing and distribution of salt-affected areas at ground level through Remote Sensing Techniques is considered another alternative that is consistent with natural changes in the environment while helping to save operational expenses. Moreover, it also gives some

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predictive answers for dealing with and managing possible problems caused by saline soil at ground level properly.

This study aims to develop evaluation methods on salinity level and Electrical Conductivity of salt-affected areas at ground level through Remote Sensing Techniques. In Thailand, most researches focus on the estimation of carbon storage in forestry areas and forest parks. Nevertheless, the data collection of carbon storage in fruit orchards has not been brought to focus. Therefore, this research aims to study the amounts of the above-ground carbon sequestration by using remote sensing technology of orchards in Sang Kho sub-district, Phu Phan district, Sakon Nakhon Province in northeast Thailand.

STUDY AREA

The research area of this research was the Mueang Phia Sub-district located in the west of Ban Phai District, Khon Kaen Province (Figure-1) because it was the area with the highest level of saline soil in Khon Kaen Province. The approximate area of Mueang Phia Sub-district is 73.40 km^2 with territory next to the following nearby administrative districts: The northern part is next to Nong Pan Sub-district (Manja Kiri District) and Khok Samran Sub-district (Ban Haet District). The eastern part is next to Ban Phai Sub-district and Hua Nong Sub-district. The southern part is next to the Pueai Yai Sub-district (Non Sila District).

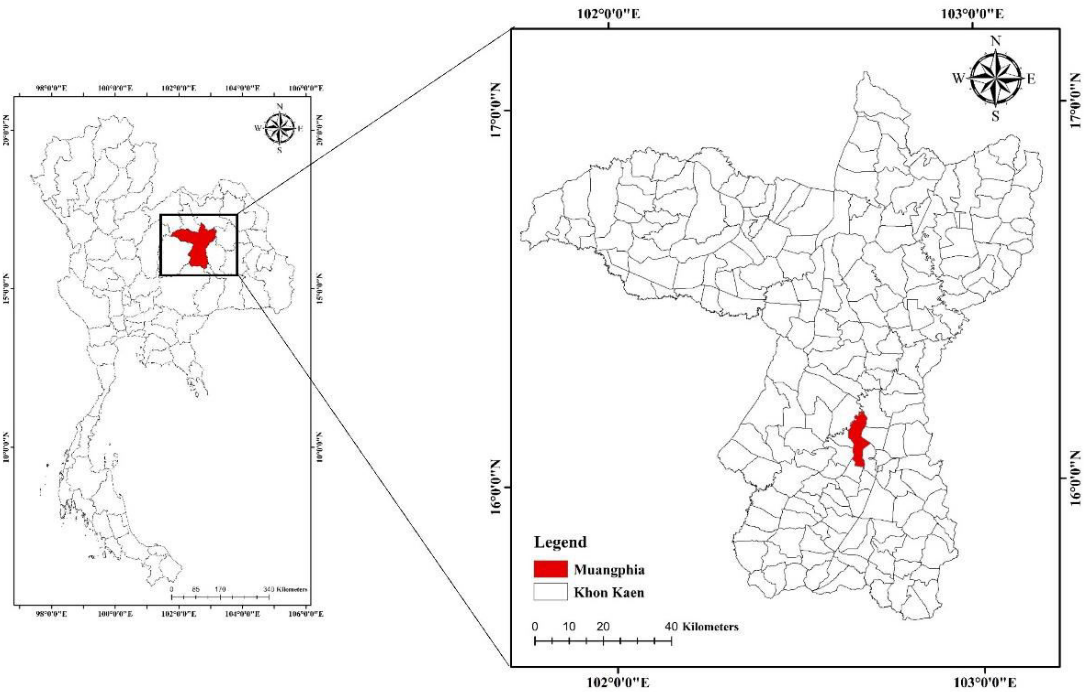

Figure-1. Mueang Phia Sub-district.

MATERIALS AND METHODS

Data Collection

In this research, data obtained from the Landsat-8 satellite, which is a U.S. earth observation satellite, were used. Landsat-8 satellite occupies the same location in orbit every 16 days. The range of photography was 185 km and consisted of 2 types of recording systems, i.e., Operation land Image (OLI) and The Thermal Infrared Sensor (TIRS) with several 11 bands. The pixel size of the visible NIR and SWIR wave was 30 m, the pixel size of the thermal wave was 100 m, and the pixel size of the panchromatic wave was 15 m [30]. Generally, the best period to detect salt on the ground is summer because there is the dissolution of salt during the rainy season. White color will be shown on salt-affected areas. On the other hand, alkaline soil often has a black surface due to an excessive quantity of sodium causing the distribution of organic substances. As a result, data obtained from the Landsat-8 satellite that was recorded on May 5th, 2021, were used.

Indices Used In This Research

Indices used in this research consisted of the Salinity Index (SI), Brightness index (BI), and Normalized Differential Salinity Index (NDSI). Details could be explained as follows:

- Salinity Index (SI): SI as shown in Equation 1 [31] was used for testing the salinity of soil with sensitivity to surface reflection of soil affected by salt or plants in the range of Blue wave and Red wave. SI ranged from 0 to 1 whereas the value close to 0 represented an area with a low level of salt and the value close to 1 represented an area with the highest level of salt.

$$SI = \sqrt{Blue \times Red} \quad (1)$$

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Where;
Blue = Band 2 of Landsat 8 (0.452 - 0.512 µm)
Red = Band 4 of Landsat 8 (0.636 - 0.673 µm)

- Brightness index (BI): BI as shown in Equation 2 [32] was a brightness index used for testing the brightness of the ground. This index was sensitive to the reflection of soil's brightness and the high level of soil's brightness connected with soil's moisture and salt. It was a combination of the range of Red waves and Near Infrared waves. BI ranged from 0 to 1 whereas the value close to 0 represented an area with a low level of salt and the value close to 1 represented an area with the highest level of salt.

$$BI = \sqrt{Red^2 + NIR^2} \qquad (2)$$

Where;
Red = Band 4 of Landsat 8 (0.636 – 0.673 µm)
NIR = Band 5 of Landsat 8 (0.636 – 0.673 µm)

- Normalized Differential Salinity Index (NDSI): NDSI as shown in Equation 3 [33] was used for testing salt strain levels on soil or plants based on the amount of solar radiation reflected from soil or plants in the range of Red wave and Near Infrared wave. NDSI ranged from -1 to 1 whereas a value close to -1 represented an area with a low level of salt and a value close to 1 represented an area with the highest level of salt.

$$NDSI = \frac{Red - NIR}{Red + NIR} \qquad (3)$$

Where;
Red = Band 4 of Landsat 8 (0.636 - 0.673 µm)
NIR = Band 5 of Landsat 8 (0.636 - 0.673 µm)

Field Survey

There are many methods for measuring salinity but the method that is generally preferred is consideration of the intensity of measured salt which Electrical Conductivity (EC) is applied with a unit of intensity as dS/m. Soil's Electrical Conductivity extracted from soil can be measured from dissolution while being saturated with water (Electrical Conductivity at Saturation Extract; Ece) at 25°C. It could be used for evaluating salt content and the influence of salt in soil on the growth and productivity of plants which observed relationship was briefly shown in Table-1.

Table-1. Classification of salinity levels affecting plants [1, 34].

EC (dS/m)	Salinity level	Affecting plants
< 2	None	No effect on plants
2-4	Low level	Affects the growth of plants, not resistant to salt
4-8	Moderate level	Affects the growth of many plants
8-16	High level	Only salt-tolerant plants can grow and produce
> 16	Highest level	Salt-tolerant plants can grow and produce yields

This research was conducted in May 2021 that was the time when the COVID-19 pandemic was severe in Khon Kaen Province hindering the researchers from travelling to collect data in all research areas due to limitations on area access (official letters issued by the government were required by some villages). For this reason, the researchers selected 10 locations of a field survey that could be accessed easily as the case study by using the Electrical Conductivity (EC) of the Hanna brand. For example of a field survey is shown in Figure-2.

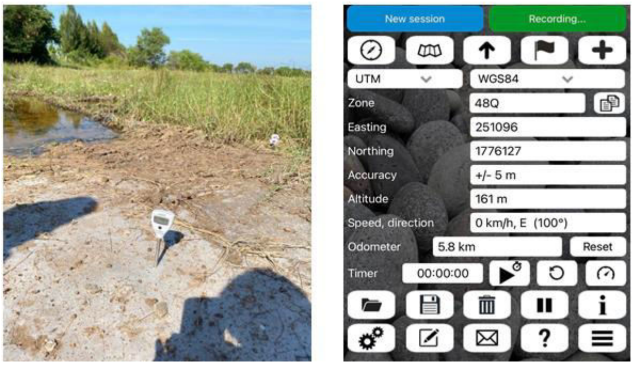

Figure-2. Illustration of an example of field survey.

Simple Linear Regression

This research selected simple linear regression to analyze regression with linear relationship of variables. There was one estimated variable (X) and one response variable. Relationship was represented by a mathematical equation as shown in Equation 5:

$$Y = a + bX \qquad (5)$$

Where;
y = is the dependent variable
x = is the independent variable
a and b = constants

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RESULTS AND DISCUSSIONS

Results of Satellite Data Analysis

Results of satellite data analysis along with 3 formats of spectral indices, i.e., SI, BI, and NDSI, were as follows:

- Results of Data Analysis with SI: Results of data analysis with SI revealed that the lowest value was 0.000, the highest value was 31.960, the mean was 6.133, and StdDev was 6.199. Results of data analysis were classified into 5 ranges (Figure-3), i.e., 0 to 6.392 (none salinity), 6.392 to 12.784 (low salinity), 12.784 to 19.176 (moderate salinity), 19.176 to 25.568 (high salinity), and 25.568 to 31.960 (highest salinity). To analyze data representing the percentage of areas of Mueang Phia Sub-district, Ban Phai District, Khon Kaen Province, with a total area of 73.4 km^2, it was found that the area of the 1st was 3.502 km^2, the area of the 2nd was 37.621 km^2, the area of the 3rd was 25.734 km^2, the area of the 4th was 3.313 km^2, and the area of the 5th was 3.230 km^2.

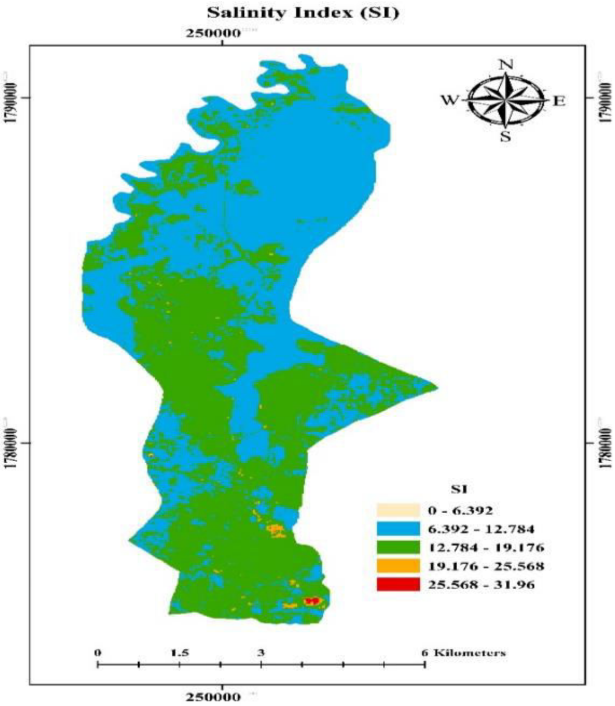

Figure-3. Data Analysis with SI.

- Results of Data Analysis with BI: Results of data analysis with BI revealed that the lowest value was 0.000, the highest value was 51.869, mean was 13.444, and StdDev was 14.197. Results of data analysis were classified into 5 ranges (Figure-4), i.e., 0 to 10.379 (none salinity), 10.379 to 20.758 (low salinity), 20.758 to 31.157 (moderate salinity), 31.157 to 41.51 6 (high salinity), and 41.516 to 41.516 (highest salinity). To analyze data representing percentage of areas of Mueang Phia Sub-district, Ban Phai District, Khon Kaen Province, with the total area of 73.4 km^2, it was found that the area of the 1st was 4.910 km^2, the area of the 2nd was 13.632 km^2, the area of the 3rd was 29.405 km^2, the area of the 4th was 20.923 km^2, and the area of the 5th was 4.532 km^2.

- Results of Data Analysis with NDSI: Results of data analysis with NDSI revealed that the lowest value was -76.786, the highest value was 52.228, the mean was 31.085, and StdDev was 17.792. Results of data analysis were classified into 5 ranges (Figure-5), i.e., -76.786 to -50.986 (none salinity), -50.986 to -25.186 (low salinity), -25.186 to -0.614 (moderate salinity), -0.614 to 26.414 (high salinity), and 26.414 to 52.214 (highest salinity). To analyze data representing percentage of areas of Mueang Phia Sub-district, Ban Phai District, Khon Kaen Province, with the total area of 73.4 km^2, it was found that the area of the 1st was 10.483 km^2, the area of the 2nd was 18.210 km^2, the area of the 3rd was 35.520 km^2, the area of the 4th was 6.267 km^2, and the area of the 5th was 4.920 km^2.

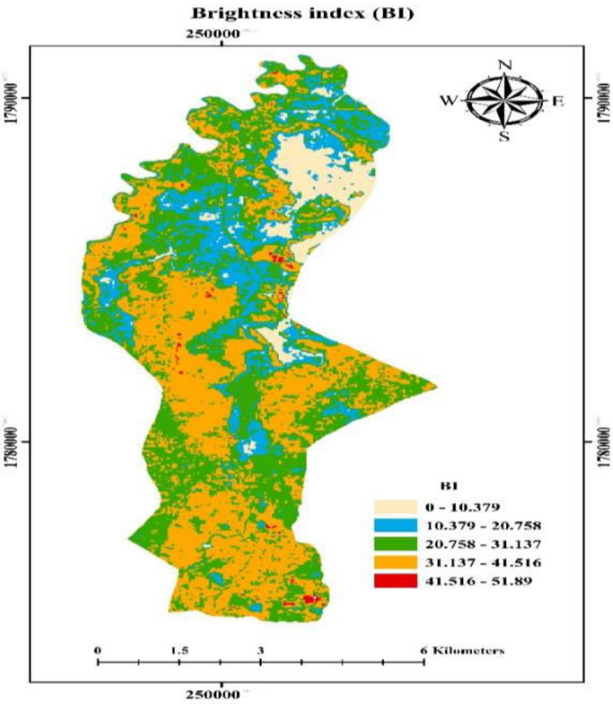

Figure-4. Data Analysis with BI.

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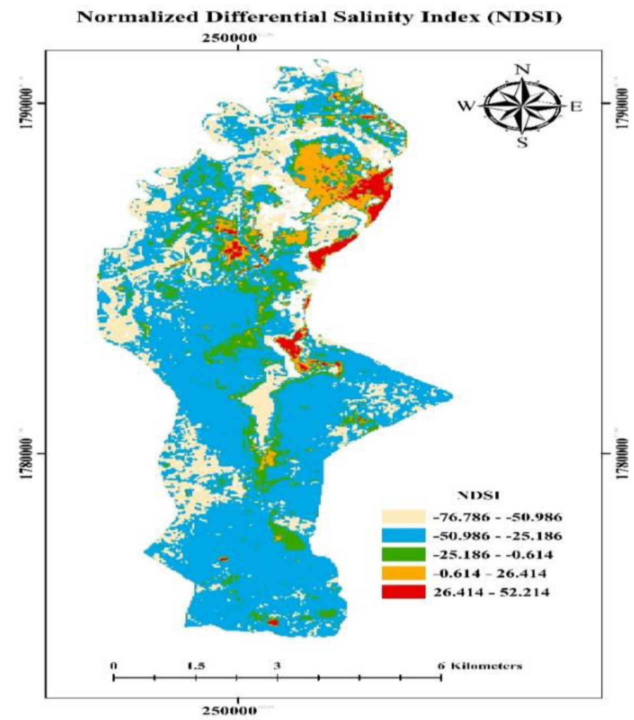

Figure-5. Data analysis with NDSI.

Results of Simple Linear Regression

To find statistical relationship with Simple Linear Regression between 2 variables, i.e., Electrical Conductivity (EC) of soil obtained from field survey and SI, BI, and NDSI at the same location of 10 locations of field survey, results were as follows: Result of analysis on statistical relationship between Electrical Conductivity (EC) of soil obtained from field survey and SI gave an equation, i.e., $y = 0.1833x + 0.8492$ with Coefficient of Determination (R^2) as 0.758 (Figure-6).

The result of the analysis of the statistical relationship between the Electrical Conductivity (EC) of soil obtained from the field survey and BI gave an equation, i.e., $y = 0.0328x + 2.5168$ with Coefficient of Determination (R^2) as 0.124 (Figure-7).

The result of the analysis of the statistical relationship between the Electrical Conductivity (EC) of soil obtained from the field survey and NDSI gave an equation, i.e., $y = 0.0293x + 4.2457$ with Coefficient of Determination (R^2) as 0.733 (Figure-8).

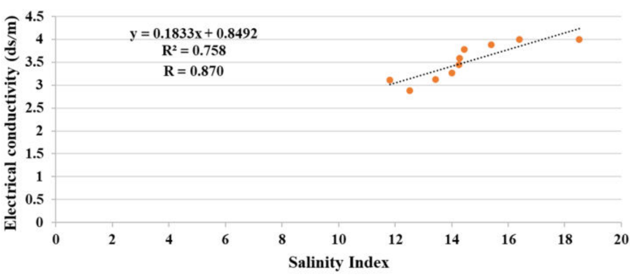

Figure-6. Relationship between SI and EC.

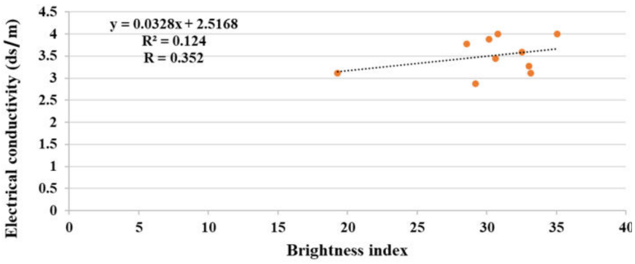

Figure-7. Relationship between BI and EC.

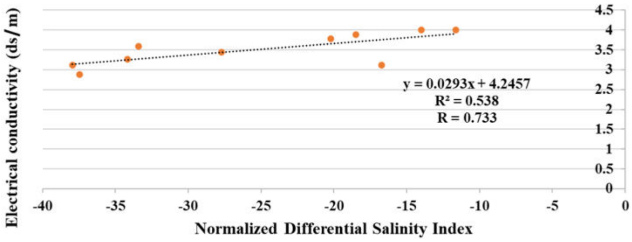

Figure-8. Relationship between NDSI and EC.

Electrical Conductivity (EC) Map of Saline Soil

To make a Saline Soil Map representing the scope of soil's Electrical Conductivity in this study, the salinity level was divided into 5 levels as shown in Figure-6. In Figure-7, the highest level of salinity of soil (> 16 dS/m), high level of salinity of soil (8-16 dS/m), and moderate level of salinity of soil (4-8 dS/m) was highly found in the lower part of Mueang Phia Sub-district, Ban Phai District, consisted of 4 villages, i.e., Ban Du Yai, Village No. 4 and Village No. 11 of Ban Du Yai, Village No. 12 of Ban Kham Rien, and Village No. 10 of Ban Mueang Phia, because such area had sandy soil with low level of abundance and water retention plus with large amount of underground rock salt.

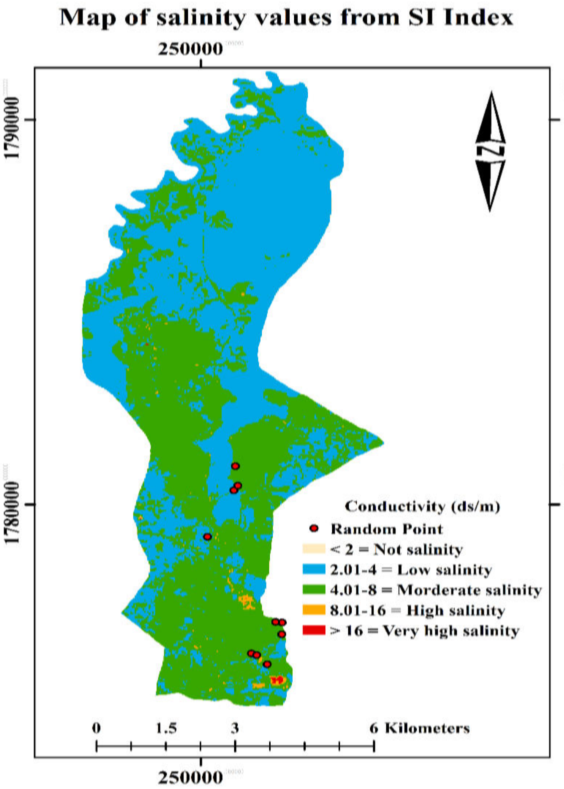

Figure-9. EC map of saline soil.

As a result, there was a distribution of salinity on the ground throughout such areas whereas the upper part of most research areas had low level of salinity and no salinity (2-4 dS/m and < 2 dS/m) consisted of 5 villages as follows: Village No. 5, 6, and 10 of Ban Lawa, Village No. 11 of Ban Du Phoe Tak, and Village No. 13 of Ban Chik Kor. This area switched with areas with high levels of salt and a moderate level of salt consisting of 4 villages, i.e., Village No. 1, 2, and 8 of Ban Mueang Phia, and Village No. 9 of Ban Nong Na Kwan. When considering on size of salt-affected areas, it was found that there were different levels of distribution of saline soil in all research areas, i.e., the area with the highest level of saline soil (>16 dS/m) was around 0.01% of the total research areas, the area with high level of saline soil (8-16 dS/m) was around 0.23% of total research areas, the area with moderate level of saline soil (4-8 dS/m) was around 40% of research areas, the area with low level of saline soil (2-4 dS/m) was around 59.71% of total research areas, and the area with no effect from salt was around 0.01% of total research areas.

CONCLUSIONS

Although the danger of saline soil may not be comparable to earthquakes or landslides, it may cause severe damage to the environment, especially the agricultural environment. Evaluation of salinity and Electrical Conductivity of salt-affected areas at ground level through Remote Sensing Techniques was consistent with the distribution of salt strains in actual areas differently. This could be seen from the analysis of the statistical relationship between soil's Electrical Conductivity (EC) and SI, BI, and NDSI. Consequently, it could be seen that SI gave the most actual value of a relationship with the distribution of saline soil (over 70%) leading to the creation of a linear regression model with a high confidence interval (R^2 = 0.758). Such an equation could be used as a tool to predict soil's Electrical Conductivity in research areas leading to the creation of a Saline Soil Map representing the scope of soil's Electrical Conductivity. As a result, Remote Sensing Techniques were considered as another alternative that was consistent with natural changes in the environment while helping to save operational expenses. Moreover, it also helped to give some predictive answers for dealing with and managing possible problems caused by saline soil at ground level properly. In addition, it was also used as a tool to monitor changes in saline soil in the future.

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