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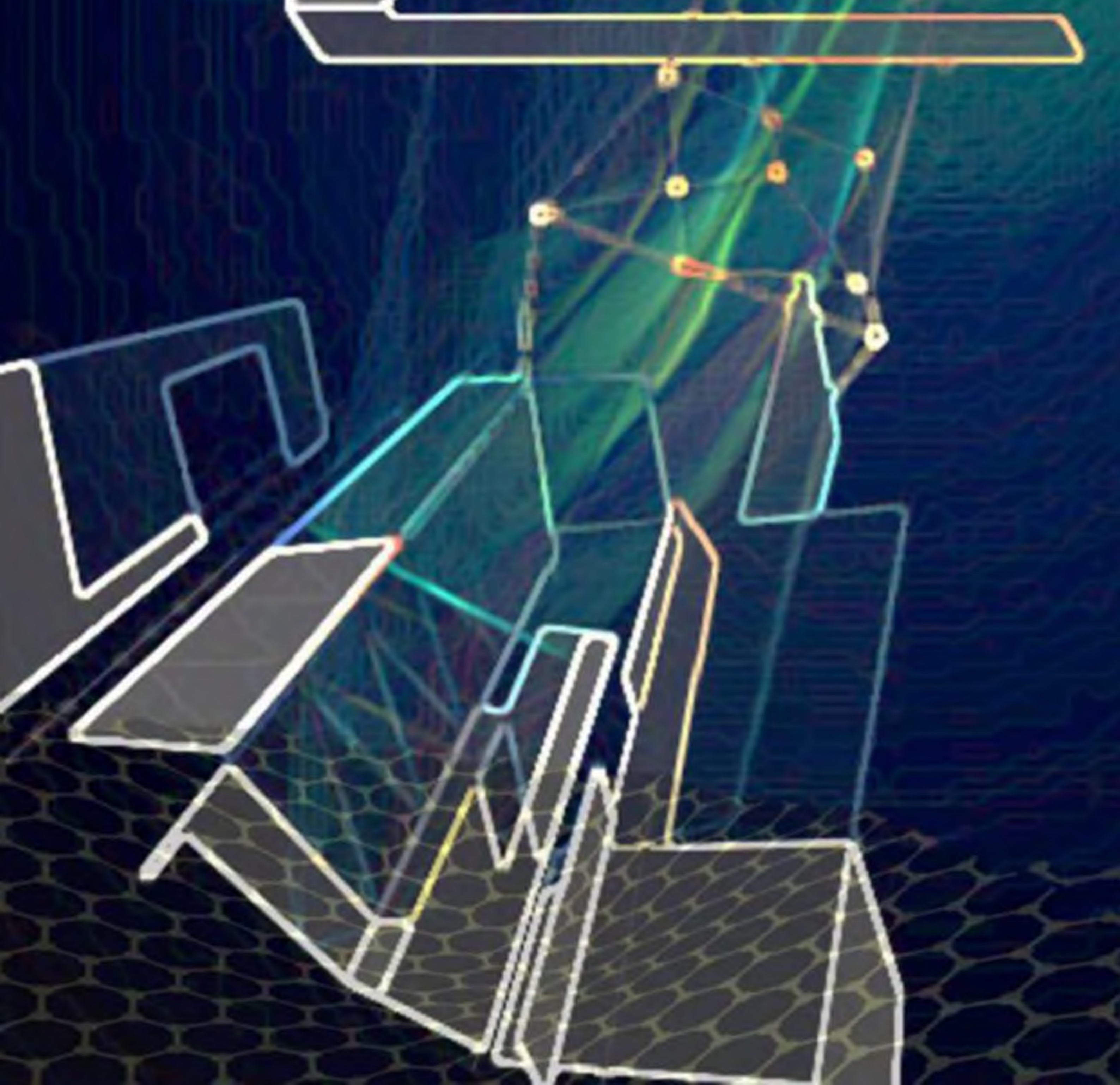

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Mapping the pH and Salinity Values for Paddy Field Area in East Coast Malaysia using Kriging Interpolation Technique

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Abstract
In paddy farming, the condition of soil is one of the important factors to promote a healthy growing plant. Certain pH and salinity levels are required in order to have soil condition which suits the microorganism life and promotes nutrient opportunity to the plant. Currently, the method used to identify the pH and salinity levels of the soil is by embedding a sensor on the soil which requires cost and time. Furthermore, it will only show the pH and salinity values at only one point and there are limitations if the area of interest is difficult to be accessed. In this research, a method was studied by using Kriging interpolation technique to map soil salinity and pH near Kelantan and Terengganu paddy cultivation area. Ground truth data were pre-processed to generate an image model mapping which consists of acidity, neutral, alkalinity and level of salinity at coordinates of interest using ArcGIS Pro software. As a result, the estimated pH and salinity value range were between 3.9 to 5.9 and 0.48 to 0.71 ds m^{-1} respectively. To test the accuracy of the model, analysis of RMSE was done for pH (0.854) and salinity (0.057). This research shall contribute as a preliminary study to model the soil pH and salinity values for monitoring purpose and as an aid to the farmers.

Keywords
pH; Salinity; Kriging; ArcGIS; Paddy

1 Introduction

Paddy planting is a crucial crop in Asia. In Asian countries, paddy or rice is a staple food. The Asia-Pacific region produces and consumes more than 90% of the world's rice. For the last 30 years, Malaysia imports roughly 30% to 40% of its annual rice demand and will probably continue as a net importer of rice[1] in the years to come. Thus, to guarantee national food security, it is important to increase paddy production in Malaysia.

The decrease in paddy production is affected by several factors such as soil quality deteriorates, drainage and pests. Soil salinity is one of the soil conditions which occurs when there is overuse or misuse of irrigation without drainage facilitated water retention[2]. The effect of soil salinity is a serious issue as it affects 20% and 50% of record yields. Addition of microorganisms can be one of the methods to overcome the drawback of high soil salinity[3].

Paddy is a tropical climate cultivation crop. However, due to the tropical climate especially in the East Coast Region which experiences 5080 mm of annual rainfall[4], water moving throughout the soil leaches the essential nutrients such as Calcium (Ca) and Magnesium (Mg) along with the soil. Furthermore, the soil is supplanted by acidic elements such as Aluminum (Al) and Iron (Fe). As such, the soil will be more acidic when they are formed under high rainfall conditions than those formed under dry conditions[5]. A research study by Shrivastava & Kumar (2015) observed the correlation of acidic soil versus paddy crop yield. The data was collected at an acidic paddy field i.e. pH 3.76 in Merbok, Kedah. From the research, the paddy yield increased when compost treatment was made to the soil, as the soil pH increased to 6.76. Therefore, soil pH influenced crop development and its yield where the most favourable for paddy cultivation is between the range of pH 4 and 8[7].

As salinity and pH of the soil greatly affect the crop's yield, it is important to accurately measure both values before taking actions to modify the soil condition. The current practice of determining salinity and pH value is by embedding sensors or experimental data[8]. This method requires cost and time.

Lately, utilization of satellite technology has been a topic of interest, for a larger spatial mapping. The pH and salinity values can be identified by processing spatial data from the satellite at the coordinates of interest. Recent research by Ghazali et al. (2020) mapped soil pH, salinity and moisture by analysing the Landsat 8 satellite images, ground truth data, analysis of lab data and statistical computation. A soil pH index has been developed on bare soil and paddy leaf models. Both proposed models detected 4.49-7.59, 4.66 in the bare soil model and 6.62 in the paddy leaf model. During the planting period, the soil pH in the bare soil model decreased to 2.12-6.47 while the paddy leaf model increased to 4.49-7.59 with RMSE 1.40 and PRMSE 24% of accuracy.

In another study by Ghazali et al. (2017), an experimental area of paddy cultivation located over the industrial zone in Majalaya Subdistrict, Bandung Region was studied to predict soil pH values. Information for this study area was collected using a combination of remote sensing which were Landsat 8 imagery and regression model to predict the soil pH distribution and to anticipate the soil quality.

Shit et al. (2016) analysed spatial variability data, a mix of traditional analytical techniques and geostatistical techniques. In November 2014, 32 soil specimens were collected in the field area by random sampling in Medinipur Sadar block of Paschim Medinipur district in West Bengal, India. Kriging interpolation was used for direct visualization of soil properties. The topography, climate, soil characteristic, parent material, and other natural factors are influenced by structural factors in the spatial distribution of electrical conductivity, pH and organic carbon. Six soil properties semivariograms matched the exponential curve and the root mean square error values were nearly zero.

From literature, it was found that there are two methods to map pH and salinity values using either Kriging or satellite images. These two methods have its own advantages and disadvantages. In terms of accuracy, satellite data indicates lower accuracy due to low resolution of the satellite image. Hence, this research focuses on investigating Kriging interpolation technique to estimate the pH and salinity values in Peninsular Malaysia. To the best of author's knowledge, there is no published result on spatial mapping for pH and salinity data for East Coast Malaysia region at present.

2 Methodology

Figure 1 shows the overall flow chart of the research methodology. First, the collection of data was made based on ground truth data at the point of interest. The data was pre-processed using Kriging interpolation technique to obtain the pH and salinity image model. The measurement of the ground truth data was done by calibrated sensors.

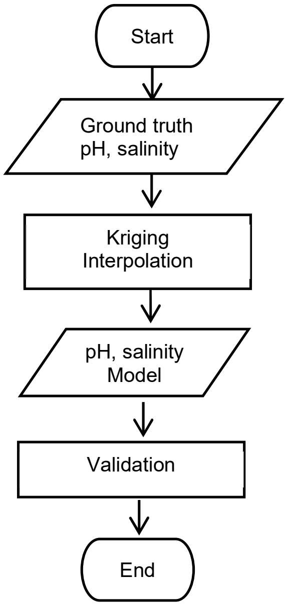
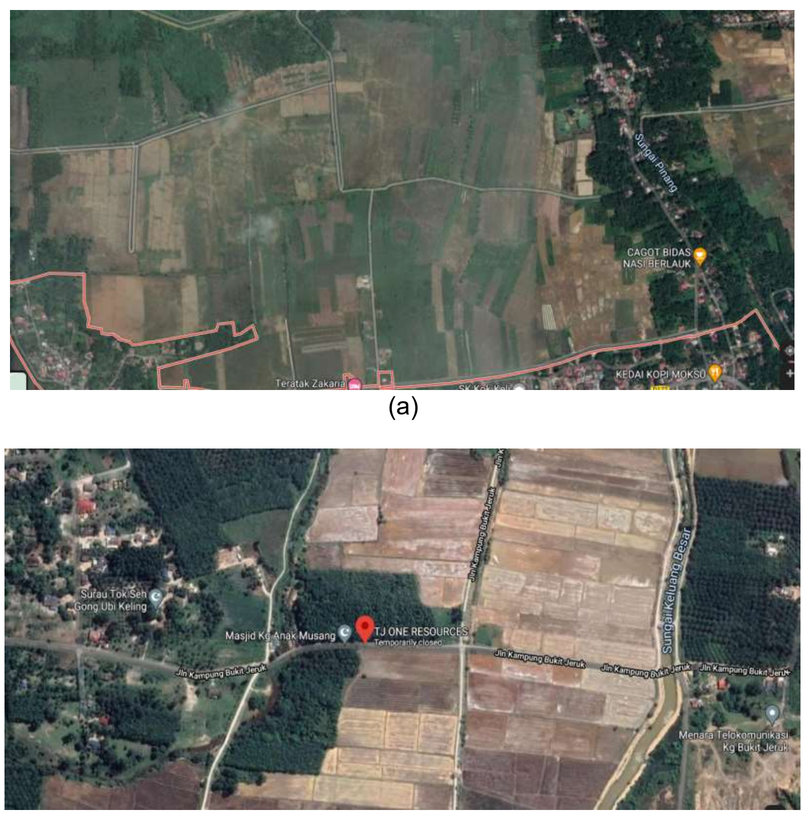


Figure 1. The process flowchart of the overall methodology

2.1 Data collection area

The research of soil salinity was conducted in selected areas of Kampung Kok Keli. It is a village located in Tumpat, Kelantan. Kelantan is the state in the east coast of Malaysia with an area of about 14,922 km². It is situated in the northeast of peninsula Malaysia, facing the South China Sea and neighbouring the province of Narathiwat, Thailand. The geographical coordinates of the research area are approximately at 6.183333N, 102. 216667E. Meanwhile, the soil pH paddy cultivation study was conducted at Kampung Bukit Jeruk, Besut Terengganu. The coordinates are at 5.689294N and 102.627095E. The area is lowland and covers an area of 150 hectares. This area is also considered as a premium class area because it produces paddy twice a year which are in June and December. Figure 2 shows the map of the study location.



(b)

Figure 2. Maps of the study location:

(a) Kampung Kok Keli, Kelantan, and (b) Kampung Bukit Jeruk, Terengganu

2.2 Ground Truth Measurement

Ground truth measurement was carried out in this research to measure on-site pH and salinity values using a pH and salinity sensor as shown in Figure 3. The sensors were embedded (5-10 cm) in the soil which was free from any interference such as dry leaves, rubbish, grass, and others. It is important to sprinkle some water on the soil surface if the soil is too arid or contains too much fertilizer and be left for 25 to 30 minutes before testing the soil. In addition, it is a good practice to thoroughly clean the metallic surface probe with a piece of tissue or a clean cloth. All the locations where the data are being measured were recorded based on GPS locator in terms of its longitude and latitude. Eight measurements for both pH and salinity were collected. This project selected three days from December 2020 to January 2021 to model the pH and salinity values during day time. Table 1 summarises the ground truth data.

(a)

(b)

Figure 3. (a) pH, and (b) salinity sensor for ground truth data

2.3 Soil pH and Salinity Image Mapping Model

To create the soil pH and salinity mapping model, the first step was to identify the surface of pH and salinity values from the point of observations or coordinates. The next step was to add the data as the points which were used to create a new point feature layer with *x* and *y* coordinates (location) or known as Make XY Event layer in the Data Management tools of ArcGIS Pro.

These data were then used to perform Spline interpolation or Kriging method in the Space Analyst. Kriging indicates that there is a spatial correlation in between distance or direction of the sample points which could be used to clarify surface variation. The formula for Kriging interpolation[12] is shown in equation (1):

$$Z^{*}(So)=\sum_{i=1}^{N} \lambda i Z(Si) \qquad (1)$$

where, Z^* (*So*) is the predicted value at location So, $Z(Si)$ is the value measured at the location of the i^{th}, λi is an uncertain weight for the value measured at its position and N represents the number of values measured. Next was to map a visual indicator of soil salinity and pH at the coordinates by using the raster calculator[10]. Raster form was used for a non-linear art image. It is the best way to depict non-line art images, since these usually involve subtle chromatic measures, ambiguous lines and shapes as well as complex composition. The flow chart to create the soil pH and salinity mapping using ArcGIS Pro is shown in Figure 4.

Table 1. Ground truth measurement data

Data type	Description	Unit
Salinity	Salt content which is measured by electrical conductivity	dS m^{-1}
pH	Indication of acidity or alkalinity	range between 1-14

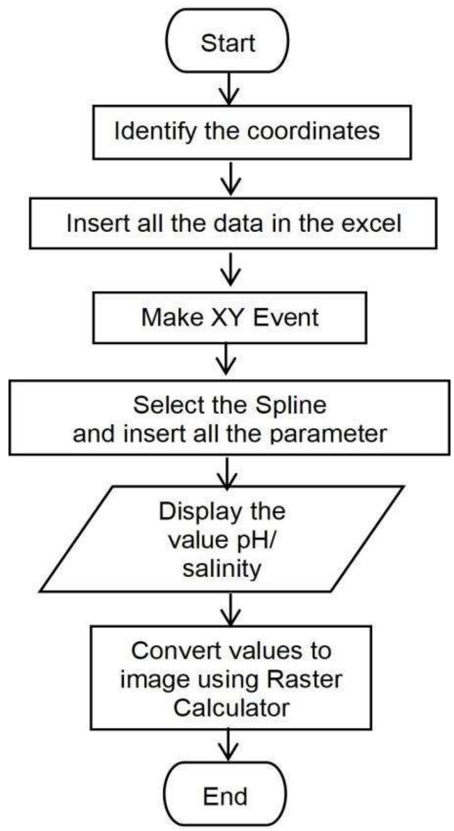


Figure 4. The process flowchart of soil pH and salinity mapping model

2.4 Model Validation

In this study, calculation of the root mean square error (RMSE) is shown in equation (2) and was done to measure how well the salinity and pH model performed.

$$\text{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(X1 - X2)^2} \qquad (2)$$

where n is the total observation of data, $X1$ is the observed data value, $X2$ is estimated data value, i=1 symbolizes the measure from the first to the last sample of data and n is the total amount of sample data.

3 Results and Discussion

3.1 Ground Truth Data Measurement

The ground truth data were measured using calibrated sensors at different locations and days. All data were taken during day time and the measured data are shown in Table 2 and 3 for both salinity and pH respectively.

3.2 Estimation of Soil pH and Salinity Mapping Model

Estimation of pH and salinity mapping model was based on the eight points samples. The range of soil pH readings was within 3.0-8.5 as shown in Figure 5. The red colours represent more acidity, the yellow colours represent moderate acidity and green colours represent the combination of low acidity, neutrality and low alkalinity.

Meanwhile, the estimation mapping model for the soil salinity index is depicted in Figure 6. The colour of the model indicates the different values of salinity i.e., between 0.397 dS m^{-1} to 0.758 dS m^{-1}. It can be observed that the blue colour contour shows the least amount of salinity level which is 0.397 dSm^{-1}.

3.3 Model Accuracy

From Table 4 and Table 5, overall, it can be observed that the highest RMSE value is 0.83 for pH and 0.05 for salinity. The RMSE for salinity is low[11], however for pH, the RMSE is quite high. Thus, it shows that our method is reliable for salinity but need some improvement for estimating the pH. Factors such as environment, topology and sample distance can be the reasons for the low model accuracy[11].

Table 2. Salinity measured values

Date	LONGITUDE_X	LATITUDE_Y	Salinity (dS m^{-1})
25/12	102.211387	6.176426	0.503
25/12	102.211346	6.17666	0.452
25/12	102.211136	6.176679	0.642
3/1	102.211113	6.176399	0.573
3/1	102.210948	6.176655	0.397
3/1	102.211219	6.176744	0.677
9/1	102.21148	6.176456	0.584
9/1	102.210639	6.176597	0.758

Table 3. Soil pH readings

Date	LONGITUDE_X	LATITUDE_Y	pH
28/12	102.6265852	5.6929561	3.1
28/12	102.6286128	5.6927542	3.8
28/12	102.6264711	5.692447	4.5
3/1	102.6284373	5.6922188	4.8
3/1	102.6262692	5.6913849	5.1
3/1	102.6284109	5.6911128	6.4
9/1	102.6258830	5.6899279	6.7
9/1	102.6282266	5.6896909	7.1

Figure 5. Estimation of soil pH image mapping

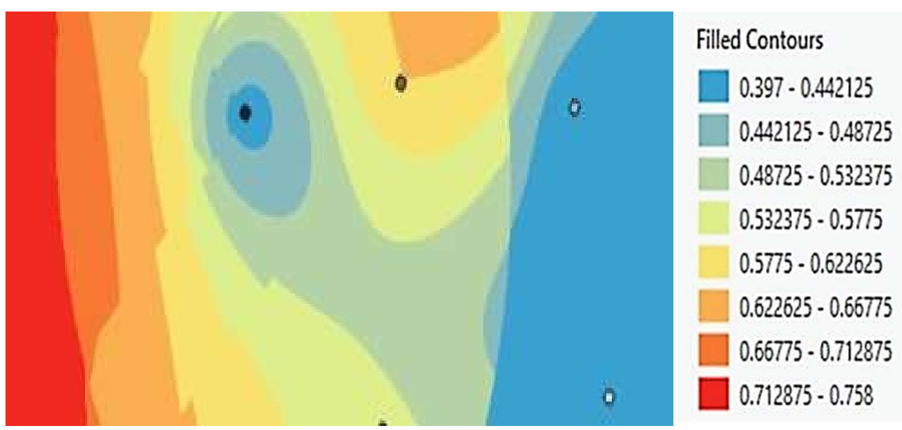


Figure 6. Estimation of soil salinity image mapping

Table 4. RMSE of estimated soil pH value and ground truth data

Longitude	Latitude	Ground Truth	Estimated pH	Error	RMSE
102.6265852	5.6929561	3.1	3.9	0.8	0.854
102.6286128	5.6927542	3.8	4.2	0.4	
102.6264711	5.6924470	4.5	5.5	1	
102.6284373	5.6922188	4.8	5.2	0.4	
102.6262692	5.6913849	5.1	3.9	1.2	
102.6284109	5.6911128	6.4	5.8	0.6	
102.6258830	5.6899279	6.7	5.9	0.8	
102.6282266	5.6896909	7.1	5.9	1.2	

Table 5. RMSE of estimated soil salinity index and ground truth data

Longitude	Latitude	Ground Truth	Estimated Salinity	Error	RMSE
102.21137	6.17646	0.503	0.487	0.016	0.057
102.211346	6.17666	0.452	0.442	0.01	
102.211136	6.176679	0.642	0.623	0.019	
102.211113	6.176399	0.573	0.532	0.041	
102.210948	6.176655	0.397	0.432	0.035	
102.211219	6.176744	0.677	0.668	0.009	
102.21148	6.176456	0.584	0.442	0.142	
102.210639	6.176597	0.758	0.713	0.045	

4 Conclusion

This paper has developed the mapping model of soil pH using Kriging interpolation technique for paddy fields in Kelantan and Terengganu. The accuracy of the model was based on RMSE value, where the highest value for pH and salinity is 0.854 and 0.057, respectively. This indicates that a reliable model was generated for salinity using Kriging interpolation technique. Some improvements should be made to estimate the pH value, such as revising the method for ground truth data. Future recommendation may investigate the reliability of the result at different times, such as during monsoon season as the research area is always hit by flood every year as well as having a model which estimated pH and salinity value for a vegetative data area.

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