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Application of Remote Sensing and GIS Technology in Mapping Partition Saline Intrusion to Paddy Land: A Case Study at Phu Vang District, Thua Thien Hue Province

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Abstract: Adapting and restricting salinity intrusion in Vietnam is being concerned by more researchers as well as the local authorities. This study aimed to use remote sensing and geographic information system (GIS) technology for mapping paddy areas and salinity intrusion in spring crop 2015 at Phu Vang district, thereby helping precondition for assessing and monitoring changes in salinity intrusion to serve for salinization management in study area. Based on acquisition imagery, land use map and normalized difference vegetation index (NDVI) were extracted to interpolate the salinity of area by combining the laboratory analysis of collected soil samples from the field. The result showed that there were 1,067.107 ha of salinity land area accounting for 10.04% of the rice land in Phu Vang district, where the moderate salinity level was 180.67 ha and low salinity level was 866.431 ha. The salinity rice land was mainly distributed in Vinh Ha commune, Phu An commune and Phu Dien commune. The salinity in this area ranged from 0.4 mS/cm to 1.41 mS/cm and the moderate salinity was approximately 0.9 mS/cm. Besides, this research also showed that the salinity (electrical conductivity) and the development of vegetation (NDVI) were closely related with each other up to 61.4%.

Key words: GIS, remote sensing, normalized difference vegetation index, salinity intrusion, paddy land.

1. Introduction

Nowadays, salinity intrusion is becoming more complicated and has big impact on agricultural production as well as the life of the residents [1, 2]. Therefore, there were several researches which focused on salinity done recently in different provinces along the coastal regions of Vietnam [3, 4]. Annual survey showed that the district's salinity of coastal soil has been significantly increasing, which adversely affects cultivation, husbandry and the life of local residents [5].

The situation requires local authorities having various solutions to monitor and forecast for salinity intrusion assessment. Mapping the status of salinity intrusion at different period could be considered as an effective method for monitoring any changing, thus help decision-makers assess the extent of development and timely direct interventions. Based on salinity intrusion map, the affected areas could be detected by the characteristics of soil, thereby identifying the extent of the effects of salty entry to the cultivated species. However, it would be time consuming and costly, if it is done by traditional method, such as collecting a large numerous of salinity soil samples, laboratory analysis, statistics analysis, etc.. Therefore, remote sensing technology has created a revolution for researches in recent years. With the advantage of being able to provide full image of the Earth surface,

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it is considered as an appropriate and effective tool in identifying suitable cropping pattern—the factor that shows the attributes and salinity of soil and water, as well as being directly affected by salinity intrusion [6, 7]. In addition, the geographic information system (GIS) with the ability to overlay multiple map layers helps to effectively assess and analyze current salinity intrusion situation [8]. Salinity intrusion partition mapping will serve as basis for state agencies to improve land management and use. Being a coastal district in the Central region, salinity intrusion situation in Phu Vang is the concern of villagers as well as a pressing issue for local authorities. This article aimed to study the application of GIS and remote sensing technology in salinity intrusion partition of paddy land in Phu Vang district, Thua Thien Hue province.

2. Methodology

2.1 Study Area

Phu Vang is a low-lying coastal plain within the Tam Giang-Cau Hai lagoon system and locates to the Northeast of Thua Thien Hue province, with total natural area of 27,824.48 ha, covering 5.53% total natural area of Thua Thien Hue province (Fig. 1). According to statistics of year 2015, agricultural land covered an area of 12,182.23 ha, accounting for 44% of the total natural area, of which land for agriculture production occupied an area of 8,406.23 ha (69%). Phu Vang district has being one of the most vulnerable regions to climate change, especially to sea level rise, drought and salinity intrusion. Recently, the affected agricultural areas by salinity have been increased dramatically.

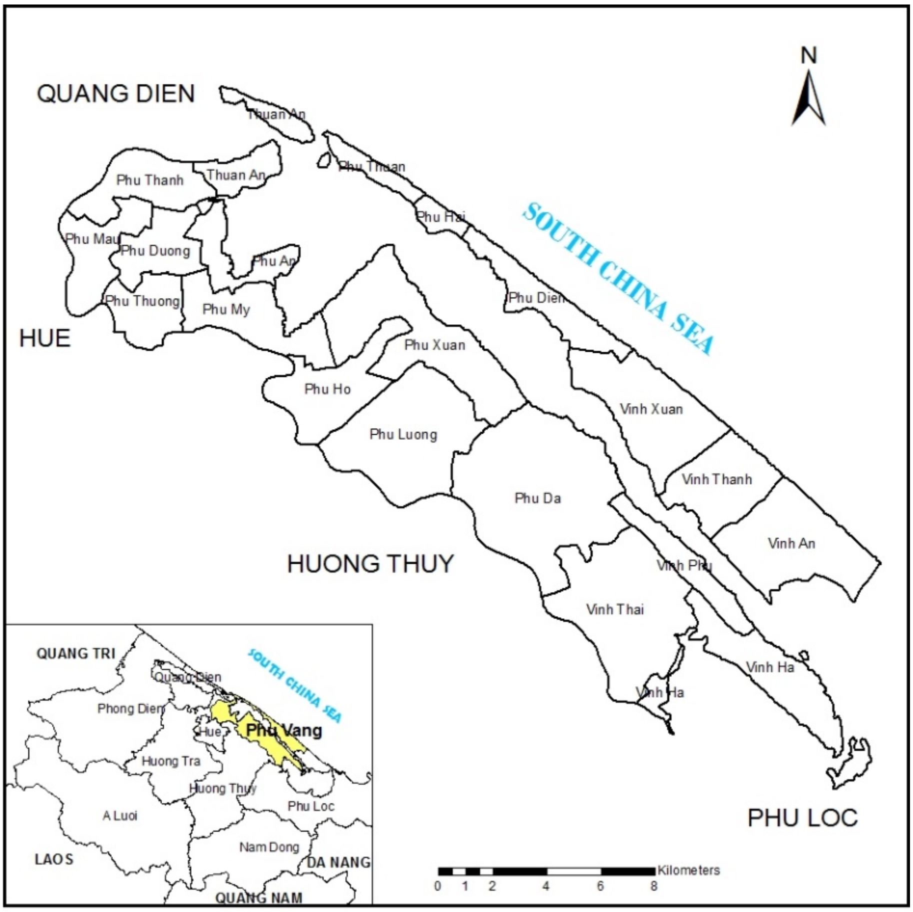

Fig. 1 Location of Phu Vang district.

2.2 On-Site Sampling Survey

For on-site sampling method, sampling sites should be accurately and thoughtfully selected in order to optimize traveling and avoid going into areas with difficult terrain, thus making it more difficult for actual sampling. Besides, samples selected must be large enough to differentiate from other samples. For this research, 60 samples were selected from paddy rice field in communes and town belonging to Phu Vang district and nearby Tam Giang-Cau Hai lagoon, including Phu Thuan, Phu Hai, Phu Dien, Vinh Xuan, Vinh An, Vinh Hai, Vinh Thai, Vinh Phu, Phu Da, Phu Xuan, Phu My, Phu An, Phu Thanh and Thuan An.

2.3 Classification of Remote Sensing Images Using ENVI Software

To conduct partition of salinity intrusion map in paddy area at Phu Vang district, Landsat 8 satellite images were downloaded from Earth Explorer (http://earthexplorer.usgs.gov). The images cover the first eight months of 2015 based on Phu Vang district's 2015 seasonal calendar, in which winter-spring season is from January to April and summer-autumn season is from April to August according to Gregorian calendar (Table 1). Although the average cloud coverage percentage of some images is high, there is almost no covered cloud in study area. Therefore, they are appropriate to use for conducting research. After downloading, image channels were combined and cropped to the boundary of Phu Vang district, Thua Thien Hue province.

2.3.1 Unsupervised Classification

In this method, image pixels are automatically distributed into layers based on several homogeneous usage spectrum attributes, using group classification technique. This method is used when entities recorded on the images are unknown or unfamiliar, and it also helps avoid subjective human errors.

2.3.2 Supervised Classification

Supervised classification requires a sample area to be selected as a criterion for classification. From the selected samples, computer will identify pixels that have the same features on reflection spectrum. Then comparison algorithms are run to evaluate whether a specific pixel is qualified to be assigned to a layer. The algorithm used in supervised classification is maximum likelihood. This method assumes that spectrum band with standard distribution will be classified into layers with the highest likelihood. The calculation is not based only on the distance, but also on the gray-scale variation trend of each layer.

2.4 Determining the Normalized Difference Vegetation Index (NDVI)

NDVI is used to demonstrate and monitor vegetation distribution at Phu Vang district. NDVI is calculated based on the reflectance difference of near-infrared band (NIR) and red band of Landsat image, as following Eq. (1):

$$NDVI = \frac{r_{NIR} - r_{red}}{r_{NIR} + r_{red}} \quad (1)$$

Table 1 Landsat 8 images used in the research.

No.	Image name	Cloud cover (%)	Date acquired
1	LC81250492015024LGN00	0.30	24/01/2015
2	LC81250492015056LGN00	10.36	25/02/2015
3	LC81250492015088LGN00	25.77	29/03/2015
4	LC81250492015120LGN00	9.83	14/04/2015
5	LC81250492015136LGN00	26.24	16/05/2015
6	LC81250492015168LGN00	12.34	16/06/2015
7	LC81250492015232LGN00	48.85	03/07/2015
8	LC81250492015264LGN00	15.7	20/08/2015

where, r_{NIR} and r_{red} stand for the spectral reflectance measurements acquired in the near-infrared and red (visible) regions, respectively.

NDVI values range from +1.0 to -1.0, but values less than 0 typically do not have any ecological meaning, so the range of the index is truncated to 0.0-1.0.

After NDVI values have been processed and calculated, the sequence images are aggregated using maximum value composite (MVC) method. In this method, the highest combined values of pixels in the input images are used to determine the output. This will correct, remove or reduce pixels whose value is interpreted as clouds (absolute value of NDVI is smaller than or approximately equal to 0), or pixels affected by system differences or other causes that may decrease the value of NDVI compared with reality.

2.5 Accuracy Assessment

It is needed to assess the accuracy of extracted map and give evidence for implementing the next steps. In this study, the Kappa coefficient (K) was used to calculate the accuracy of classification result. The K value ranges from 0 to 1 and indicates the proportional reduction of error, done by a factor completely random classification [9]. Kappa index is calculated by the following Eq. (2):

$$K = \frac{N \times \sum_{i=1}^{r} x_{ij} - \sum_{i=1}^{r} (x_{i+} \cdot x_{+i})}{N^2 - \sum_{i=1}^{r} (x_{i+} \cdot x_{+i})} \qquad (2)$$

where, x_{ij}: number of counts in the ijth cell of the confusion matrix; N: total number of counts in the confusion matrix; x_{+i}: marginal total of column i; x_{i+}: marginal total of row i. The value of K lies between 0 and 1, where 0 represents agreement due to chance only and 1 represents complete agreement between the two data sets.

2.6 Laboratory Analysis of Soil Samples

Coordinates of sampling sites were taken using GPS, and then soil samples were collected and analyzed in the laboratory. The soil samples were dried and then large aggregates were crushed by 0.1 mm size. After that, 5 g of soil sample was added to 20 mL of distilled water in jar. The mixed stuff in the jar was shaken before measuring the salinity by electrical conductivity (EC) device. The salinity level based on EC value was determined according to standard of the United States Department of Agriculture (Table 2).

2.7 Analyzing and Processing Survey Data

Linear regression analysis was used to determine the relationship between extracted NDVI on Landsat images (independent variable) and actual EC salinity index (dependent variable), as Eq. (3):

$$y = \mathrm{a}x + \mathrm{b} \qquad (3)$$

where, y = actual EC value; x = NDVI; a, b are the coefficients of linear equation.

In addition, Pearson correlation coefficient was identified for two variables x, y from n samples, as Eq. (4):

$$r = \frac{\sum_{i=1}^{n} (x_i - \bar{X})(y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{n} (x_i - \bar{X})^2 \sum_{i=1}^{n} (y_i - \bar{Y})^2}} \qquad (4)$$

where, $\bar{X}$ and $\bar{Y}$ are the medium value of the variables x and y, respectively. If positive ($r > 0$), the two variables x and y have the same variation in one

Table 2 Salinity level based on EC value.

No.	EC value (mS/cm)	Salinity level
1	< 0.4	No salinity
2	0.4-0.8	Low salinity
3	0.8-1.5	Moderate salinity
4	> 1.5	High salinity

Data according to the United States Department of Agriculture.

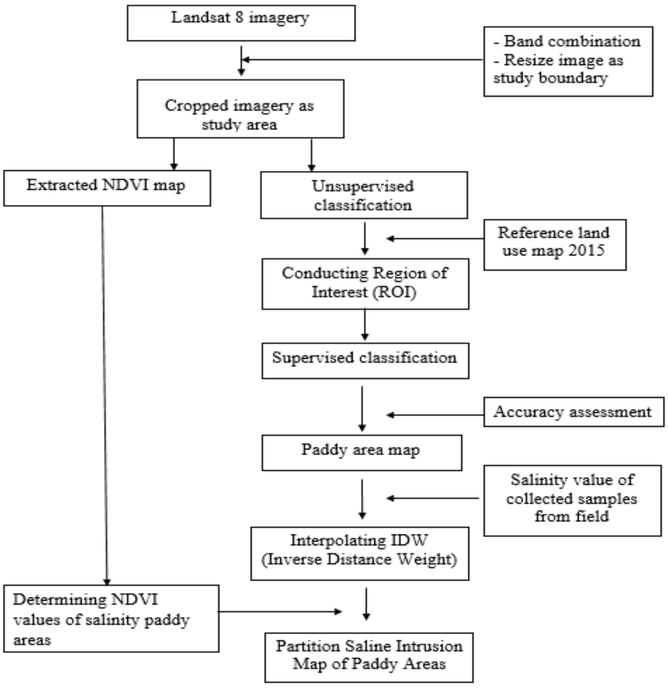

Fig. 2 Frame work of methodology.

direction; if negative ($r < 0$), x and y are reversed, i.e., when x increases, y decreases. If $r = 1$ or $r = -1$, the relationship of x and y is determined, which means that for any value of x, the value of y can be determined. If $r = 0$, the two variables x and y are completely independent, with no relation with each other. The r value is categorized as follows: low correlation ($0.1 \le r < 0.3$), medium correlation ($0.3 \le r < 0.5$) and high correlation ($r \ge 0.5$).

The methodology of mapping partition saline intrusion of paddy area in Phu Vang district is presented in Fig. 2.

3. Results and Discussion

3.1 Mapping Rice Land Partition in Phu Vang District

After images were cropped to the research area, NDVI was then calculated for each image. Then these NDVI images together formed a sequence of NDVI images in order to calculate the mean value. NDVI sequence was created from eight satellite images taken from November 24 to August 20, 2015. To increase accuracy for image analysis, unsupervised classification therefore was used in combination with ISODATA method to classify different spectrum layers of different soil types based on NDVI index. The result of unsupervised classification based on sequence images is presented in Fig. 3.

Based on the results of unsupervised classification method, NDVI index of different soil layers was then analyzed. Results showed that the 5th layer had the highest NDVI value during April and May, then declining (Fig. 4). Combining with practical research, it was found that this is the rice-soil layer, mainly two-season rice.

After studying the NDVI fluctuation of one-season rice and two-season rice in the research area, interpretation key was created for four layers of land use, including one-season rice, two-season rice, hydrology and other land. From the selected samples, supervised classification was conducted using maximum likelihood algorithm, then 240 samples were randomly selected and classified to evaluate accuracy. Evaluation of four layers of land use had overall accuracy of 82.9%, and Kappa coefficient was 0.804. This is considered highly acceptable values for optical remote sensing image classification. Rice land

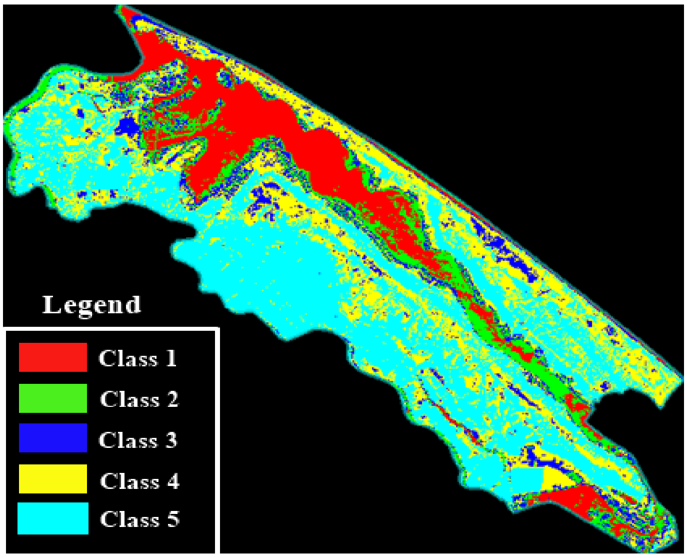

Fig. 3 Unsupervised classification results based on Landsat imagery.

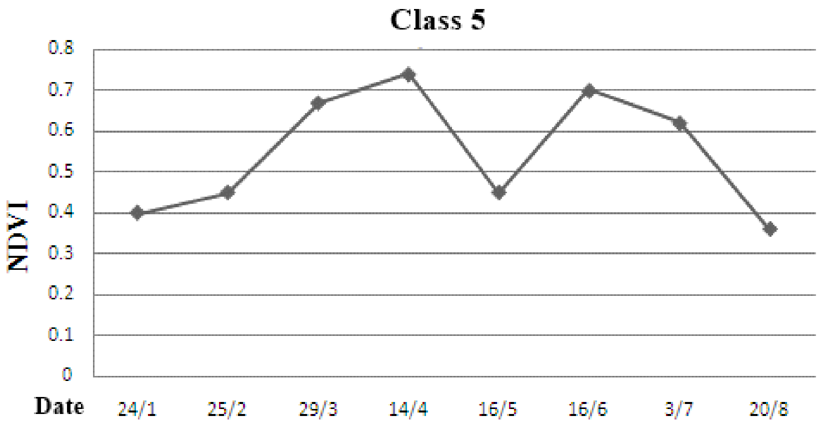

Fig. 4 The NDVI value in unsupervised classification.

partition map of Phu Vang in 2015 was edited using Mapinfo software as shown in Fig. 5.

The rice land partition map of Phu Vang district in 2015 showed that the area of one-season rice was 1,401.96 ha and concentrated mostly in Phu Dien, Vinh Ha and Phu An communes. The area of two-season rice was 8,539.39 ha, which covered most areas of the district with concentration in Phu My, Phu Ho, Phu Luong, Phu Da and Vinh Thai communes.

3.2 Zoning Salinity Areas for Sampling

Zoning and identifying salinity rice land was conducted using rice land partition map of Phu Vang district and with inputs from agricultural officers of Phu Vang district.

After zoning salinity areas on rice land partition map, soil samples were collected and coordinates of sampling sites were recorded using GPS. In addition to samples collected from zoned areas, more samples were collected from other one-season rice land further away from the lagoon in order to compare their salinity. Locations of sampling sites are shown in Fig. 6.

Test results of soil samples collected from zoned area based on their NDVI index shown on map showed that most of the samples were one-season rice land concentrated mostly around the lagoon. Salinity areas were affected by many environmental factors,

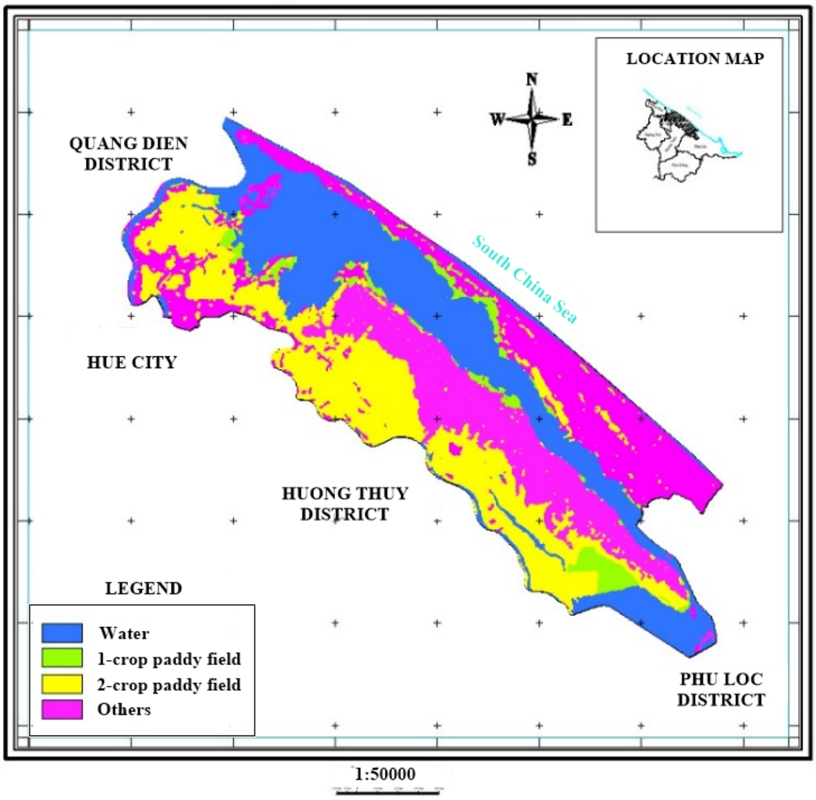

Fig. 5 Distribution of paddy rice at Phu Vang district.

including topography, method of cultivation, tradition, purpose of land use and hydrology, etc.. Salinity level of each area varied greatly, as shown in Table 3. The results showed that the salinity values fluctuated from 0.43 mS/cm to 1.41 mS/cm. As can be seen, low-lying areas, or areas near shrimp ponds, brackish or salty water fish ponds had high salinity, typically in Vinh Xuan, Phu Xuan and Phu Dien communes.

Sampling and calculation of EC value in salinity areas were preliminary based only on image analysis, NDVI value and inputs from experts. Therefore, it was not possible to measure salinity level or the extent of salinity intrusion for the whole area. In order to identify the extent of salinity intrusion and salinity level of areas surrounding the sampling sites, the calculated EC table must be interpolated.

Interpolation was done by importing coordinates of sampling sites, together with their corresponding EC value, into ArcMap and then run the interpolation function from ArcGIS to calculate values for the whole region using inverse distance weighting (IDW) algorithm. Interpolation result of rice land salinity is shown in Fig. 7.

3.3 The Relationship between EC Salinity Index and NDVI Value

Based on the extracted NDVI on the map and opinions of local people, the sample sites in the field were identified to measure the salinity. To get more information about the salinity of whole study area, the interpolated salinity boundary of the paddy areas was overlapped to the NDVI map to find the relationship between the NDVI and salinity levels. The results showed that there were two different salinity levels at paddy land within Phu Vang district, including low and moderate salinity areas. Most of salinity areas were concentrated around lagoon (Fig. 8).

Table 4 shows that low salinity occurred on both single and two-season rice crop areas, where, NDVI values fluctuated from 0.12 to 0.20 for one-season rice

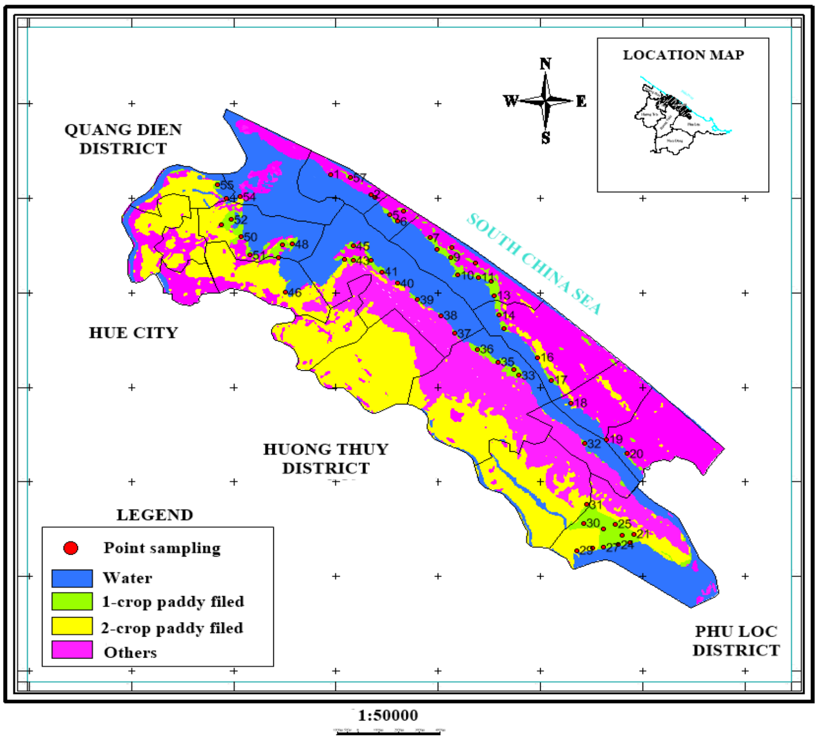

Fig. 6 Map of sampling sites.

Table 3 Salinity value of samples collected from different communes.

No.	Commune	EC value (mS/cm)	
		Min.	Max.
1	Phu Thuan	0.80	0.95
2	Phu Hai	0.53	0.72
3	Phu Dien	0.56	1.07
4	Vinh Xuan	0.72	0.96
5	Vinh An	0.75	0.92
6	Vinh Hai	0.47	0.97
7	Phu Da	0.52	0.89
8	Phu Xuan	0.44	1.41
9	Phu An	0.43	0.92

crop, with mean NDVI = 0.16, while for the two-season rice crop, it ranged from 0.21 to 0.31 with mean NDVI = 0.26. For the moderated salinity, it happened only in one-season rice crop (NDVI values from 0.07 to 0.01 with mean = 0.135) and did not occur in two-season rice crop. It was assumed from statistic that the salinity affected on the growth of rice plants. To clarify this assumption, the relationship between salinity index (EC) and NDVI within Phu Vang boundary was determined by Pearson's correlation coefficient of linear regression analysis (Fig. 9). The linear equation is NDVI = -0.308 × EC + 0.404. It means that when the EC index increases 1 unit, NDVI predicts a decrease of 0.308 units.

In addition, Fig. 9 shows that the NDVI difference index has an inverse correlation with EC with R^2 = 0.614, meaning that the EC factor explains about 61.4% of the NDVI change.

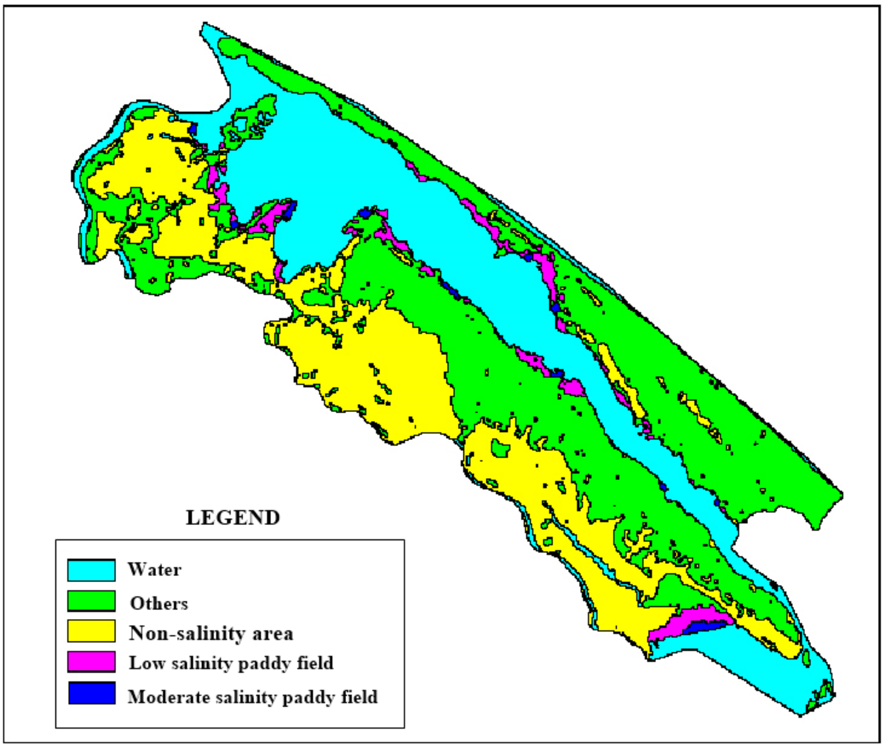

Fig. 7 Interpolation result of rice land salinity.

Fig. 8 The result of overlapping salt boundary on the NDVI image.

Table 4 NDVI value at different salinity areas.

No.	Study area	Crop	NDVI	
			Min.	Max.
1	Low salinity areas	One-season rice crop	0.12	0.20
		Two-season rice crop	0.21	0.31
2	Moderate salinity areas	One-season rice crop	0.07	0.20
		Two-season rice crop	None	

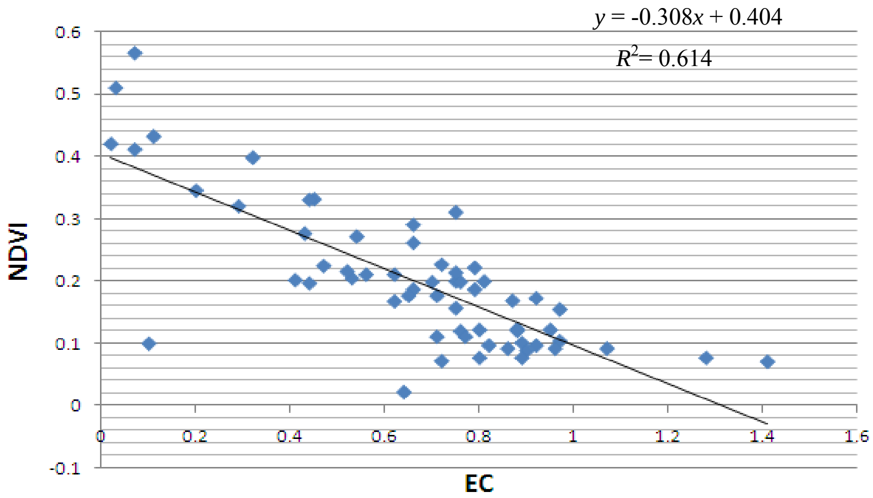

Fig. 9 The correlation between salinity index (EC) and NDVI index.

The analysis shows that EC salinity index has a strong correlation with NDVI value (R^2 = 0.614), meaning that the more saline soil is, the less rice plant develops and conversely. It shows that salinity was one of the factors that greatly affected the cultivation of rice in Phu Vang district.

3.4 Mapping Partition Saline Intrusion Areas at Phu Vang District

Most salinized areas are rice-cultivated land and concentrated in coastal and lagoon areas. Depending on the terrain conditions and type of cultivation, the saline intrusion level occurs differently. To map the partition saline intrusion areas in Phu Vang district, the interpolation from salinity values of sample sites and NDVI index could be determined. The result of mapping saline intrusion areas at Phu Vang district is shown in Fig. 10.

From saline intrusion map, the total area of effected paddy land in Phu Vang district was determined as 1,067.107 ha by using the calculation tool in ArcGIS software, of which, there were 886.431 ha (83%) of low saline intrusion and 180.676 ha (17%) of moderate saline intrusion. The salinized paddy areas in each commune are shown in Table 5.

The results in Table 5 show that salinized paddy area were concentrated mostly in Vinh Ha, Phu An, Phu Dien, Phu Da and Phu Xuan communes. The paddy land at Vinh Ha commune was mostly effected with an area of 244.07 ha, including 193.02 ha of low salinity intrusion and 51.06 ha of moderate salinity intrusion. At Phu An commune, the effected paddy land was covered in an area of 184.21 ha with 160.13 ha of low salinity intrusion and 24.08 ha of moderate salinity intrusion. At Phu Dien commune, there was 176.23 ha effected paddy land, including 156.74 ha of low salinity intrusion and 19.48 ha of moderate salinity intrusion. Following is Phu Da and Phu Xuan commune, which had salinity area of about 100 ha.

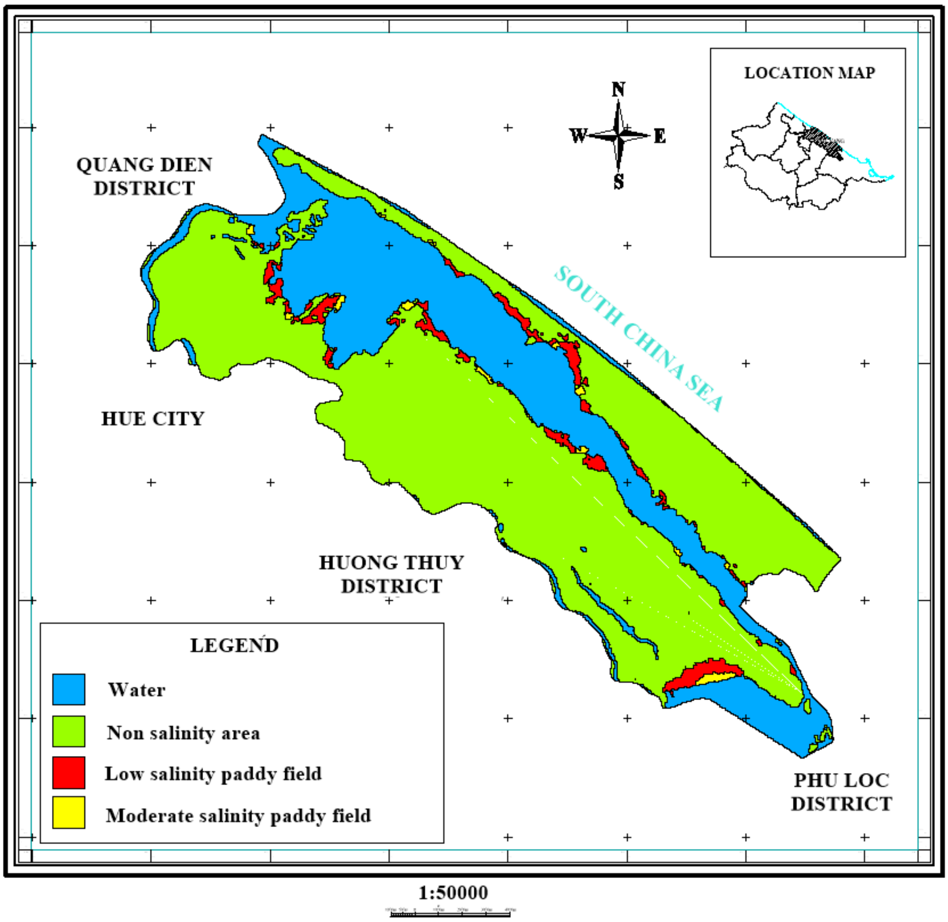

Fig. 10 Map of partition salinity rice land in spring crop in Phu Vang district in 2015.

Table 5 Saline intrusion areas within different communes.

No.	Commune	Salinity areas			
		Low salinity (ha)	Percentage (%)	Moderate salinity (ha)	Percentage (%)
1	Thuan An	3.70	0.42	0.00	0.00
2	Phu Thuan	1.17	0.13	5.59	3.10
3	Phu Hai	18.68	2.11	0.00	0.00
4	Phu Dien	156.74	17.68	19.48	10.78
5	Phu Xuan	67.41	7.61	11.81	6.54
6	Vinh Thanh	18.43	2.08	0.00	0.00
7	Vinh An	14.10	1.59	3.88	2.15
8	Vinh Ha	193.02	21.77	51.06	28.26
9	Vinh Phu	13.82	1.56	6.94	3.84
10	Phu Da	98.65	11.13	11.20	6.20
11	Phu Xuan	101.47	11.45	35.99	19.92
12	Phu My	33.08	3.73	0.00	0.00
13	Phu An	160.13	1.82	24.08	13.33
14	Phu Thanh	6.04	0.68	10.64	5.89
Total		886.43		180.68	

4. Conclusions

The integration of remote satellite and field survey is a new approach for mapping paddy land and the salinity intrusion. The extracted maps could be used to assess the change of land use and the level of salinity intrusion in different periods of time, which help the local authorities at Phu Vang district have good strategies in management of the effected paddy land. Based on the map of paddy land at Phu Vang district in 2015, it was estimated that the area of one-season rice crop was 1,401.96 ha and 8,539.39 ha for two-season rice crop. There were around 1,067.107 ha salinity area, accounting for 10.04% of total paddy land, of which 180.67 ha moderate salinity area and 866.43 ha low salinity areas. The salinity at Phu Vang district ranged from 0.4 mS/cm to 1.41 mS/cm and the average salinity was approximately 0.9 mS/cm.

In addition, the research also showed the negative relationship between salinity index (EC) and vegetation development (NDVI). According to the results, the salinity and NDVI within the boundary of Phu Vang district were closely related to 61.4%. The higher the salinity of land was, the lower the established NDVI of rice plant was, and conversely.

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