Factors Affecting the Salinity Intrusion at the Paddy Field in Thua Thien Hue Province, Vietnam

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ABSTRACT

Background: Several coastal regions in Vietnam have been suffered from salinity intrusion as a consequence of global climate change. However, there are limited studies on saline intrusion in Vietnam. This paper aimed to investigate the salinity intrusion of water and soil samples in paddy fields along Tam Giang lagoon, Thua Thien Hue province and clarify the factors affecting the salinity level.

Methods: We measured the salinity concentrations (EC, Electrical conductivity) of water and soil samples in paddy fields at different distances (400, 600, 800, 1000 and 1200 m) from Tam Giang lagoon. The multiple regression analysis was performed to figure out the factors affecting the salinity concentrations.

Result: The salinity concentrations of water were assessed as 48% high saline (10-25 dS m^{-1}), 34% moderately saline (2-10 dS m^{-1}), 2% slightly saline (0.7-2 dS m^{-1}) and 15% non-saline (<0.7 dS m^{-1}). As for surface soil in paddy field, 14.3% moderately saline (4-8 dS m^{-1}), 35.4% slightly saline (2-4 dS m^{-1}) and 50.3% non-saline (0-2 dS m^{-1}) were measured. A significantly positive correlation was found between salinity concentrations of water and soil (n=175, r=0.886, p<0.01). The distances from salinity sources, Tam Giang lagoon and shrimp pond, were major factors affecting the salinity concentrations. The paddy fields near Tam Giang lagoon and shrimp pond have higher salinity concentrations compared to those areas close to the residential area. The surface water in the paddy field within 1000 m from the salinity source was assessed as saline that might harm the paddy soil and rice production. The results of this study provide highly useful information for local policymakers and farmers about the status of salinity intrusion in paddy land.

Key words: Paddy field, Phu xuan commune, Salinity intrusion, Tam giang lagoon.

INTRODUCTION

Soil salinity is one of the most crucial environmental problems affecting developing countries in arid and semi-arid regions (Mahesh *et al.* 2019). The increasing salinity of coastal deltas can be attributed partly to the rising of sea levels and the increasing frequency of drought events as a result of global climate change (Baten *et al.* 2015; Wassmann *et al.* 2004). Many coastal regions in Vietnam have been suffered from complex salinity intrusion. Various studies on salinity intrusion have been conducted in the most vulnerable regions under climate change effects including Vietnamese Mekong (Ha *et al.* 2020; Nhung *et al.* 2019; United Nation, 2020; Wassmann *et al.* 2004), Red River Delta (Ca *et al.* 1994; Yen *et al.* 2017). However, salinity situations in the areas of central coastal Vietnam have been received less attention in the literature (Trang *et al.* 2019). Among the provinces in the north-central coastal region, agricultural soil in Thua Thien Hue province is seriously affected by soil salinization (Lam *et al.* 2014). In this region, about 2500 ha of agricultural lands adjacent to the Tam Giang lagoon, which is the biggest lagoon in Southeast Asia (approximately 22,000 ha), are saline (Dan *et al.* 2006). Phu Vang district of Thu Thien Hue province has been considered as one of the most vulnerable regions to climate change effects including sea-level rise, drought and salinity intrusion. Saline intrusion is the main cause affecting agricultural production, many rice production areas cannot be cultivated and have to turn to aquaculture. Therefore, research on the current state of saline intrusion is really necessary for the development of agriculture in the context of climate change in the central region and Thua Thien Hue province.

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The effect of soil salinity on rice production has been reported by many authors (Funakawa *et al.* 2000; Lam *et al.* 2014). The impact of saline water intrusion on the productivity of rice farms has been addressed by Trang *et al.* (2019). The yields of salt-tolerant rice cultivars had positive correlations with traits of plant height, panicles per plant, panicle weight and dry biomass which directly affected the rice yield (Lam *et al.* 2020; Elayaraja and Sathiyamurthi, 2020). Minh *et al.* (2020) indicated that potential salinity is one of the factors affecting rice cultivation in Southern Vietnam. However, the salinity relationship between water and soil at the paddy field has not been determined yet. Furthermore, there has been no investigation on the effects of saline sources on the paddy fields. Therefore, our objectives of this study are to (1) measure simultaneous water and soil samples for salinity concentration, (2) investigate the factors affecting the salinity level of the paddy field, (3) build the map presenting the level of salinity.

MATERIALS AND METHODS

Study site

Phu Vang is a low-lying coastal plain within the Tam Giang lagoon system and located in the Northeast of Thua Thien Hue province, with a total natural area of 27,824 ha, covering 5.53% of the total natural area of Thua Thien Hue province. In this study, we surveyed the Phu Xuan commune (from 16°46′12″ to 16°53′42″N and 107°65′32″ to 107°73′40″E) in the northeast of Phu Vang district. The soil conditions are mainly sea sand, dune soil and sea sand changed by rice cultivation with the mechanical components of over 70% being coarse sand. Most of the agricultural land is used for rice cultivation and aquaculture. Due to being adjacent to the Tam Giang lagoon system with a length of 11.5 km, the saline intrusion has affected agricultural production, especially rice production. Many rice land areas have to be converted to aquaculture, cultivated other crops such as potatoes and melons, or not cultivated.

Experimental design

We collected the surface water and soil for salinity measurement. In this study, we aimed to investigate the effect of salinity source and seasonal change of salinity concentration in the paddy field.

Considering the boundary of the studying site, we collected samples at the 5 different designated locations (PX1, PX2, PX3, PX4 and PX5). For each location, 5 distant plots (approximately 400 m, 600 m, 800 m, 1000 m and 1200 m) from Tam Giang Lagoon were sampled for salinity measurement (Fig 1). The first plot (400 m) of the survey location is adjacent to the Tam Giang lagoon and ends with paddy land near the residential area. Besides, at each location, the water samples from Tam Giang lagoon and shrimp pond were also collected for salinity measurement (Fig 1). The survey was conducted once a month from March to September 2020.

Salinity measurement

The presence of salts enhances the ability of a solution to conduct an electrical current and therefore high EC (Electrical Conductivity) values indicate high salinity levels. EC values of water samples were directly measured at the field using Hana HI 993310 (Hana Instrument, Inc, Romania). EC values of soil samples were measured at the laboratory using the "EC 1:1 w/v" method. Soil samples collected from the surface horizon were air-dried and gently grounded to pass through a 2 mm mesh sieve. The soil salinity was determined by mixing an aliquot of a sample with deionized water, at a soil/liquid ratio of 1:1 (w/v) (Zhang *et al.* 2005; Matthees *et al.* 2017). In brief, a 10 g sample of air-dried soil was pretreated with 10 ml deionized water (10 ml) at room temperature (25°C). After 30 minutes the electrical conductivity is measured and the levels of salt in the soil are determined. A glass electrode was used to measure the value for each sample.

Data collection and statistical analysis

The meteorological conditions at sampling sites are collected by the local meteorological office. In this study, the data on

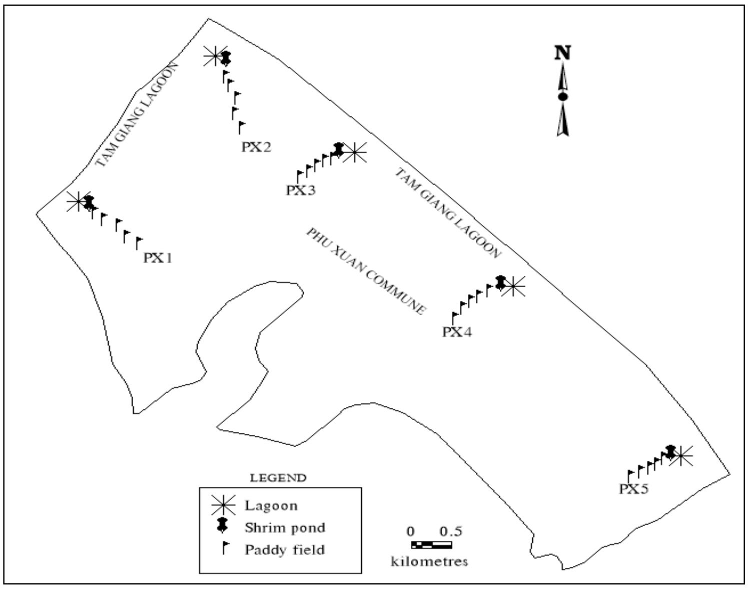

Fig 1: Sampling map at Phu Xuan commune of Phu Vang district, Thua Thien Hue Province.

monthly temperature (°C), rainfall (mm), humidity (%) and evaporation rate (mm) are obtained.

We performed multiple regression analysis to figure out the factors influencing the salinity using the equation:

$$S = a + b_1 \cdot \text{distance} + b_2 \cdot \text{temperature} + b_3 \cdot \text{rainfall} + b_4 \cdot \text{humidity} + b_5 \cdot \text{evaporation} + \varepsilon$$

Where

S = Concentration of salinity (dS m^{-1}).

ε = Error term that follows a normal distribution with mean 0 and variance σ^2.

a = Intercept; b_1, b_2, b_3, b_4.

b_5= Regression coefficients.

The model was run by the Stata 15 software (StataCorp LP, Texas, USA).

Mapping by GIS technique

Mapping the salinity level was conducted by the Natural Neighbor Interpolation method (Sibson, 1981) using ArcGIS 10.3 (Esri Institute, Inc., USA). To determine the natural neighbor of an interpolation point x, one can imagine this point is virtually inserted into the Voronoi diagram. This virtual insertion modifies the original Voronoi diagram and creates a new Voronoi cell V (x), a set of points that are closer to x than to any known x_i. The V (x_i) share edges with V(x); consequently, sample points of x_i are a natural neighbor of x. Weighted averaging of the sample values for these natural neighbors gives the interpolated value at x. The simple natural neighbor interpolation is defined as the following formula:

$$f(x) = \frac{\sum_i a_i * f(x_i)}{\sum_i a_i}$$

Where

a_i is the overlap area corresponding to the know data site x_i. The term overlap area refers to the area shared by V (x_i) and V (x). The overlap polygon is called the second-order Voronoi cell (Sambridge *et al.* 1995). If the sample point x_i lies outside of the convex hull of all known sample points, the overlapping polygon is un-bounded and ai in equation 1 is infinite. Therefore, only points that lie inside the convex hull of known sample point x_i can be interpolated to mapping.

RESULTS AND DISCUSSION

Level of water salinity in Tam Giang Lagoon and shrimp pond

To understand the salinity intrusion from the lagoon to the paddy field, we first measured the salinity levels of surface waters at the lagoon and shrimp pond (former paddy field) from March to September 2020. The mean (standard deviation) values of water at the lagoon and shrimp pond were 23.0±1.88 dS m^{-1} and 26.8±1.6 dS m^{-1}, respectively. These values were classified as very high saline according to salinity standards by FAO (1992).

Table 1: Salinity concentrations of water and soil in the paddy field.

Plot	Distance to Lagoon (m)	Monthly water (dS m^{-1})							Monthly soil (dS m^{-1})						
		3	4	5	6	7	8	9	3	4	5	6	7	8	9
PX1.1	400	14.8	15.9	22.4	22.7	20.7	22.5	14.2	3.2	5.6	1.9	2.7	4.7	4.7	3.3
PX2.1	400	14.9	16.2	22.8	19.2	21.2	20.9	14.4	3.7	4.0	2.5	5.4	5.2	4.0	3.5
PX3.1	400	14.4	15.6	19.1	23.1	21.1	23.4	14.7	3.6	4.3	5.3	6.4	5.9	2.5	4.1
PX4.1	400	13.9	21.2	22.3	22.7	19.5	19.7	14.2	2.0	4.1	6.5	2.8	3.9	1.7	4.1
PX5.1	400	14.3	16.3	22.6	23.5	15.5	19.3	14.0	3.5	3.0	4.8	5.7	1.9	4.8	4.5
PX1.2	600	12.0	13.4	14.3	16.3	17.5	14.8	12.6	1.7	2.2	3.3	3.4	3.3	4.0	2.8
PX2.2	600	12.6	13.9	14.9	15.5	18.2	18.0	13.3	3.0	3.3	3.6	3.5	4.4	3.4	3.2
PX3.2	600	12.3	12.9	14.7	16.7	18.3	16.8	14.1	3.1	3.6	4.1	4.6	5.1	3.7	3.8
PX4.2	600	12.2	18.3	14.4	16.1	15.0	14.4	13.4	3.1	3.4	4.7	4.2	3.4	3.7	3.5
PX5.2	600	12.6	13.5	14.8	16.7	13.7	14.8	13.3	3.3	2.7	4.1	4.1	2.9	3.5	3.7
PX1.3	800	9.1	11.1	10.4	9.3	9.2	11.7	9.2	0.4	2.9	2.2	2.4	2.0	0.9	1.9
PX2.3	800	8.5	8.9	9.7	10.6	8.9	11.1	8.9	2.3	2.8	1.0	2.4	2.3	1.2	2.3
PX3.3	800	10.0	11.4	9.1	11.4	11.6	8.9	11.4	2.0	3.2	2.5	3.2	3.2	2.1	3.2
PX4.3	800	10.5	8.0	12.2	10.6	8.6	10.6	11.0	1.8	2.0	2.5	2.0	2.3	1.9	2.8
PX5.3	800	7.3	8.0	8.4	7.8	9.2	7.5	7.9	2.0	1.8	2.3	2.3	1.4	2.8	2.3
PX1.4	1000	3.0	9.1	2.3	2.3	3.2	3.9	2.2	0.7	1.0	0.7	1.2	1.0	0.4	0.5
PX2.4	1000	4.1	4.5	3.3	5.3	4.3	8.8	3.3	0.8	0.7	0.6	1.0	0.8	1.5	0.6
PX3.4	1000	5.3	6.0	3.0	4.1	5.6	3.4	3.9	0.5	0.6	0.8	1.1	1.0	1.1	0.6
PX4.4	1000	8.4	5.4	7.0	7.2	4.1	8.4	7.0	0.5	0.6	0.9	1.1	0.9	1.3	0.5
PX5.4	1000	5.2	5.7	4.3	4.4	3.4	5.2	4.3	0.4	0.0	0.0	0.6	0.1	1.0	0.8
PX1.5	1200	0.6	3.3	0.0	0.0	0.0	0.0	0.5	0.1	0.0	0.0	0.0	0.0	0.4	0.0
PX2.5	1200	0.2	0.2	0.0	0.0	0.0	1.9	0.3	0.1	0.8	0.0	0.0	0.0	0.0	0.1
PX3.5	1200	0.0	0.2	0.2	0.0	0.0	0.0	1.5	0.0	0.0	0.1	0.0	0.0	0.0	0.4
PX4.5	1200	1.6	0.1	0.0	3.0	0.2	3.1	4.6	0.1	0.2	0.0	0.1	0.1	0.2	0.0
PX5.5	1200	0.3	0.7	0.0	0.6	0.4	0.6	1.2	0.3	0.0	0.0	0.0	0.0	0.0	0.0

Level of salinity in surface water and soil samples in the paddy field

We measured simultaneous water and soil samples at different distances from Tam Giang Lagoon from March to September 2020 to clarify the distance effect and seasonal change of salinity concentration. Table 1 presents the salinity concentrations of surface water and soil in the paddy field at Phu Xuan commune. The mean values of salinity concentrations of water and soil were 9.7 dS m^{-1} (range: 0-23.5 dS m^{-1}) and 2.1 dS m^{-1} (range: 0-6.5 dS m^{-1}), respectively. In another survey at Phu Vang district in 2015, the average salinity levels of soils were 0.9 dS m^{-1} (fluctuated from 0.43 to 1.41 dS m^{-1}) (Linh *et al.* 2017). The salinity intrusion on the paddy field in 2020 was wider than that intrusion in 2015 conducted by Linh *et al.* (2017). The possible reasons were that extreme conditions with high temperatures and serious drought starting from February to September 2020.

Table 2: Classification of salinity level on water simple.

Classification	Salinity concentration of water (dS m^{-1}) Standard FAO (1992)	No. of sample in this study (n=175)
Non-saline	<0.7	27
Slightly saline	0.7-2	4
Moderately saline	2-10	60
Highly saline	10-25	84
Very high saline	25-45	0

The surface waters in paddy field were classified as 48% high saline (10-25 dS m^{-1}), 34% moderately saline (2-10 dS m^{-1}), 2% slightly saline (0.7-2 dS m^{-1}) and 15% non-saline (<0.7 dS m^{-1}) (Table 2). The moderately and high saline water (from a distance of 400-1000 m) may cause the salinity intrusion potential on paddy land. From Table 1, the non-saline or slightly saline waters are distributed from a distance of 1200 m from the lagoon. The salinity level of water in the paddy field was relatively high (moderately saline) ranging from 8.3 to 10.8 dS m^{-1} (mean±sd: 9.7±6.8 dS m^{-1}) and varies from month to month (Table 3) with highest in June and lowest in March. The main reason for the lowest salinity in March was that the farmer supplies the freshwater for rice production. Thus, a certain amount of freshwater diluted the salinity concentration at this time. Meanwhile, the highest salinity concentration in June was connected with high temperature (29.9°C) and less rain (14 mm) (Table 3). It was also the time when the paddy field lacks water and suffers from drought, which was a favorable condition for salinity to penetrate the soil and water.

The surface soils in paddy field were assessed as 14.3% moderately saline (4-8 dS m^{-1}), 35.4% slightly saline (2-4 dS m^{-1}) and 50.3% non-saline (0-2 dS m^{-1}) (Table 4). Grattan *et al.* (2002) suggested that if the salinity concentration of soil is larger than 1.9 dS m^{-1}, the rice growth will be adversely affected. The soil in this survey was classified as 53% was affected by salinity (>1.9 dS m^{-1}) and 47% wasn't affected by salinity (<1.9 dS m^{-1}). The affected salinity soils (>1.9 dS m^{-1}) were mostly distributed near the salinity source with

Table 3: Monthly salinity concentrations in surface water, soil and corresponding meteorological conditions.

Item	March n = 25	April n = 25	May n = 25	June n = 25	July n = 25	August n = 25	September n = 25
Salinity concentration in water (dS m^{-1})	8.3	9.6	10.1	10.8	10.0	10.8	8.6
Salinity concentration in soil (dS m^{-1})	1.7	2.1	2.2	2.4	2.2	2.0	2.1
Temperature (°C)	25.7	24.8	29.5	29.9	29.6	28.9	28.6
Rainfall (mm)	47.8	217.4	35.6	14.0	48.2	153.4	225.1
Humidity (%)	87	89	81	76	77	81	82
Evaporation rate (mm)	50.6	36.0	80.2	98.7	108.5	72.2	72.3

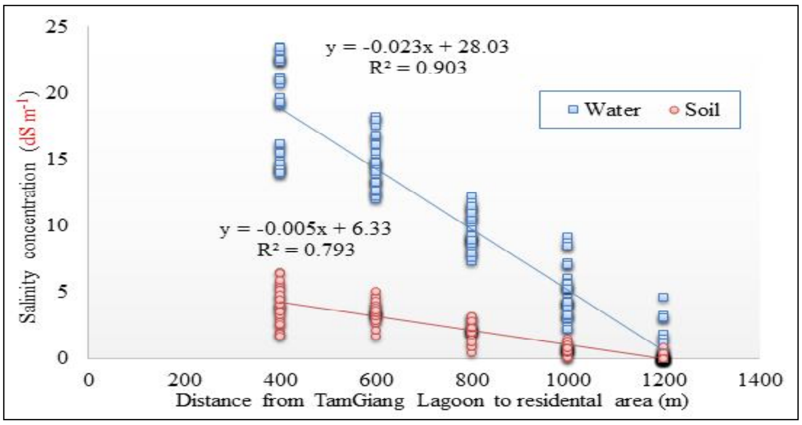

Fig 2: Relationship between salinity concentration and salinity source.

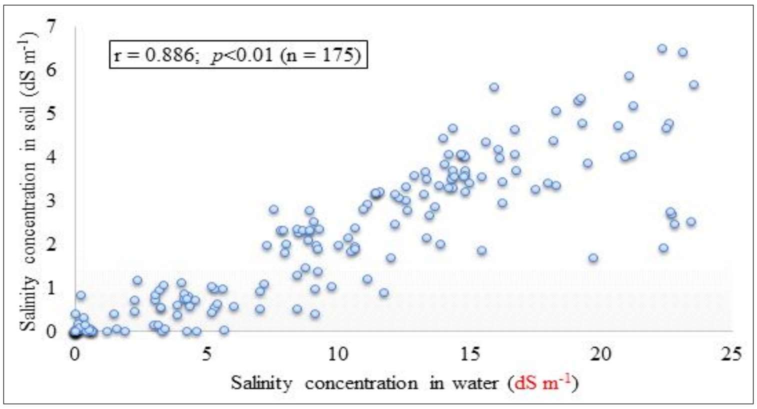

Fig 3: Pearson correlation between salinity concentrations in water and soil.

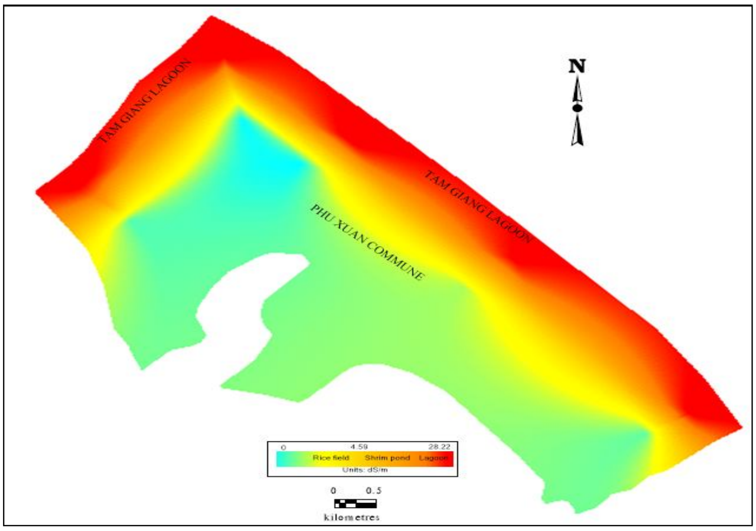

Fig 4: Mapping the salinity levels of soil in Phu Xuan commune.

distances of 400, 600 and 800 m from the lagoon. Salinity levels of paddy soil from April to September (ranging from 2.0 to 2.4 dS m^{-1}) were higher than that of March (1.7 dS m^{-1}) (Table 3). The reason for higher salinity levels of paddy soils in April-September was that the hot and dry weather increases the salinity intrusion into the soil.

Fig 2 presents the significantly inverse relationship between salinity concentrations of water (r=-0.95; p<0.01) and soil (r=-0.89; p<0.01) and distance of salinity source. This means that the paddy fields near Tam Giang Lagoon and shrimp pond have higher salinity concentrations compared to those areas close to the residential areas. The cause of the saline intrusion is determined by the water level in Tam Giang lagoon that penetrates the paddy soil according to the irrigation system. Furthermore, in the summer, a high amount of water evaporates from the sea and lagoons and then condenses in the paddy fields. Besides, there are many activities of domestic wells in residential areas absorbing groundwater in the soil. As a result, saltwater in the aquifer may penetrate deeper into the soil.

Fig 3 shows that water salinity has a significantly positive correlation with soil salinity (r=0.886, p<0.01). As a result, higher salinity in water will lead to higher salinity in paddy soil. This shows that the salinity in water in the paddy fields is the cause of the accumulation of salt content in the soil. The result from this study is consistent with those researches on the effects of salinity intrusion in the Red River and Mekong Delta regions (Ha *et al.* 2020; Yen *et al.* 2017). Fig 4 presents the mapping of the salinity levels of the soil in paddy fields that provide highly useful information for local policymakers and farmers about the status of salinity intrusion in paddy land.

Table 4: Classification of salinity level on soil simple.

Classification	Salinity concentration of soil (dS m^{-1})	
	Standard FAO (1988) and Abrol *et al.* (1988)	No. of sample in this study (n=175)
Non-saline	0-2	88
Slightly saline	2-4	62
Moderately saline	4-8	25
Strongly saline	8-16	0
Very strongly saline	>16	0

Table 5: Result of regression analysis for surface water and topsoil samples.

	Parameter	Coefficient	Std. Err.	*p-value*	n	R^2
Surface water	Distance	-0.023	0.001	<0.001***	175	0.9123
	Temperature	-0.067	0.272	0.807		
	Rainfall	-0.001	0.002	0.552		
	Humidity	-0.559	0.213	0.010**		
	Evaporation	-0.082	0.033	0.015**		
Topsoil	Distance	-0.005	0.0002	<0.001***	175	0.8013
	Temperature	-0.053	0.101	0.599		
	Rainfall	0.001	0.001	0.467		
	Humidity	-0.088	0.079	0.266		
	Evaporation	-0.006	0.012	0.657		

Notes: *p*-value is significance level. ***Represents $p<0.001$. **Represents $p<0.01$. *Represents $p<0.05$.

Factors influencing the salinity concentrations in the paddy field

To quantify the factors influencing the salinity concentrations in the paddy field, we applied multiple regression analysis considering the distance from the salinity source, meteorological conditions including temperature, rainfall, humidity and evaporation rate.

For surface water, the regression result presented a significant inverse relationship between the salinity concentration and distance, humidity and evaporation rate. These findings are consistent with those researches on the meteorological factors affecting the salinity levels. Lam *et al.* (2014) concluded that salinity concentrations were higher at low elevations (from Tam Giang lagoon) than those concentrations at high elevations. Al-Shammiri (2002) found that a decrease in the evaporation rate led to an increase in the water salinity because of the reduction in the water vapor pressure at the water surface. High atmospheric humidity reduced the level of salinity (Nieman and Poulson, 1967). Temperature and rainfall tended to have an inverse relationship with salinity concentration (but insignificant statistics). For soil, only distance had a significant inverse relationship with the salinity concentration. Therefore, the distance from the salinity source is the most important factor affecting the salinity concentration in the paddy field.

CONCLUSION

The mean values of salinity concentrations of water and soil in the paddy field were relatively high with 9.7 (range: 0-23.5 dS m^{-1}) and 2.1 dS m^{-1} (range: 0-6.5 dS m^{-1}), respectively. By simultaneously measuring water and soil salinity in paddy fields, we found a significantly positive correlation between water and soil salinity. This means that saline water may cause the accumulation of salt content into the soil. The distances from salinity sources, water from Tam Giang lagoon and shrimp pond were major factors affecting the salinity concentrations. We found that a significant inverse relationship between salinity concentrations of water (r=-0.95; $p<0.01$) and soil (r=-0.89; $p<0.01$) and distance of salinity source. The concentrations of surface water within 1000 m from the salinity source were saline that might harm the paddy soil and rice production. Therefore, we highly recommend strict management when the rice cultivation activities take place at a distance of 1000 m from the Tam Giang lagoon and shrimp pond.

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