POLISH JOURNAL OF SOIL SCIENCE
VOL. LI/2 2018 PL ISSN 0079-2985

DOI: 10.17951/pjss/2018.51.2.205

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EFFECT OF LAND-USE CHANGES RESULTING FROM SHRIMP FARMING ON ACID SULFATE SOILS IN THE CAN GIO COASTAL WETLAND AREA (VIETNAM)

Received: 05.05.2018
Accepted: 07.07.2018

Abstract. Acid sulfate soils in coastal wetland areas are particularly vulnerable to land-use changes. We identified the potential impacts of land-use changes in the Can Gio coastal wetland area in Vietnam due to the reclamation of acid sulfate soils from shrimp farms. Our study applied the support of vector machine algorithm in ENVI software to observe land-use changes from 1995 to 2015, using Landsat Thematic Mapper and Operational Land Imager data. We classified the land use of the study area into four major classes including vegetation, bare land, dedicated land and aquaculture land. Our study successfully met the overall classification accuracy requirement above 95% and kappa statistics above 0.95. Between 1995 and 2006, about 2,938.05 ha of bare land and 1,464.66 ha of vegetation (mangrove forest) were converted to aquaculture land. In contrast, between 2006 and 2015, 2,423.88 ha of aquaculture land converted back to bare land, mainly related to the abandonment of shrimp ponds due to crop failure and disease. The disturbance of acid sulfate soils through initial soil reclamation and subsequent fallowing is considered a key reason for hastening and extending soil acidification in the study area. We collected 144 topsoil samples from 17 fallowed ponds in two batches, and 142 of these were acidic: 128 samples were extremely and strongly acidic (pH < 5.5), 14 samples were moderately and slightly acid (pH between 5.5 and 6.5), and only two samples were neutral (pH over 6.5).

Keywords: land use, acid sulfate soils, shrimp farming, supervised classification, soil reclamation

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INTRODUCTION

Naturally occurring acid sulfate soils (ASSs) contain sulfides (e.g., pyrite) and sulfuric acid. They can also generate acid through the oxidation of sulfides (Shi *et al.* 2014). The worldwide distribution of ASSs is estimated to be over 500,000 km^2 and occurs across climatic regions ranging from temperate to tropical zones (Fanning *et al.* 2017, Ruprecht *et al.* 2018). Most ASSs are located in coastal wetland areas (Högfors-Rönnholm *et al.* 2018), which are also often developed areas with high population densities due to their good climatic conditions. This makes them potentially valuable for the development of aquaculture (Widyatmanti and Sammut 2017). The rapid development of shrimp farming in coastal plains has coincided with the loss of natural mangrove forests, wetlands and sediments (Mahmood and Saikat 1995, Perryman *et al.* 2017).

This rapid expansion of shrimp farm has resulted in the over-exploitation of coastal sediments and ASS disturbances through drainage. This has, in turn, increased the exposure of pyrite to oxygen, thus, generating excess of acid and leading to a soil pH of less than 3.5. As the concentration of sulphate has increased, so has the presence of secondary iron minerals (jarosite, hematite, goethite, etc.). Once shrimp farms become acidified, they are often abandoned, leading to increased pollution pressure on both land and water resources (Sammut *et al.* 1997). Currently, the production of shrimp on ASS is considered unsustainable (Mahmood and Saikat 1995) and soil acidification caused by reclaimed ASS for aquaculture has become a worldwide concern in coastal wetlands in recent years. Because of this, detecting and evaluating the potential presence of acidic soil is necessary work to limit the over-exploitation of ASS and prevent formation of new acidified areas. Newly acidified areas can increase the risk of pollution as soil is reclaimed back into the environment.

The traditional method to monitor the acidic state of soil has been the analysis of soil samples, but this method has not shown the linkage between land-use changes and alteration of soil properties at large scales. However, the combination of remote sensing and traditional methods promises to clarify the process of land-use changes caused by human activities in particular areas.

Remote sensing is a cost-effective and time-saving tool for detecting land-use changes. Many researchers around the world use a support vector machine (SVM), which is a supervised classification method to analyse images and detect land-use changes (Karan and Samadder 2016, Martins *et al.* 2016, Ustuner *et al.* 2015). Their results verify that the SVM algorithm has higher accuracy than the maximum likelihood classifier algorithm in land-use mapping. Therefore, the SVM algorithm has been suggested as an optimal classifier for extraction of data from land-use maps due to its higher accuracy (Karan and Samadder 2016, Taati *et al.* 2014).

In Vietnam, the massive and unplanned development of shrimp farms has created a problem for sustainable development. Large farming areas have been abandoned after only a few crops due to disease, crop failure, devaluation, etc. (Nho *et al.* 2018, Phuoc and Massel 2006, Thuong and Thach 2017). Thao *et al*. (2012) indicated that, in 2008, fallowed areas of shrimp ponds comprised 28,821 ha in North and North Central Vietnam; 13,907 ha in Central Vietnam, and 67,591 ha in South Vietnam, indicating a total of 110,320 ha of fallowed land for the entire country of Vietnam.

We sought to monitor the land-use changes due to reclamation of ASS for shrimp farm in the Can Gio area. Rapid development of aquaculture in Can Gio has led to environmental problems such as mangrove forest degradation (Son *et al.* 2016), soil acidification (Lieu 2002), and surface water pollution from waste water generated by soil raising activities (Anh *et al.* 2010, Trai *et al.* 2006, Tuan *et al.* 2005). We analysed remotely sensed data to distinguish the extent of changes that have occurred in the Can Gio coastal wetland area over a 20-year time period (1995 to 2015) and assessed the effects of ASS reclamation for shrimp farm on soil properties.

MATERIALS AND METHODS

Study area

Can Gio is located about 50 km southeast of Ho Chi Minh City between latitude of 10°22’14”N and 10°40’00”N, and between longitude of 106°46’12”E and 107°00’50”E (Fig. 1) and has a total area of ±70,421.58 ha (including 20,922.66 ha of waterways). Together with Can Thanh Township, six communes – including Can Thanh Township, Binh Khanh, An Thoi Dong, Tam Thon Hiep, Long Hoa and Thanh An – form the human communities of Can Gio with a population of ±71,000 people (Nam *et al.* 2014, Thuong and Thach 2017).

The topography of Can Gio is generally flat and low-lying with an average elevation of 0.5 to 2 m. It is mostly composed of clayey/silty soils that contain peat. The parent materials of these soils are Quaternary pyritic deposits of the late–present Holocene age with marine, alluvial-marine, or swampy-marine origins (Hai *et al.* 1989), and is dominated by saline ASS (Thionic-Salic Fluvisols) in 43,945 ha of the Can Gio (Lieu 2002).

The tropical climate of Can Gio is typically monsoonal with two distinctive seasons (Kuenzer and Tuan 2013, McDonough *et al.* 2014, Son *et al*. 2016). The dry season is from November to May and the rainy season is from June to October. The average daily temperature is 25.7 to 28.5°C and the amount of sunshine varies between five and nine hours per day. Solar radiation is very high at ±140 kcal cm^{-2} $year^{-1}$, evaporation is between 1,000 and 1,200 mm/$year^{-1}$, and

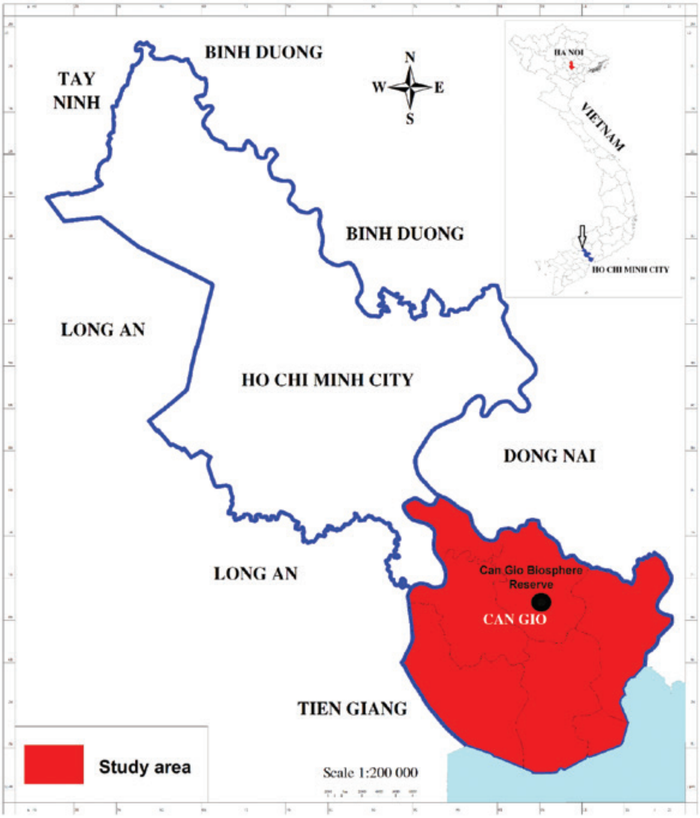

Fig. 1. Geographic location of the study area

air humidity is between 74 and 83%. These natural conditions ensure that soil oxidation occurs rapidly and with high intensity.

In Can Gio, the main land-use types include mangrove forest (±33,050.39 ha, –46.93%) – which is strictly protected by the board of the Can Gio Mangrove Biosphere Reserve, land used for residents, agriculture, aquaculture and dedicated purposes to human use, i.e. settlements, roads or salt pans (±37,353.26 ha, –53.04%), and unused land (±17.93 ha, –0.03%) (Nho *et al.* 2018).

The initial soil reclamation through drainage or fallow Thionic Fluvisols would hasten soil acidification, and adversely affect habitats in Can Gio by threatening the ecological values of this study area which is declared as a Biosphere Reserve by UNESCO since 2000 (Nam *et al.* 2014, Son *et al.* 2016).

Data preparation

The data used in this research included Landsat 5 Thematic Mapper (TM) data and Landsat 8 Operational Land Imager (OLI) data. Ground truth data were collected using a Geographical Positioning System device (Garmin eTrex® 20) in March 2015 to use as reference data for image classification and overall accuracy assessment of the classification results. Satellite data for three years (1995, 2006, and 2015) consisted of multi-spectral data acquired by Landsat satellite for the months of February and March, provided by the US Geological Survey (USGS) Earth Explorer.

We conducted two soil sampling batches, in March 2015 and again in February 2017, to investigate soil properties after being reclaimed for shrimp farming and subsequently abandoned. In the first batch, 90 topsoil samples were randomly taken from 11 fallow farms (ca. 6.1 ha) three months to two years after being abandoned. In the second batch, 54 topsoil samples were randomly taken from six fallowed farming (ca. 1.44 ha) two months to three years after being abandoned. Although many fallowed farms had not been reclaimed, some of the fallowed farms were filled with sulfidic materials from adjacent canals. These farms subsequently became bare land.

Of the 144 total topsoil samples from the 17 sites and two batches, 114 samples were taken from inside dry farms and 30 samples were taken from the edges of wet farms. Of the 17 sites, two sites were repeated to check the progress of soil acidification over time (CG1-A6 ≅ CG2-A4; CG1-A9 ≅ CG2-A3). The soil type of the samples were Thionic Fluvisols at depths of zero to 10 cm (Fig. 2). The pH values of the soil samples were measured in natural conditions (the ratio of soil to distilled water was one to five) by using a hand-held, field model pH probe (Takemura Electric Works, Tokyo). The locations of soil samples were transformed to the Universal Transverse Mercator (WGS84) projection in zone 48N so that they would be the same as the Landsat data projections.

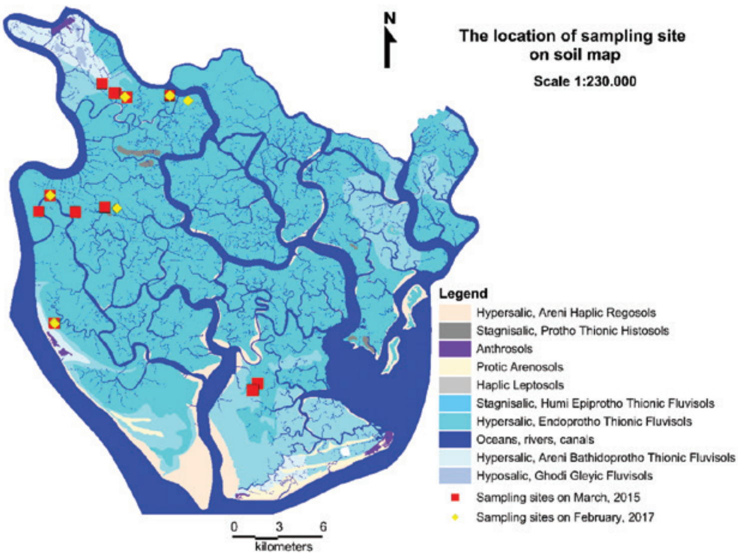

Fig. 2. The location of sampling sites on a soil map of Can Gio

Pre-processing and classification

Data were pre-processed in ENVI 4.5 for geo-referencing, mosaicking and sub-setting of the region of interest. All satellite data were assigned per-pixel signatures into four classes. These delineated classes were vegetation, including mangrove forest, rice fields and fruit trees; bare land that was reclaimed from cut-down mangrove forest in the past for agricultural purposes but fallowed thereafter; aquaculture land, including shrimp farming; and land dedicated to human use with the presence of settlements, roads and salt pans. We then used the SVM algorithm for supervised classification. Finally, the classified images were cut to eliminate river systems using the district and river boundaries of a topography map at scale of 1:5,000.

Accuracy assessment of the classification method

To determine the quality of information derived from the satellite images, we evaluated the classification accuracy of the 1995, 2006 and 2015 images. We assessed our data using a stratified random method proportionate to 50% of the sample size to confirm the different land-use classes of the study area.

Detection of land-use changes

We used a post-classification technique called *change detection analysis* to detect the location, nature, and area sizes of land-use changes. A change detection statistic was determined for the stages from 1995 to 2006 and again from 2006 to 2015 to identify the conversions from one distinct land-use type to another land-use type.

RESULTS

The overall classification accuracies of our 1995, 2006 and 2015 images were 96.87%, 98.18% and 98.72%, respectively. Our overall kappa statistics for the 1995, 2006 and 2015 images were 0.9609, 0.9773 and 0.9840, respectively. These results show that we successfully met both the required overall classification accuracy above 95% and that our kappa statistics were above 0.95. The results of our change detection for 1995, 2006 and 2015 are summarised in Figure 3 and Table 1.

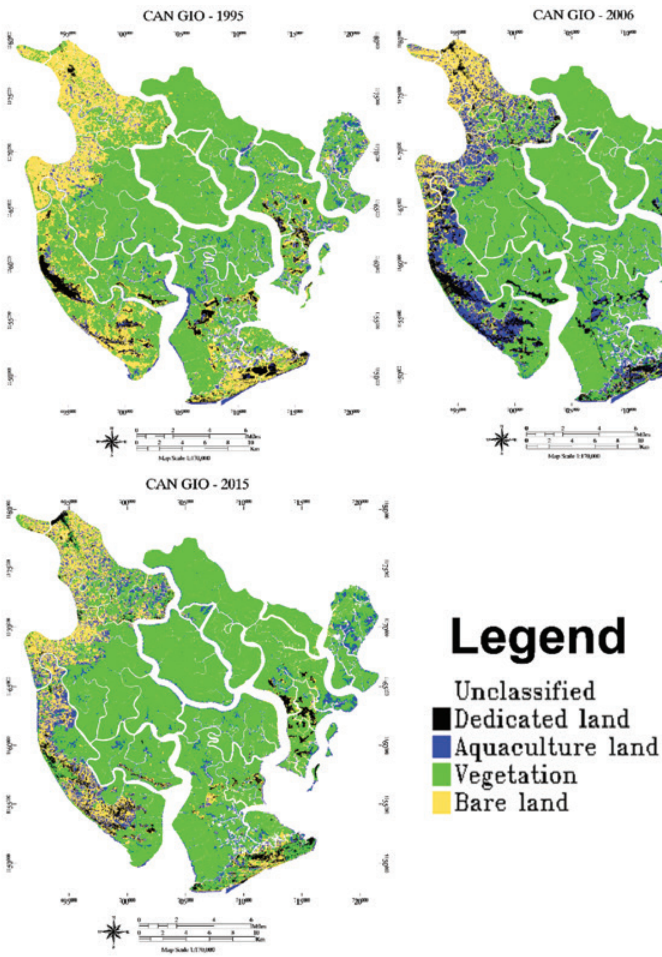

Fig. 3. Classified maps of Can Gio area (1995, 2006 and 2015)

Table 1. Land-use change overtime (area in hectares)

Land-use classes	1995	2006	2015	Change from1995 to 2006	Change from 2006 to 2015
Vegetation	32,693.13	34,281.9	36,334.89	1,588.77	2,052.99
Dedicated land	1,979.46	3,878.91	1,964.25	1,899.45	-1,914.66
Bare land	12,020.4	5,132.25	7,258.14	-6,888.15	2,125.89
Aquaculture land	2,805.93	6,205.86	3,941.64	3,399.93	-2,264.22
Total	49,498.92	49,498.92	49,498.92	0	0

As seen in Table 1, the amount of bare land decreased by 6,888.15 ha between 1995 and 2006, and this corresponds to the increase in vegetation (1,588.77 ha), dedicated land (1,899.45 ha), and aquaculture land (3,399.93 ha).

During this time, 2,938.05 ha of bare land and 1,464.66 ha of vegetation (mangrove forest) were converted to aquaculture land (Table 2).

In contrast, between 2006 and 2015, vegetation increased by 2,052.99 ha and bare land increased by 2,125.89 ha, which corresponds to a decrease of dedicated land by 1,914.66 ha and aquaculture land by 2,264.22 ha. In particular, 2,423.88 ha of aquaculture land converted to bare land and this relates to the abandonment of shrimp farm due to crop failure and disease. The detail of conversions between land-use types and their changes of equivalent areas, between 1995 and 2006 and between 2006 and 2015 are shown in Table 2 and Table 3, respectively.

Table 2. The detailed change of land-use types between 1995 and 2006 (area in hectares)

Land-use classes		1995				
		Vegetation	Dedicated land	Bare land	Aquaculture land	Class Total
2006	Vegetation	29,341.26	114.75	3,853.71	972.18	34,281.9
	Dedicated land	642.6	1,474.83	1,668.87	92.61	3,878.91
	Bare land	1,244.61	160.02	3,559.77	167.85	5,132.25
	Aquaculture land	1,464.66	229.86	2,938.05	1,573.29	6,205.86
	Class total	32,693.13	1,979.46	12,020.4	2,805.93	0
	Class changes	3,351.87	504.63	8,460.63	1,232.64	0
	Image difference	1,588.77	1,899.45	-6,888.15	3,399.93	0

Table 3. The detailed change of land-use types between 2006 and 2015 (area in hectares)

Land-use classes		2006				
		Vegetation	Dedicated land	Bare land	Aquaculture land	Class Total
2015	Vegetation	33,147.63	707.58	1,480.59	999.09	36,334.89
	Dedicated land	58.95	1,410.84	224.55	269.91	1,964.25
	Bare land	510.66	1,503.54	2,820.06	2,423.88	7,258.14
	Aquaculture land	564.66	256.95	607.05	2,512.98	3,941.64
	Class total	3,4281.9	3,878.91	5,132.25	6,205.86	0
	Class changes	1,134.27	2,468.07	2,312.19	3,692.88	0
	Image difference	2,052.99	-1,914.66	2,125.89	-2,264.22	0

Since most of the soils in Can Gio are ASSs, the mutual conversion processes of reclaiming bare land to become aquaculture land and then allowing them to go fallow again will directly alter soil properties. Potential ASS layers can become actual ASS layers through digging and turning over the soil. We collected 144 topsoil samples in two batches to assess the impact of reclaiming ASS for aquaculture (shrimp farm) on changes in soil properties. We especially considered the acidic state of the soil by measuring pH values. Our analysis showed that 128 sampling sites were strongly acidic (pH < 5.5), 14 samples were moderately to slightly acidic (5.5 ≤ pH ≤ 6.5), and two samples were pH neutral (Fig. 4). The largest number of strong acidic soil samples came from the edges of farms (30 samples) and fallowed farms that had oxidised within the last two months to three years (98 samples). The moderately acidic to neutral samples were mainly scattered in fallowed farms that had undergone a liming regime during soil reclamation and before raising. We conclude that irregular liming regimes may have had an impact on the change of soil acidity within the same farm.

We repeated sampling at two of the 17 investigated sites to check the progress of soil acidity at these fallowed farms over time. Table 4 shows the slight increase in soil acidity over the two years. It is noted that soil acidity could have remained stable for many years under natural condition if left untreated by liming.

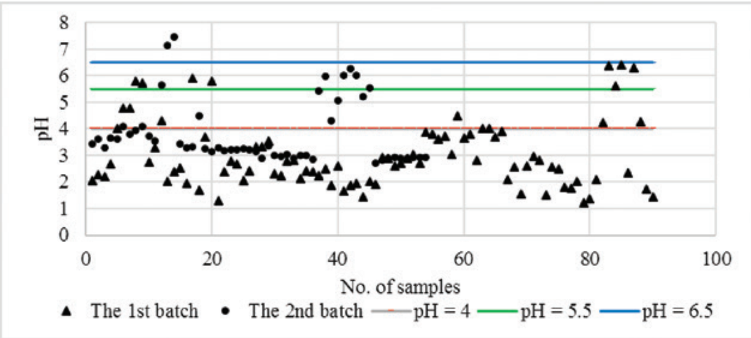

Fig. 4. pH values of topsoil samples in two sampling batches

Table 4. pH values indicating soil acidity at two shrimp farms, repeated over a two-year period

No. of samples	CG1-A9 ≅ CG2-A3		CG1-A6 ≅ CG2-A4	
	Mar-15	Feb-17	Mar-15	Feb-17
1	2.10	3.24	1.88	2.90
2	2.55	3.13	2.61	3.36
3	1.55	3.27	1.64	2.99
4	2.60	3.19	1.86	2.97
5	2.96	3.22	1.95	3.04
6	2.81	3.20	1.42	2.88
7	1.49	3.24	2.03	3.00
8	2.56	3.20	1.90	2.99
9	2.50	3.15	2.91	2.86

DISCUSSION

The soil $pH_{1:5w}$ measurements of the fallowed farms proved that the topsoil was an actual ASS layer, while the research by Lieu (2002) showed that the topsoil layer of bare land had a soil pH of approximately 3.5. This demonstrates that the topsoil layer investigated in this study is a potential ASS layer that was disturbed and exposed to air through soil reclamation for the shrimp farms, leading to oxidation and turning the potential ASS into actual ASS layers.

It should be noted that, in the Can Gio area, soil acidification can happen repeatedly during soil reclamation for land-use purposes such as cutting down mangroves for rice fields or converting uncultivated rice fields to shrimp farms and fallowing them thereafter. This inefficient way of using the land can make ASSs degrade more rapidly and can contribute to the potential risk of future contamination.

CONCLUSIONS

The results from the study have led to the following conclusions:

1. There was a continuous reclamation of bare land for shrimp farms between 1995 and 2006, and a conversion from shrimp farms back to bare land (fallowed farms) between 2006 and 2015.

2. Some shrimp farms became fallowed farms after only a few crop cycles due to economic losses caused by disease, poor crops, devaluation, etc.

3. Most soil samples (89%) collected from fallowed farms in Can Gio were strongly acidic (128/144), 10% were moderately to slightly acidic with a pH between 5.5 and 6.5 (14/144), and only 1% were in a neutral condition (2/144).

4. Natural recovery from soil acidification in the farming will require many years if left untreated by liming.

It is essential to tightly control the coastal wetland resources of Can Gio to prevent enlargement of ASS layers in the future.

ACKNOWLEDGMENTS

The authors are thankful to the Hokkaido University and Vietnam National University – Ho Chi Minh City for their financial and technical supports. We also owe special thanks to Professor Kazuhiro Toyoda from the Hokkaido University and Professor Phuoc Van Nguyen from Vietnam National University – Ho Chi Minh City for their valuable suggestions at various stages of our research.

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