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The Impact of Coal Exploitation on Tidal Flat Changes, an Investigation Using Remote Sensing Data in Vietnam

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Abstract. Tidal flat plays a crucial role in socio-economic development and ecological environment. Tidal flats in Ha Long-Cam Pha in Vietnam are impacted by human activities, especially coal mining activities. Using remote sensing data is able to detect, extract, and monitor the changes of tidal flats and exploited coal mine area with multi-temporal, in various scales, and for a large coverage. This study aims to investigate the impact of coal mining activities on the changes of tidal flats using remote sensing in Cam Pha, Ha Long, one of the biggest coal basins in Vietnam. Digital Elevation Models (DEMs) of tidal flats constructed by Landsat satellite images acquired in years 1989, 2001, and 2014 are compared to determine the volume changes. Besides, coal mining activities including coal production, waste rock dump area, and the expansion of open coal mine during the period 1989-2014 are investigated using correspondent Landsat images and the reports from the coal mine companies in the study area. Sediment samples in tidal flats are analyzed to determine the origin of the sediments. As the results, organic matter in the tidal flats is dominant with the concentration of 459 g/kg to 607 g/kg, which is evidence for the impact of coal exploitation on the coastal environment. In addition, the relationship between coal mine activities and tidal flat variation is well observed in this study.

Keywords: Tidal flat, Coal, Remote Sensing

1. Introduction

Tidal flats are the transition between land and sea, suffering by the interaction between tidal and other hydrodynamic forces to form areas in flat, fine-grained sediment and usually non-vegetated cover [1]. Tidal flat plays a crucial role in society, economy, and ecology. However, they are threatened by human activities and the phenomenon of climate change such as sea-level rise [2, 3]. One of the human activities affecting tidal flat change is coal mining activities in coastal area. Coal is known as one of the most mining commodities, especially to provide energy for the industrial development of countries [4]. Environmental problems arising from coal mining activities in Vietnam are normally caused by open cast mines. Generally, it is difficult to monitor the change of tidal flats because of muddy, soft ground, short time of exposure to the air [5]. With the ability of instantaneous observation on a large scale, repeatable data requirements at various detailed levels, remote sensing is recommended as the most effective method to detect changes in tidal flats.

As components of the remote sensing, satellite data, aerial photos have been majors data for studies related to environmental monitoring and reclamation of mining areas [6]. Based on broad spectral range, rapid coverage of large areas, and affordable cost, remote sensing data are promising data for the assessment of environmental impacts. Particularly, remote sensing data have been used to identify, outline, and monitor the pollution sources as well as their affected areas composing of land cover, water, and ecosystems [7]. Among these applications of remote sensing in tidal flats, some studies focused on quantifying the landform variation in tidal flats [8]. Several published works have attempted to extract the change information of the topography and sedimentation in tidal flats using Digital Elevation Models (DEMs) constructed from satellite images at different times [5, 8]. These intertidal DEMs have been generated using waterlines extracted from multi-temporal satellite data [9, 10, 11]. Previous studies have focused mainly on spatial and temporal changes of tidal flats. As a crucial indicator to evaluate the soil quality, organic matter plays a vital role in terrestrial ecosystems. Monitoring organic matter is a significant step to make plans for the environmental management and ecological restoration of mining areas [12]. Several papers have attempted to qualitatively analyze surface sediments to gain the information of grain size, organic matter in the relationship with tidal flat changes.

The main objective of this paper is such a combined analysis, in which the assessment of volume change in the tidal flats is performed using multi-temporal remote sensing data. Besides, the study also investigates the impact of coal mining activities on tidal flat change. First, the DEMs of tidal flats are created using waterlines, which are extracted from multi-temporal Landsat images. Volume change of tidal flat is extracted by the comparison between the DEMs constructed at different times. Subsequently, the volume change of tidal flats is correlated to the statistical number of coal mining activities in the study area to figure out the effect of coal exploitation on the change of tidal flats. The experiment focuses on the tidal flat along Ha Long-Cam Pha coast.

2. Study areas

Ha Long Bay, one of seven wonder heritages recognized by UNESCO, is characterized by 1,600 limestone islands un-inhabited and unaffected by humans, located in the Gulf of Tonkin. An attractive sea landscape spreading in an area of 43,400 ha is the natural potentiality for the development of the tourism industry. The coastline of the Ha Long bay is the sea boundaries of Ha Long and Cam Pha cities which are known as the coal stock of Vietnam. With a special geological base, beneath Ha Long-Cam Pha is formed by petroleum and coal-bearing basins which have been exploited for more than 100 years. Cutting down from the top to create open pit mines is the main method to exploit coal, which makes the change of the topography by creating massive holes with a diameter of thousand meters. The unusable material as rocks, soil, and unqualified coal is piled up surrounding areas of the mines to create artificial mountains with a steep slope up to 8-20 degrees. Ha Long bay is in the tropical zone with a summer and a cold winter. The summer is the rainy season, specified by extreme precipitation with an average of 1,557 mm. Heavy rain falling on the unstable solid waste of the coal exportation, concentrated on steep slopes carries the coal paticles to deposit them on the near-shore water area of Ha Long bay. Besides, the seawater in Ha Long is influenced by a tidal dominance regime because the wind, waves are obstructed by dense islands seaward. Calm water is a suitable condition to fate suspended coal sediments to form the coal tidal flat in the study area. Coal tidal flats are muddy, soft, and black with sparse benthos and mangroves. This study focuses on tidal flats along 10 km of coastline in the middle Ha Long and Cam Pha cities. The coastal areas are mainly fed by sediments transported from Nui Beo and Ha Tu coal mines via the Lo Phong and C2 rivers (Fig. 5). The two rivers are around 15 m to 30 m wide and 7 km long, but they are the unique drainage system in the study area.

3. Materials and Methods

3.1. Data in use

This study aims to assess the changes of tidal flats in Ha Long-Cam Pha area, Quang Ninh province, Vietnam by comparing the DEMs of tidal flats. DEMs are generated from a series of waterlines which are extracted from multi-temporal satellite images. Elevation of DEMs is synchronized from tidal levels. The accuracy of built DEMs depends on the accuracy of the waterlines extracted from satellite images. Besides, this study also accesses the relationship between coal mining activities and the tidal flat changes. Thus, the study needs not only the tide level and the satellite images but also the information on productivity, the coal mine expansion, and the area of waste rock dumps.

Satellite images and tidal levels

Remote sensing data used to analyze the variation of tidal flats are 37 Landsat images including 19 Landsat 5 TM, 13 Landsat 7 ETM+, and 5 Landsat 8 OLI. In those images, three scenes consisting of Landsat 5 acquired on 19th August 1989, Landsat 7 acquired on 09th August 2000, and Landsat 8 acquired on 21st June 2014 are used to determine the change of coal exploitation areas. Landsat images are collected from the United States Geological Survey (USGS) website in three periods 1989-1990, 1999-2001, and 2013-2014. These satellite images have been systematically processed at Landsat Surface Reflectance High-Level Data products (Tab. 1). It means that the acquired images are minimized the effects of atmosphere and the distortion related to topography. Simultaneously, these images have been adjusted to 30m spatial resolution in Universal Transverse Mercator (UTM) projection zone 48N. To minimize the effect of wind, waves on the accuracy of tidal level estimation, the satellite images acquired at the wind speed of greater than 10 m/s are not used in the experiment.

Tide level is the crucial parameter for tidal flat researches. In this study, tide levels are not only used as the criteria for selecting satellite images but also as the referent elevation for the DEMs. The tide level is real-time estimated using hydrological models from the Service Hydrographique et Océanographique

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de la Marine (SHOM) service at the Hon Dau port in Do Son, which is located at Latitude 20°40'6.53"N, Longitude 106°48'53.50"E. Tidal levels are estimated at the acquisition time of every Landsat image (Tab. 1).

Tab. 1. Landsat image list (L7- Landsat 7 ETM+; L8 – Landsat 8; L5 - Landsat 5 TM).

Sensor	Acquisition date	Tidal level (m)	Sensor	Acquisition date	Tidal level (m)	Sensor	Acquisition date	Tidal level (m)
L8	20131109	3.21	L5	20001105	3.07	L 5	19901110	3.46
L7	20130914	3.01	L5	20001004	2.76	L5	19901025	3.25
L7	20130829	2.61	L7	20010929	2.49	L5	19881104	2.78
L7	20140104	2.5	L7	20000809	2.27	L5	19890920	2.56
L8	20131008	2.1	L5	20000630	2.09	L5	19891123	2.4
L8	20131227	1.9	L5	20001223	1.71	L5	19881120	2.21
L7	20131203	1.84	L7	20010524	1.58	L5	19890616	2.0
L8	20140621	1.61	L5	20010329	1.49	L5	19930915	1.79
L8	20130602	1.31	L5	20010820	1.22	L5	19900806	1.47
L7	20140731	1.23	L7	20010321	1.14	L5	19910606	1.24
L7	20130712	1.01	L7	20010711	0.83	L5	19890819	0.96
L7	20150413	0.75	L7	20000606	0.65	L5	19900518	0.81
						L5	19930526	0.5

Data of coal mining activities

Coal mining activities are presented by coal production, waste rock dump, and coal exploitation area. Coal production and waste rock stockpiles are collected from Ha Tu and Nui Beo mines as listed in Tab. **2**. The values of coal mining activities are origined from official reports of the mines in the years 1989, 2000, and 2014. The coal exploitation area is extracted from corresponded Landsat images.

Tab. 2. Coal production of Ha Tu and Nui Beo mine.

	Ha Tu		**Nui Beo**	
Years	Waste rock dump (m^3)	Coal production (m^3)	Waste rock dump (m^3)	Coal production (m^3)
1989	2,959,353	66,468	586,860	48,342
2001	3,516,803	804,740	1,592,713	389,627
2014	19,594,611	1,460,054	14,352,410	1,751,676

3.2 Methodology

To figure out the impacts of coal mining activities on tidal flat changes in Ha Long- Cam Pha area, the satellite images, information of coal mining activities, and fieldwork data are combined in this study. Several methods are emploited including the satellite image classification to detect coal mining areas, the waterline method to construct the DEM of tidal flats, spatial analysis methods to quantify the change of

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tidal flats, and the sediment sample analysis to determine the organic matter, carbonat content and sediment size. Besides, the a field trip is carried out to collect samples. The overall processes are outlined in a flow chart in Figure 1.

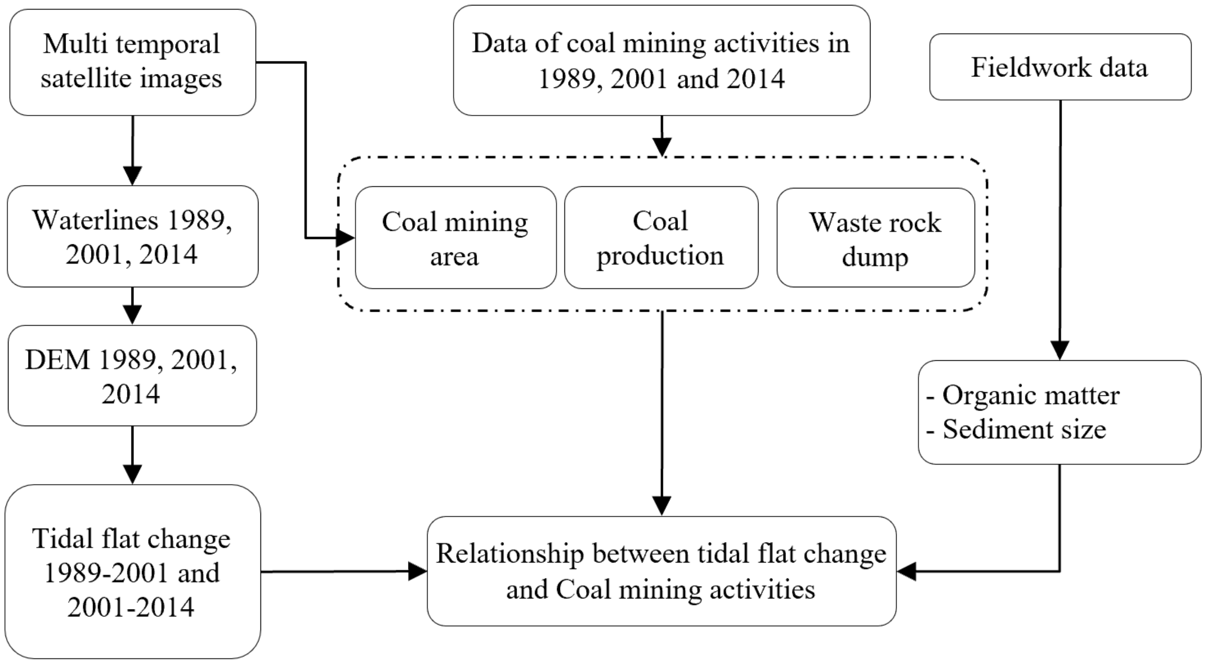

Fig. 1. Flow chart on methodology.

Mapping coal mines

The coal mining area is identified, based on the object-oriented classification method applied for Landsat images acquired in 1989, 2001, and 2014. The object-oriented classification method overcome the challenge caused by the spectral mixing between some surface objects in the coal exploitation area such as bare soil and waste rock dump [13,14]. The extraction of object-oriented features is processed with two steps; the image segmentation, and classification. Firstly, the image is discriminated into discrete segments based on statistical parameters of the image, which are compositing of the color, shape, compactness, and smoothness. Secondly, these segments are classified using features and criteria set by the user. The coal mining and waste rock dump areas in 1989, 2001, and 2014 are compared to each other to quantify the changes.

Constructing DEMs of tidal flats

To construct DEMs of tidal flats, we deploy the waterline method proposed by Mason et al., 1995 [8]. The ratio image calculated by dividing the short-wave infrared band from the green band, is used to extract the waterlines on satellite images in a coal tidal flat. The use of this ratio image is according to the suggestion from the previous study [5]. In total, 37 waterlines are generated from 37 free-cloud Landsat images acquired during the years 1989, 2001, and 2014. With an assumption that water levels at any location along a waterline are equal, these waterlines are assigned tidal levels at the acquisition times of satellite images to become contour lines. The contour lines are then used to construct a Triangular Irregular Network (TIN). The TIN model is a digital model to present geographic data by a triangular vector network of vertices. TINs created in 1989, 2001, and 2014 are then converted to corresponding DEMs with a 30 m pixel size using the linear interpolation method. Using the raster subtraction method, we subtract the DEM 2001 from DEM 2014 to quantify the erosion and deposition corresponding to negative values and positive values. The similar method is applied to the DEM 1989 and the DEM 2001 to observe the variation of tidal flats during the period 1989-2001.

Collecting and analyzing sediment samples

Sediment samples are collected and analyzed to discover the origin of the sediment. Along the 1.2 km transect counted from the coast to the lowest position of the tidal flat, we colect 5 samples at 5 positions named CP_River, CP1, CP2, CP3, CP4 (Fig. 2). In each position, we collected a sample with a 200 g weight on the top 5 cm deep layer of the tidal flats. Each sample is separated into 3 parts and dried at room temperature to analyse the grain size, organic matter, and carbonate content.

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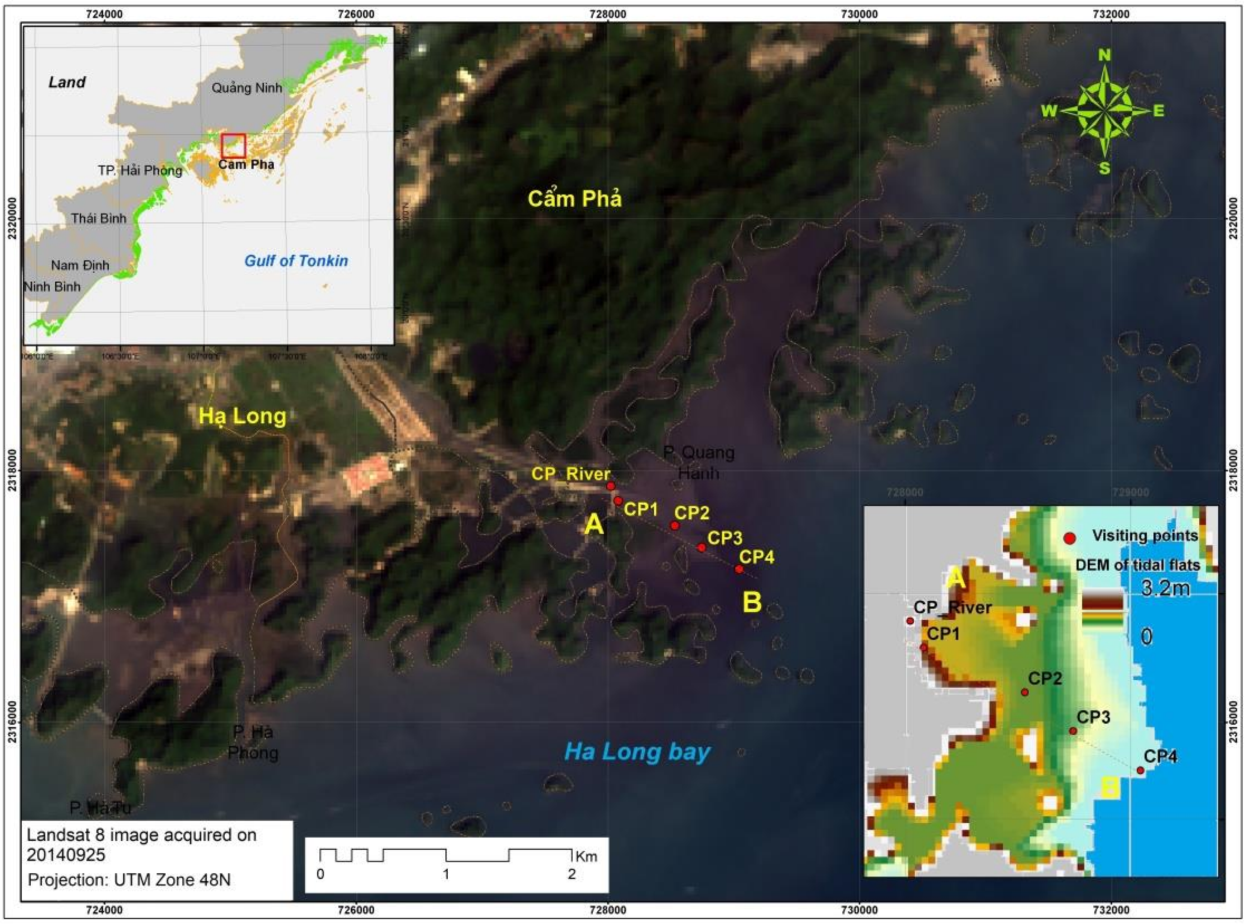
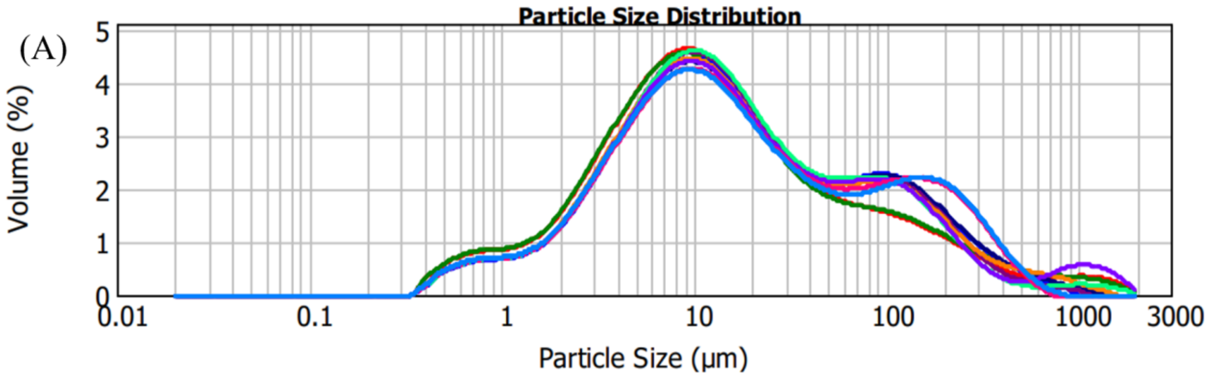


Fig. 2. Map of the study area and sample points on tidal flats in Ha Long-Cam Pha.

The sediment samples are dissolved in a solution before taking measurements using a Mastersizer device to detect the rain sizes. The Mastersizer uses a number of detector elements to capture the scattering pattern from the particles. The detectors take a "snap-shot" of the scattering pattern. Only particles passed through the analyzer beam at the time of snap-shot are captured. The measurement is repeatedly deployed in 3 snap-shots for each sample. The averaged results are used for the classification of particle sizes. Finally, sediment is classified into clay, silt, fine sand, medium sand, and coarse sand based on particle size (Fig. 3).



(B)

Clay (0-50 μm)	Silt (50-100 μm)	Fine sand (100-200 μm)	Medium sand (200-500 μm)	Coarse sand (500-2000 μm)

Fig. 3. (A) Sediment size statistics using the Mastersizer device with the colored curves corresponding to the number of measurements on a sample. (B) The scheme for classifying particle sizes.

Organic matter is strictly measured following standard ISO 12435 (1998). ISO 12435 is the international standard to specify a method for the spectrometric determination of organic carbon content in soil by oxidation in a sulfochromic medium. The standard is applicable to all types of air-dried soil samples with an exception of soils contained mineral reducing compounds, Cl- or Fe2+. Equipment for processing samples consists of 1/ Analytical balance with capable weighing 0.1mg. 2/ Heating block with capable maintaining 135° C ± 2° C, including 75 mL volumetric glass tubes. 4/ Centrifuge 5/ Glass fibre filters. 6/ Automatic pipette. 7/ Spectrophotometer (10 mm cuvette, 585 nm). To measure organic matter, each sample is dried at room temperature and milled until the particle size of samples is less than 250 µm. The organic matter of each sample is measured as the ratio of the amount of carbon in 1 kg of sample.

Carbonate minerals are mentioned as calcite (CaCO3), aragonite, and dolomite (CaCO3 and MgCO3). Carbonate content is investigated following the standard ISO 10693 in 1995. Carbon content is measured following the principle that the carbon present in the soil is oxidized to carbon dioxide. This process is carried out by heating the samples to at least 900° C in a flow of oxygen-containing gas. The amount of carbon dioxide released is then measured by using the infrared detection method.

4. Results and discussions

4.1. The variation of coal mine exploitation

Figure 4 illustrates the coal production in m^3, exploitation area in m^2, and waste rock dump in m^3 of Nui Beo and Ha Tu coal mines in 1989, 2001, and 2014. Nui Beo coal mine has just started to be exploited at an industrial scale in 1989 with a small amount of waste rock dump and coal production. However, the exploitation area is around 400 ha due to it has been illegally exploited by local people for a long time (Fig. 4a). The exploitation has a gradual increase in the period 1989-2001 indicated by a slight change of exploitation parameters. In the period 2001-2014, we witness a shape increase in the coal exploitation with the mass of coal production and waste rock dump growing from around 0.4 million m^3 to 1.8 million m^3 and from 1.6 million m^3 to 14.4 million m^3, respectively. Subsequently, the exploitation area rises doubly from around 500 ha to nearly 1000 ha in 2014. The expansion of exploitation area is observed mostly by the increase of soil dismantling and soil disposal area.

Figure 4b shows the variation of the waste rock dump and coal production in the relationship with the exploitation area of Ha Tu open pit mine. The mines in Ha Tu have been exploited for a long time before 1989, thus the statistic numbers of waste rock dumps and the exploitation area are large with 2.9 million m^3 and 770 ha in 1989, respectively. The waste rock dump is 3.5 million m^3 in 2001, lightly change compared to that in 1989, nevertheless, it dramatically rises to 19.6 million m^3 in 2014. On an opposite trend, the exploitation area increases by 130 ha during the period 1989-2001, but it gradually reduces by 50 ha from 950 ha in 2001 to 900 ha in 2014.

The continuous increase in all the activities of coal exploitation in Nui Beo during the period 2001-2014 denotes that the mine is in the exploiting outbreak state of the exploitation. The exploitation area is increasing along with the rise of the waste rock dump, is the typical characteristic of an open-pit mine which changes the landscape of the surrounding area. Inversely, the variation of statistic numbers in Ha Tu is an example of the exploitation at a stable stage. The dumping ground surrounding the exploitation center is gradually decreased by the plantation for environmental restoration. On the other hand, the coal production is collected from the official reports of coal mine companies which are joint-stock companies sharing the mines. For this reason, the number of production is normally including bias, thus it trend is not emphasized in this study.

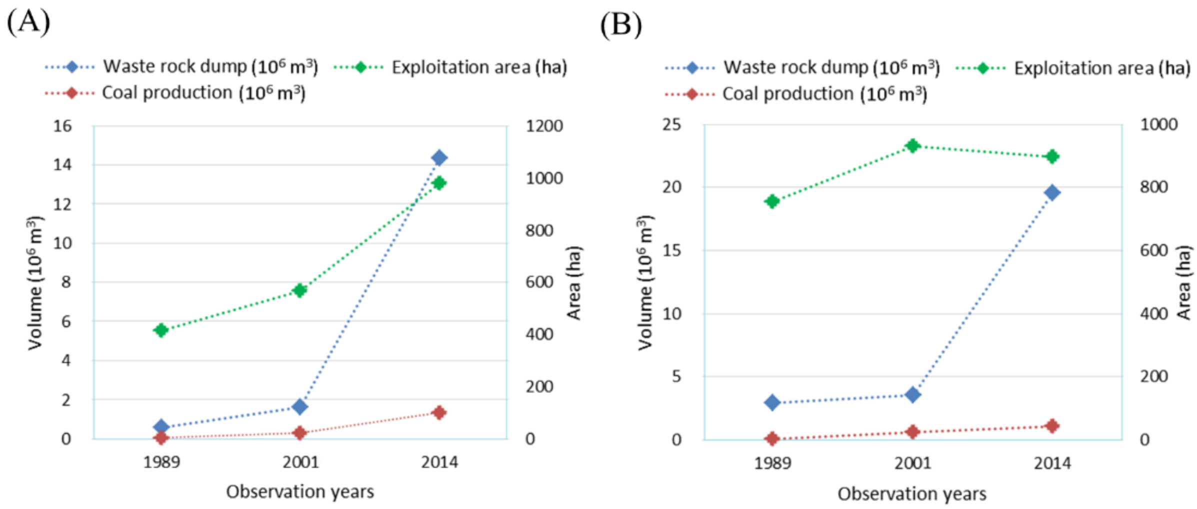


Fig. 4. (a) The variation of coal production, exploitation areas, and waste rock dump in 1989, 2001, and 2014 in (a) Nui Beo mine, and (b) Ha Tu mine.

4.2. The investigation of tidal flat changes

The changes of tidal flats are obtained by comparing DEMs of the tidal flats in 1989, 2001, and 2014. The DEM constructed in earlier years is subtracted from the one in later years to calculate the vertical changes of tidal flats. Negative values and positive values of the results correspond to vertical erosion and deposition. Vertical changes are multiplied with the area of a pixel-size (30 m x 30 m) to achieve the volume changes which indicates the amount of sediment loss or sediment concentration in m^3 unit. Fig. 5 illustrates the amount of sediment loss and sediment deposition on tidal flats during the period 1989-2014. The study area is characterized by numerous near-shore limestone islands which block suspended sediments to form tidal flats in the study areas. Accordingly, tidal flats are closer to the land and surrounded by islands, which tend to be higher deposition. Tidal flats in the Lo Phong river mouth with the red area have a higher rate of deposition than that of the C2 river mouth with the green areas.

To observe the cross-shore variation of tidal flats, 18 observation points are placed in even distribution along a cross-section of tidal flats at the C2 river mouth (Fig. 5). Figure 6 illustrates the volume changes of the tidal flat at 18 observation points in periods 1989-2001 and 2001-2014. The positive volume and negative volume correspond to the amount of sediment accretion and sediment loss in an 900 m^2 area during the periods. At the first observation point, the accretion occurs in both periods 1989-2001 and 2001-2014 with 1,008 m^3 and 621 m^3 positive volumes, respectively. The deposition is highest as the tidal flat is closest to the C2 river mouth. Tidal flats in the area from point 2nd to point 8th during two periods are similarly eroded with the maximum at more than 300 m^3 during 2001-2014. A contrasting variation of tidal flats between two periods is seen in the area from point 9th to the end of the tidal flat (point 18th). The tide flat from point 9th to point 14th experiences a strong deposition with the maximum accretion at 350 m^3 from 1989 to 2001, but it witnesses severe erosion during 2014-2020. Subsequently, an remarkable accretion is seen in the furthest area of tidal flat from point 15th to point 18th during the period 2001-2014, but the erosion is insignificantly observed during 1989-2001.

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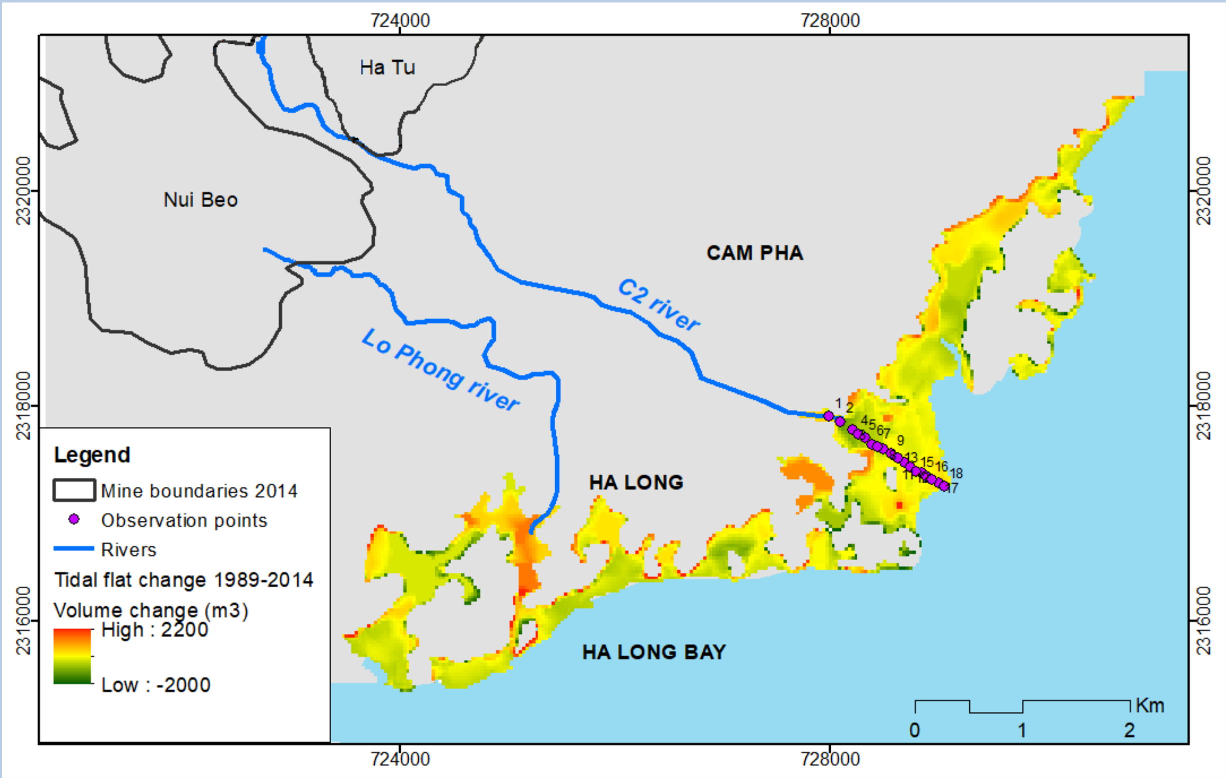

Fig. 5. Volume changes of tidal flats in the period 1989 – 2014 (m^3).

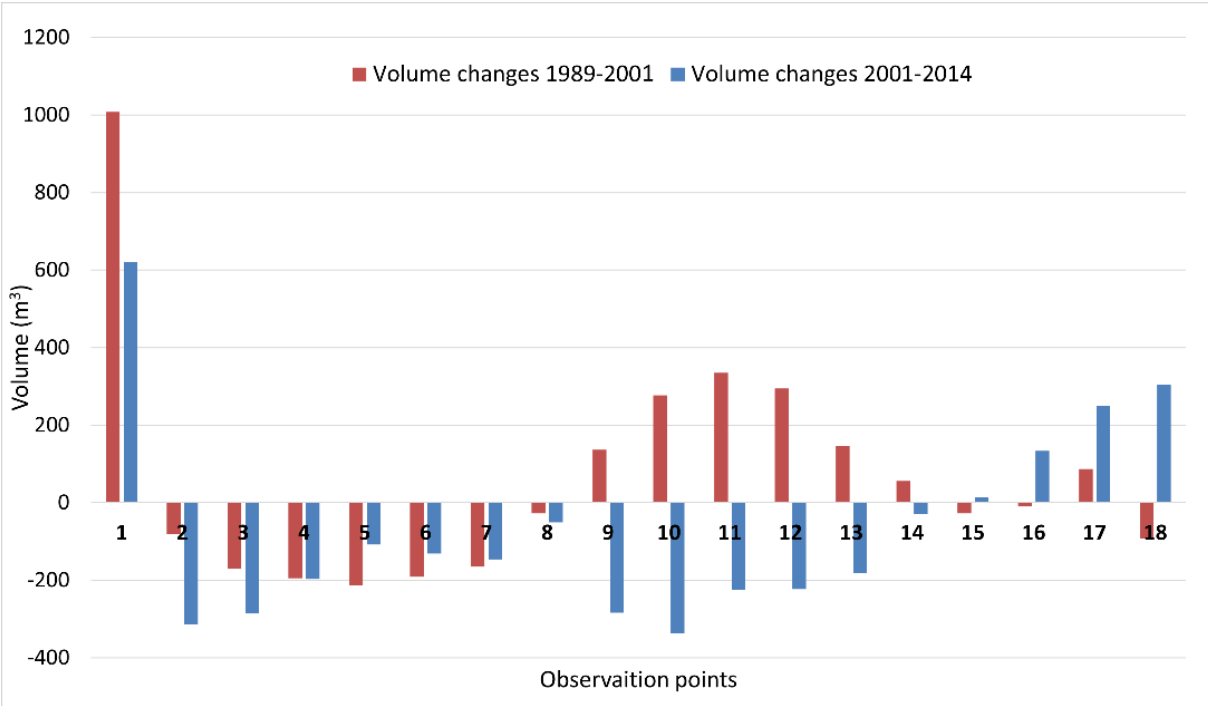

Fig. 6. The volume change of tidal flats along the observation points at the C2 River estuary during periods 1989-2001 and 2001-2014. The volume measured in m^3, is calculated in a ground area of 900 m^2 (pixel size 30 m x 30 m).

4.3 Sediment characteristic of tidal flats

Three parameters of sediment samples in this study are analyzed including sediment size, organic matter, and carbonate content. However, the carbonate content is insignificant (below 1 %) thus it is

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ignored and does not mention in other sections. Figure 7 illustrates the relationship between sediment characteristics and the topography along the cross-section in the tidal flat. The organic matter composed in sediment is from 459 g/kg to 607 g/kg (Fig. 7a). The CP_River sample is collected at the highest location of the tidal flats, closest to the C2 river mouth, which has the amount of 524 g organic matter per one kg sample. The farthest sample is collected at 1200 m from the C2 river mouth, at the lowest area of tidal flats, which has the highest concentration of organic matter with 607 g/kg. Generally, the organic matter in the tidal flat is gradually increasing from the mainland to the sea. The concentration of organic matter distributes oppositely with the elevation of tidal flats.

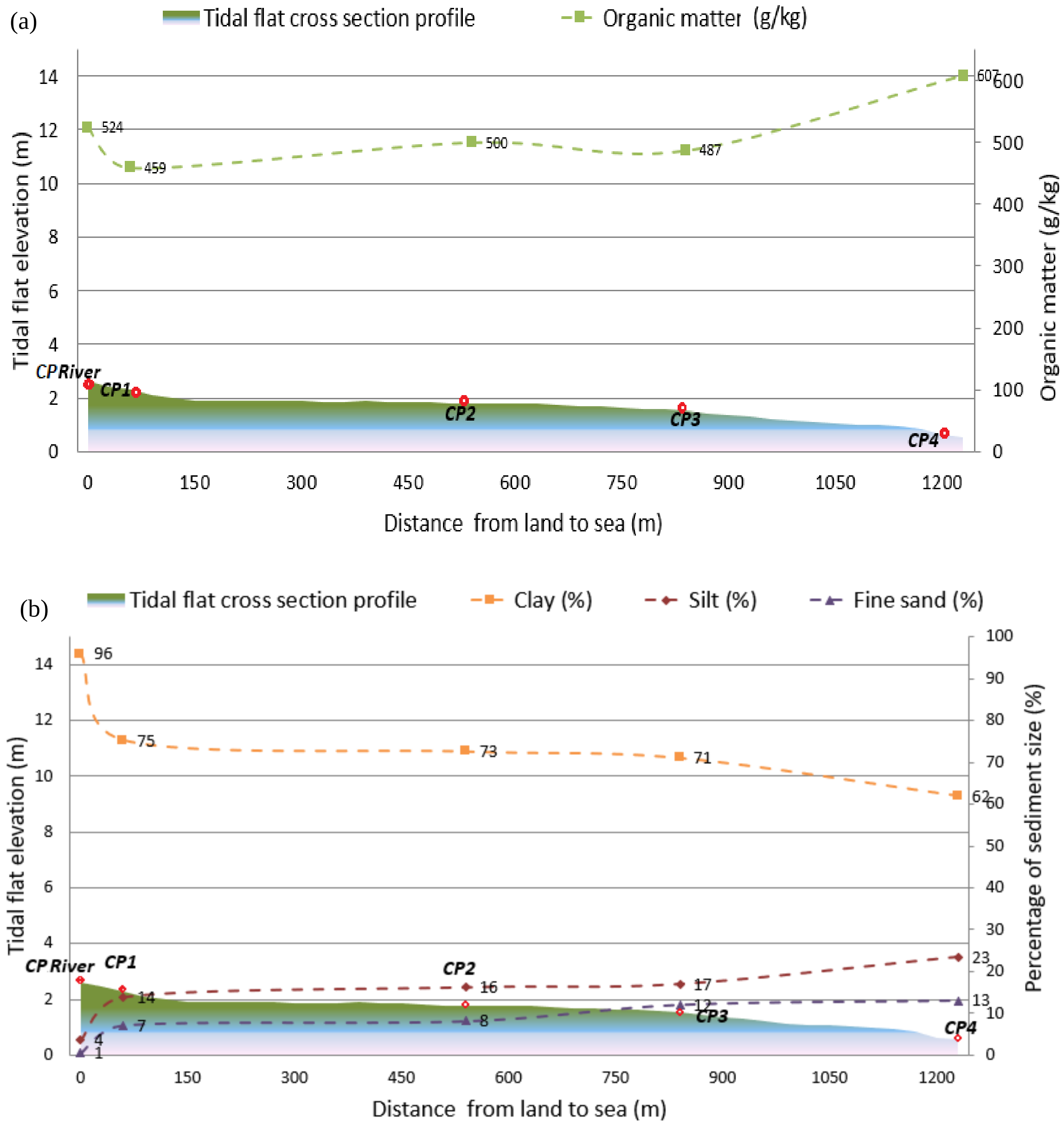

Fig. 7. (a) Organic matter and (b) sediment types distributing at 5 sample locations (CP River, CP1, CP2, CP3, CP4) in the tidal flat. Red points are the relative location of samples on tidal flats.

Figure 7b represents the distribution of sediment types in the correlation with the topography of the tidal flat. Only 3 types of sediment size are recognized in samples consisting of clay, silt, and fine sand. Clay with a size ranged from 0 to 50 µm, is predominant, which occupies more than 62 % of all the samples. Especially, the percentage of clay closing to the C2 river mouth reaches a maximum of 96 %. The concentration of the finer particles tends to gradually decrease seaward corresponding to the degradation of tidal flat elevation. The percentage of silt and fine sand occupies the small rest of the samples with a total from 5 % to 36 %. The concentration of these sediment types increases gradually seaward and correlates oppositely with the transition of tidal flat elevation.

4.4 Impact of coal exploitation on tidal flat changes

The impact of coal exploitation on the change of tidal flats is discussed in two aspects concerning 1/ the origin of sediment which forms the tidal flats and 2/ the correlation between the coal exploitation and the tidal flat variation.

To investigate the origin of the sediment forming the tidal flats, we attempt to analyze chemical and physical compounds in sediment samples collected in tidal flats. Organic matter, carbonate content, and particle size are three parameters that are measured in the study. The remains of the organism as animals, plants, and their waste products in the environment are the sources of organic matter [15]. Over millions of years, plant and mineral matter are undergone the processes of burial, compression, and heat to form coal. The rock is classified as coal since it must contain more than 50 % of organic matter [16]. As indicated in the previous sections, all sediment samples are composed of more than 50 % of organic matter, the rest of mineral such as carbonate content is insignificant. Besides, the sediment in the tidal flat is muddy and black [5]. Consequently, it is affirmed that the material forming tidal flats is coal particles, but we need to discuss more on the sources of coal particles which are originated from the ocean or from coal exploitation.

Ha Tu and Nui Beo are two open coal mines, occupies a large area of 1,400 ha, consisting of areas for coal exploitation, coal product storage, restoration area, rocky disposal, area for coal processing services, and transporting coal products, etc. All of these areas and relating coal mining activities disperse coal particles in various sizes into the water, soil, and atmospheric environment. These areas of the two mines are within the watersheds of the two rivers C2 and Lo Phong. Coal and other particles in the environment follow water flows to gather in these rivers then they are transported and spread out the near-shore water of the river mouths. The amount of suspended particles transported to the river mouths is extremely high during the rainy season. Besides, The coastal area of the study area suffers the effect of tide domination with calm water as the wind and waves are obstructed from the sea by thousands of islands in Ha Long bay. In calm conditions, suspended particles tend to settle in the shallow waters rather than moving offshore [17]. Moreover, the high percentage of organic matter containing in all sediment samples in tidal flats indicates the insufficiency of nutrients for animal habitats and plants that lead to little benthos and mangroves living in tidal flats [15]. The pure coal tidal flats with rare living things mean the tidal flats are continuously and instantaneously deposited or replaced with coal particles. For those reasons, the material which formed the tidal flats in the study area is of continental origin. According to the above discussions, it is concluded that the coal tidal flats in the study area are the consequence of coal exploitation activities in the land.

One of the objectives of this study is to figure out the relationship between the change of tidal flats and the variation of coal exploitations. Tidal flat changes in periods 1989-2001 and 2001-2014 are determined using corresponding satellite data. The quantity of coal exploitation is consisting of coal production, waste rock dump, which are collected from the reports of the mine managers. The exploitation area is determined on satellite images. During the period 1989-2001, the amount of waste rock dumps and coal production from both mines are small compared to that of the period 2001-2014 corresponding to 1.56 x 10^6 m^3 and 28.84 x 10^6 m^3 (Tab. 3). Simultaneously, the volume change of tidal flats is small with the sediment loss of 0.06 x 10^6 m^3 from 1989 to 2001. According to Tong et. al. [5], the elevation error of DEM constructed in this study is 0.144 m, the uncertainty of volume changes in 122.4 ha tidal flats in the study area is ± 0.176 x 10^6 m^3. The uncertainty is much greater than the change volume detected in tidal flats in 1989-2001, thus this change is insignificant. The sharp increase of waste rock dump and coal production in the period 2001-2014 may contribute to the accretion of tidal flats with 0.37 x 10^6 m^3 positive changes. Although the more exposition of coal rubbishes to the environment, or more active coal mines generally boost up the amount of sediment transported to the near-shore water, it is hard to affirm the direct effect of coal mine exploitation on the quantitative changes of tidal flats using one or two observations. Besides, the sediment transport in tidal flats is controlled synthetically by 5 main forcing physical processes as the waves, the wind-induced circulation, the tide, the density-driven circulation, and the drainage [18]. Among these processes, the effect of drainage processes including sediment transport upon the tidal flat evolution has not been sufficiently indicated [19]. Consequently, the increase of coal mining activities is simultaneous with the deposition of the tidal flats in this experiment. However, the long-term effect of coal mining activities on the evolution of tidal flats is probably figured out since numerous temporal observations are investigated using remote sensing data. This research direction should be continued in future studies.

Tab. 3. Tidal flat changes and the variation of coal mining activities calculated from both Nui Beo and Ha Tu mines.

Periods	Waste rock dump (10^6 m^3)	Coal production (10^6 m^3)	Exploited area (ha)	Tidal flat change (10^6 m^3)
1989-2001	1.56	0.81	327	-0.06
2001-2014	28.84	1.52	380	0.37

5. Conclusions

As an example for the assessment of the coal mining exploitation affecting the coastal area, this study attempts to determine the relationship between the tidal flat changes and the coal mining activities. Volume changes of tidal flats during two periods 1989-2001 and 2001-2014 are estimated using multi-temporal satellite images integrating instant tidal levels. Besides, the physical, chemical characteristics of sediments in tidal flats are analyzed. Coal mining activities of two open-pit mines are investigated according to three parameters consisting of waste rock dump, coal production, and exploitation area. The study has proved that the material constituted and formed the tidal flats are originated from the coal mining activities based on the characteristics of sediment samples. Although the increase of coal exploitation is simultaneous with the accretion of tidal flats in one period, it should be used numerous of observations to figure out the long-term impact of coal exploitation on the evolution of tidal flats. This issue opens a future study of applying the advance of information technology on a huge number of satellite data for long-term monitoring of the coal tidal flats changes.

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