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Spatial analysis for coastal zone changes related to land utilization

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Abstract

This paper introduces a spatial regression technique to analyze the relationship between coastal zone change and land use type along the Chao Samran beach in Thailand. The results indicate that from 1999 to 2011, Chao Samran beach eroded severely during 2005–2006 and 2009–2010; the areas that eroded were 1.36 km^2 and 1.38 km^2, respectively. In addition, the study also found accretion in 2004–2005 and 2008–2009, with deposition areas of 1.49 km^2 and 1.47 km^2, respectively. The critical area was in the southern part, with an erosion rate of more than 5 m/yr, followed by the center part, with erosion rates ranging from 1 to 4.9 m/yr. In contrast, the northern part experienced a maximum accretion rate of over 10 m/yr. Land use change showed clear trends, with aquaculture and salt flats, agriculture and rice fields, urban areas, and mangroves increasing respectively. A relationship analysis also found that increases in the urban area had the most influence on erosion, followed by increases in aquaculture, bare land, mangroves, and agriculture, respectively. In addition, the land use types that influenced accretion were, in descending order, urban area, aquaculture, mangroves, bare land, and agriculture.

Keywords: Spatial analysis; Coastal zone change; Land utilization

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1. Introduction

The coastal region of Thailand has suffered from erosion over a long period of time. Development or expansion of these coastal zones causes an imbalance along the coastline. Also, seasonal changes in current and wind-produced waves enhance the rate of loss for coastal land, government property, and residents in these areas. However, in many critical areas, most of the erosion is human-induced, through inappropriate land use, port and dam construction, and overuse of groundwater resources (Office of Natural Resources and Environment Policy and Planning, 2009). It has been documented that severely eroded land has occurred along the coastline, with an average erosion rate of 5 m/yr (Geoinformatics and Space Technology Development Agency, 2010; Siripong, 2010). A report by the FAO in 2007 stated that the erosion problem becomes worse whenever the applied countermeasures (i.e., hard or soft structural options) are inappropriate, improperly designed, built, or maintained, and if the effects on adjacent shores are not carefully evaluated. Moreover, in many coastal communities, the tourism industry is the mainstay of the local economy. Unfortunately, both tourism resources and the tourism industry are now threatened by dramatic coastal changes induced by human activities (Allen, Lu, and Potts, n.d.). 95% of land use decisions are made at the local level (Kleppel, 1998). The impacts of land use change for any purpose and exploitation of the coastal zone could be factors regarding coastal zone changes (Pearce 1995; Fedra and Feoli, 1998; European Commission, 2004; FAO, 2007 and DMCR, 2012).

The previous research on land use and coastal zone change at this level is not adequate and used conventional methodologies that have some limitations regarding spatial detection, long-term monitoring, assessment, modeling (assimilation), and prediction of coastal zone change (Allen, Lu and Potts, n.d.; Pearce, 1995; Klinebubpha and Pumijumnong, 2011). A major problem with the most common statistical modeling technique and standard applications of regression when applied to spatial data is that the processes being examined are assumed to be constant over space – that is, one model fits all. Therefore, the use of an appropriate statistical technique for spatial analysis is important. By far, the most common statistical modeling technique is regression, and it is used mostly in the social sciences. The combination of statistical techniques and spatial analysis for scientific research is still not widely used.

For this research, Chao Samram beach in Petchaburi province was selected as the study site. One of the major environmental problems at Chao Samran beach is coastal erosion, with an erosion rate of about 3–4 m/yr (DMCR, 2012; GISTDA, 2012). Because of this problem, the Hat Chao Samran municipal district coordinated with the Marine Department and allocated a budget to build breakwaters to prevent erosion and to maintain the whole beach. Breakwaters were completed in 2008. In addition, Chao Samram beach is adjacent to Chaam beach, one of the tourist beaches of Petchaburi province. Therefore, it is experiencing rapid changes in economic growth. The land use changes there had been planned at various spatial levels and within various time periods based on the strategic plan for the development of the area. Thus, land utilization in this area could be a factor regarding the coastal zone changes. On the other hand, the erosion problem may have caused socio-economic impacts in this area (DMCR, 2012) .

This research focused on three objectives. The first was to appraise the long-term situation related to changes along Chao Samran beach and the adjacent area in Petchaburi province. The second was to analyze the changes in land use in the coastal zone. The last was to apply a spatial regression technique to gain an understanding of the relationships among land use types that could be factors regarding the coastal zone changes. It is hoped that this study will provide a correlation between land use type and coastal zone change using a spatially based technique that will lead to a better understanding of coastal zone management in the long-term.

2. Material and methods

The study site is located along 7 km of Chao Samran beach and 4 km of adjacent beaches in Petchaburi province, as shown in Figure 1. It is a straight sand beach in the Hat Chao Samran municipal district**.** The Hat Chao Samran commune has a total area of 19,445 km^2 and consists of seven villages with a total population of approximately 4,532 people (Hat Chao Samran municipal district, 2012). The materials used in this study included LANDSAT images from 1999–2011, a THAICHOTE image from 2012, Differential Global Positioning System (DGPS), GPS, boat, digital camera, eCognition Developer 64, and ArcGIS software.

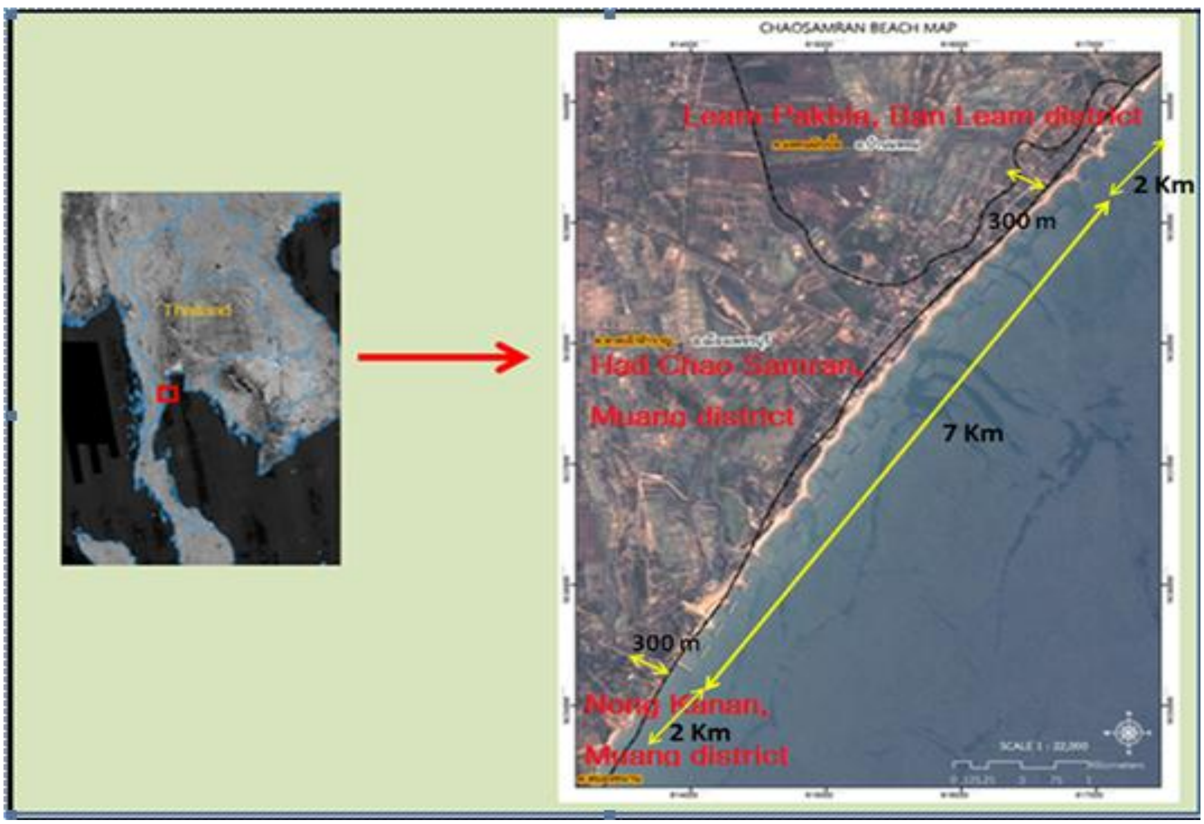

Figure 1. The study area located along Chao Samran beach, Petchaburi province, Thailand (Source: THAICHOTE image, GISTDA, 2012)

There were three main processing steps:

- 1) analysis of long-term coastal zone changes using LANDSAT images from 1999 to 2011,

- 2) detection of land use changes, and
- 3) analysis of the spatial correlations between land use types that affected coastal area changes. The overall methodology flow chart is shown in Figure 2.

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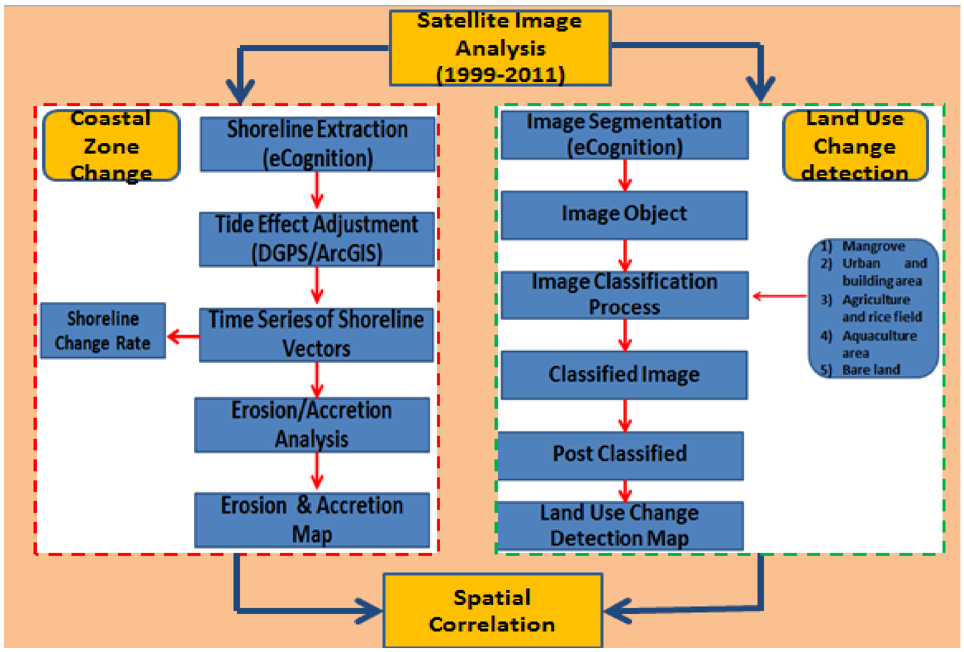

Figure 2. Overall methodology flow chart

2.1. Coastal zone changes

Coastal zone changes were investigated using remote sensing techniques and spatial data analysis. LANDSAT satellite images at 30-m resolution taken from 1999 to 2011 were selected as the input data. All satellite images were rectified and extracted into a time series of shoreline vectors using object-based analysis techniques provided by eCognition Developer 64 software. The accuracy of shoreline mapping is based on the tide-coordinated shoreline (Li, Ma, and Di, 2002; Striping A., 2010); thus, the effects of tides need to be included. A time series of shoreline vectors was processed to determine the erosion and accretion areas using the union and intersect techniques provided by the Arc Toolbox of ArcGIS. Finally, a baseline measurement method was introduced to calculate the erosion and accretion rates from a time series of shoreline images using the Digital Shoreline Analysis System (DSAS) (Himmelstoss, 2009).

2.2. Land use change and the growth of the community

The changes in land use for the past 10 years were derived from the satellite images. The rectified LANDSAT images during 1999 and 2011 were processed using image segmentation and classified images. The image classification process involved these steps: create a rule set, classify thresholds, supervise classification, post classification, and mapping. The images were classified into five land use types:

- 1) Mangroves,
- 2) Aquaculture and salt flats,
- 3) Agriculture and rice fields,
- 4) Bare land, and
- 5) Urban and building area.

The classified images were checked for accuracy by a ground truth survey, and the classified maps were then analyzed using the post classification technique. The growth of the community was reflected by the expansion of the urban area, along with the growth of income and population. This assessment was obtained by viewing a time series of land use detection THAICHOTE images at 2-m resolution. Moreover, the collection and synthesis of data from the Petchaburi provincial statistical office report, the Hat Chao Samran municipal district report, and census data were used for the statistical analysis.

2.3. Spatial regression analysis

To analyze the correlations among land use types and the changes in the coastal area, the spatial relationships modeling toolset including Ordinary Least Squares (OLS) and Geographically Weighted Regression (GWR) was used to provide spatial regression techniques. OLS and GWR allowed the modeling of processes that varied over space (Charton, Fotheringham, and Brunsdon, 2002).

The modeling of spatial relationships is considered to be a local regression model and is given by:

$$Y_i = a_0(U_i, V_i) + \sum_k a_k (U_i, V_i) X_{ik} + \varepsilon_i \qquad (1)$$

where, (U_i, V_i) denotes the coordinates of the i^{th} point in space and $a_k(U_i, V_i)$ is a realization of the continuous function $a_k(U,V)$ at point i.

We allowed a continuous surface of parameter values, and measurements of this surface were taken at certain points to denote the spatial variability of the surface. In determining the spatial relationships, an observation was weighted in accordance with its proximity to point i, so the data from observations close to i were weighted more than data from observations farther away. It was assumed that observed data near point i have more of an influence in the estimation of the $a_k(U_i, V_i)$'s than data located farther from i.

Regression analysis terms and concepts are given by ESRI (2013), which states that reliable statistics for examining and estimating linear relationships are provided by the regression equation below:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots\ldots\ldots\ldots + \beta_n X_n + \varepsilon \qquad (2)$$

Where,

Y = Dependent variable

X_i = Independent/Explanatory variables

β_i = Regression coefficients / β_0 = Regression intercept

ε = Residuals / random error term

The analysis of spatial regression between coastal area change and the type of land use from 1999 to 2011 was done using the spatial statistical technique in Eq.2. Thus, we utilized the following variables:

Dependent variables: Y_1 = Erosion area and Y_2 = Accretion area

Independent variables: X_1 = Mangrove area

X_2 = Aquaculture and salt flat area

X_3 = Agriculture and rice field area

X_4 = Bare land

X_5 = Urban and building area

3. Results and discussion

3.1. Coastal zone change situation

The changes in the coastal zone including Chao Samran beach for the past 10 years were differentiated by two periods: before the breakwater (1999–2007) and after the breakwater's construction (2009–2011). Table 1 show that the beach at Chao Samran changed markedly in 2005–2006 and 2009–2010, with areas of 1.36 km^2 and 1.38 km^2, respectively, being eroded. In addition, the study also found accretion in 2004–2005 and 2008–2009, with deposition areas of 1.49 km^2 and 1.47 km^2, respectively. Coastal areas were severely eroded during the years 2005–2006, causing the Hat Chao Samran district to create a breakwater to protect the beach. The breakwater was completed in 2008. It is obvious that in 2008–2009 the beach accreted deposited material, especially along the middle of Chao Samran beach. However, the interest in the coastal erosion that occurred after 2009 still remains.

Table 1. Erosion and accretion areas from 1999 to 2011

Year	Erosion Area (Km^2)	Accretion Area (Km^2)
1999 & 2000	0.27	0.17
2000 & 2001	0.02	1.02
2001 & 2003	0.33	0.20
2003 & 2004	0.98	0.05
2004 & 2005	0.04	1.49
2005 & 2006	1.36	0.06
2006 & 2007	0.34	0.18
2007 & 2008	0.24	0.28
2008 & 2009	0.03	1.47
2009 & 2010	1.38	0.16
2010 & 2011	0.29	0.62

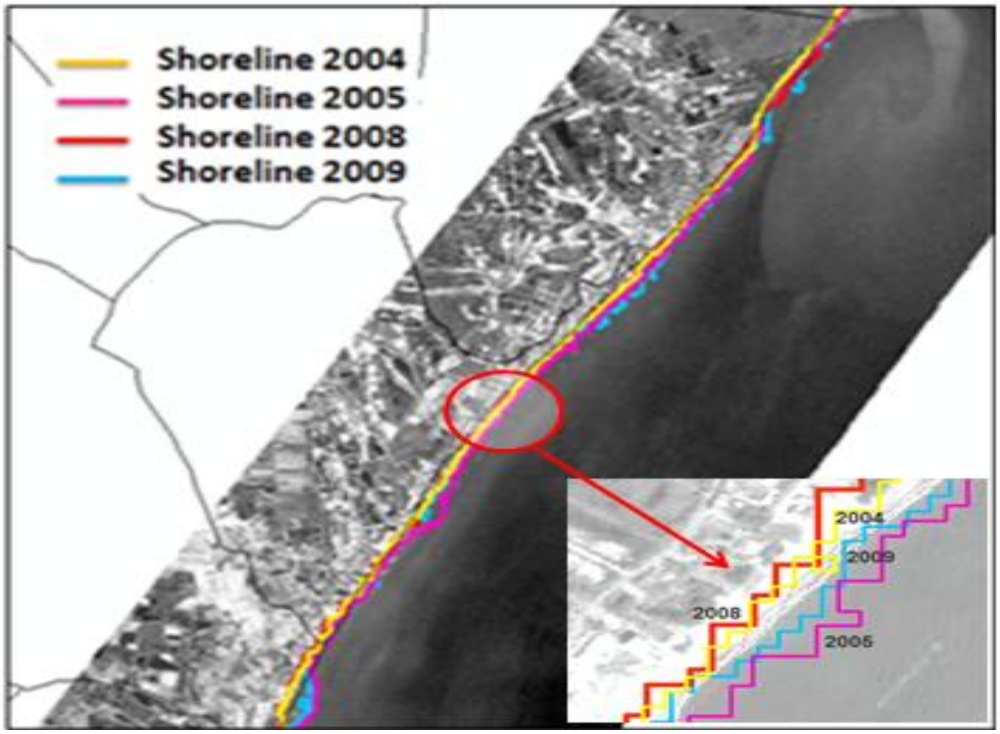

Figure 3. Maximum erosion area during 2005-2006 was about 1.36 km^2, and that during 2009-2010 was about 1.38 km^2

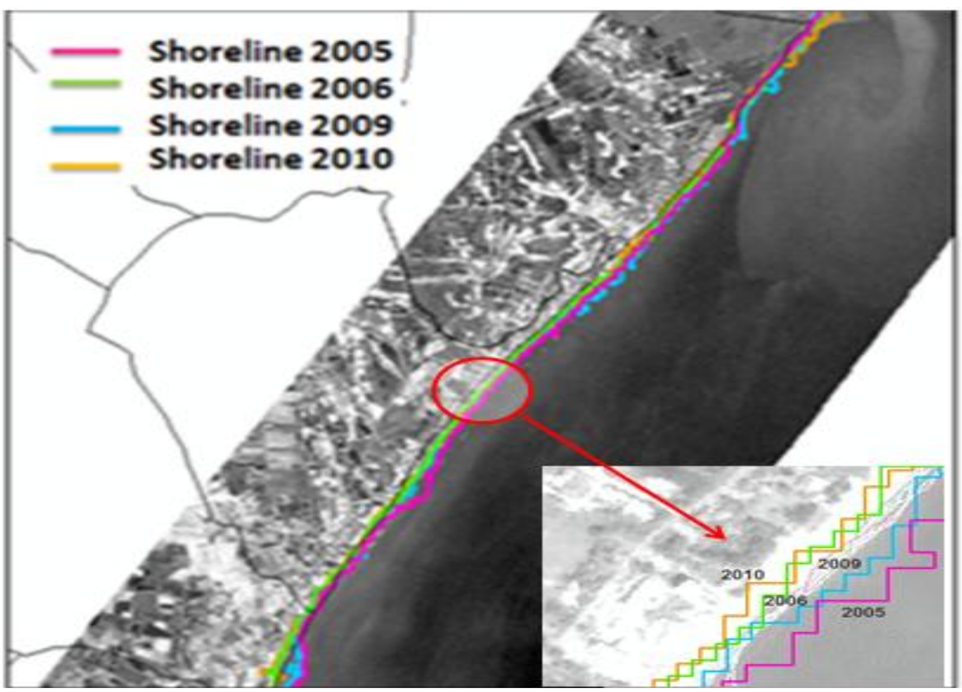

Figure 4. Maximum accretion area during 2004-2005 was about 1.49 km^2, and that during 2008-2009 was about 1.47 km^2

Calculation of the change rate from 1999 to 2011 as shown in Figure 5 indicated that the southern part of the study area experienced a severe erosion rate of more than 5 m/yr, followed by the center part, which had erosion rates ranging from 0 to 4.9 m/yr and accretion rates of 1–10 m/yr. The area in the northern part experienced a high accretion rate of over 10 m/yr. This classification is according to Sinsakul et al. (2002) and DMCR (2012), which concluded that coastal changes can be classified as the following in accordance with severity criteria:

- Severely erosional coast with an erosion rate of more than 5 m/yr.
- Moderately erosional coast with an erosion rate of 1–5 m/yr.
- Depositional coast with a deposition rate of 1–5 m/yr.
- Stable coast with a change rate of ±1 m/yr.

The upper part of the Chao Samran beach area consists of mangrove stands, which cause the deposition of a natural beach. The middle part of the beach had severely eroded. However, after the breakwater was completed in 2008 to protect the beach, it caused this part to have medium levels of both erosion and deposition. For the lower part of Chao Samran beach, which had the most severe erosion, it was possible that the bare land there caused the erosion as a result of an imbalance of sediment movement in the area.

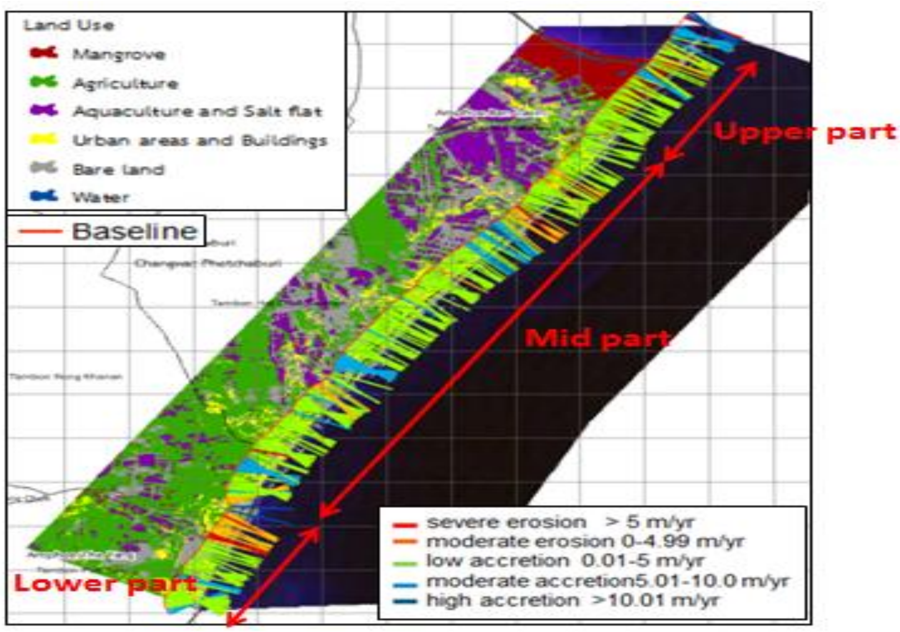

Figure 5. Coastal area change rate analyzed by the Digital Shoreline Analysis System

3.2. Factors affecting coastal zone change

3.2.1. Weather characteristics

The historical data for tropical cyclones in the past 60 years shown in Figure 6 reveal that the wind-wave characteristics and monsoon intensities clearly affected the beach area before 2007. Conversely, after 2008, they indicate that the change in coastal area was not related to the monsoon factor.

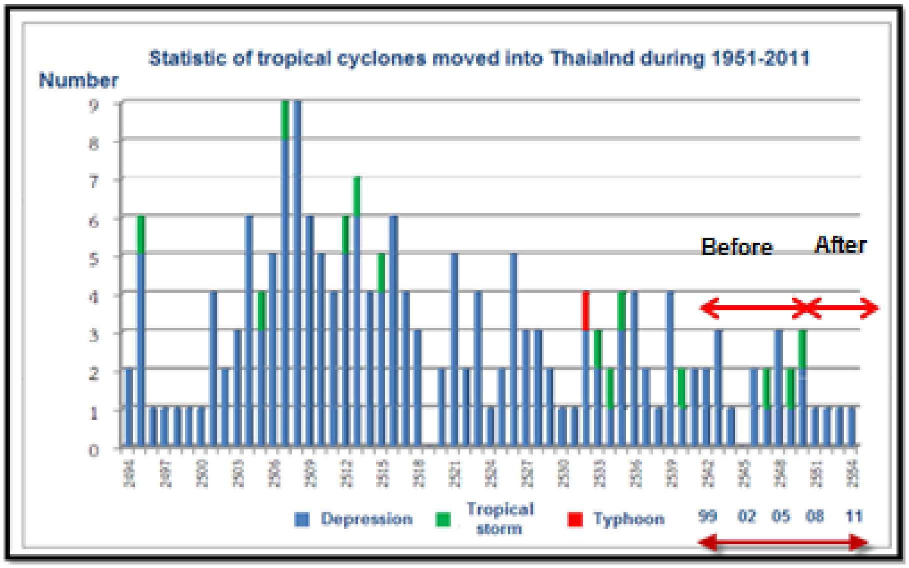

Figure 6. Historical data for tropical cyclones in the past 60 years (Source: Meteorological department, 2007)

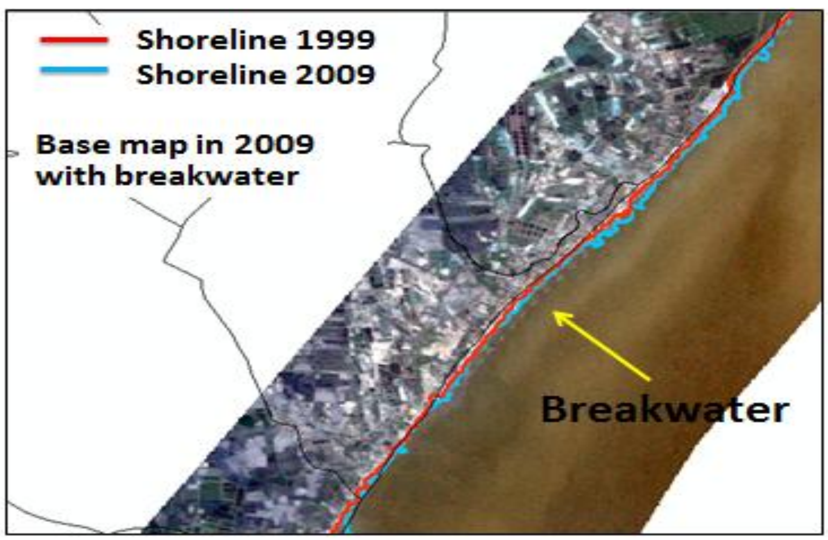

Figure 7. Scenario for the coastal sediment transport that accretes on the front of the breakwater and erodes behind the breakwater. Dotted line is the coastline (Source: Satumanatpan, 2012)

3.2.2. Breakwater construction

The changes in the coastal area could be due to anthropogenic activities such as the protection for the beach that was built in 2007–2008. The construction of the breakwater caused a marked sediment imbalance in this area, especially after 2009. The deposition of sediments will increase on the front and erosion will increase on the back side of the breakwater (Satumanatpan, 2012; Taveira-Pinto, Silva, and Pais-Barbosa, 2011).

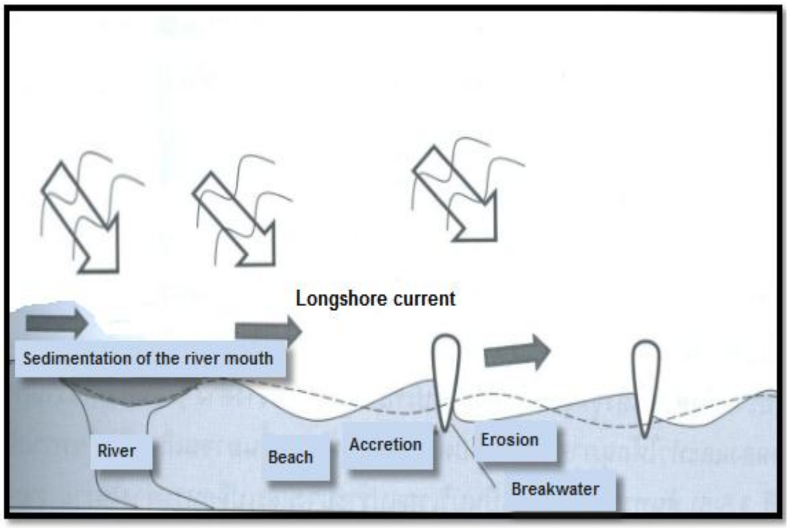

Figure 8. The shoreline in 1999 compared to 2009 shows the maximum accretion area in 2009

3.2.3. Land use change and expansion of the urban area along the coast:

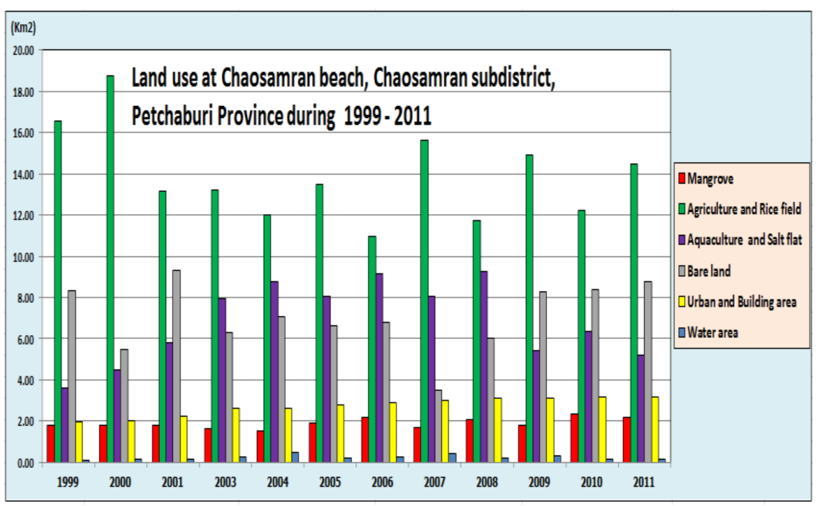

Figure 9. Land use utilization at Chao Samran beach during 1999–2011

Land usage was investigated using LANDSAT satellite images from 1999 to 2011. The land use types were classified into five categories, namely mangroves, agriculture and rice fields, aquaculture and salt flats, urban and building area, and bare land.

Between 1999 and 2011, most of the coastal area was used for agriculture, especially rice cultivation, with the maximum in the year 2000; this land use is still ongoing. The second most common land use was for aquaculture and salt flats, with the amount increasing from 1999 to 2008, and after that decreasing from 2009 to 2011. The next most common use was for the urban areas and buildings, which have been continuously increasing since 1999. The variation in the amount of bare land was related to the variation of aquaculture area. The least common land use was the mangrove area, which changed less than the other areas. According to synthesis data from the Petchaburi provincial statistical office and the strategic development plan report of the Hat Chao Samran municipal district in 2012, agriculture was the main income source of the Hat Chao Samran municipal district. Income from rice was 59.29% of the total and was followed by income from tourism, which accounted for 36.6%. An increase in the community density along the coast was also noted (Hat Chao Samran municipal district, 2012; Petchaburi provincial statistical office, 2012).

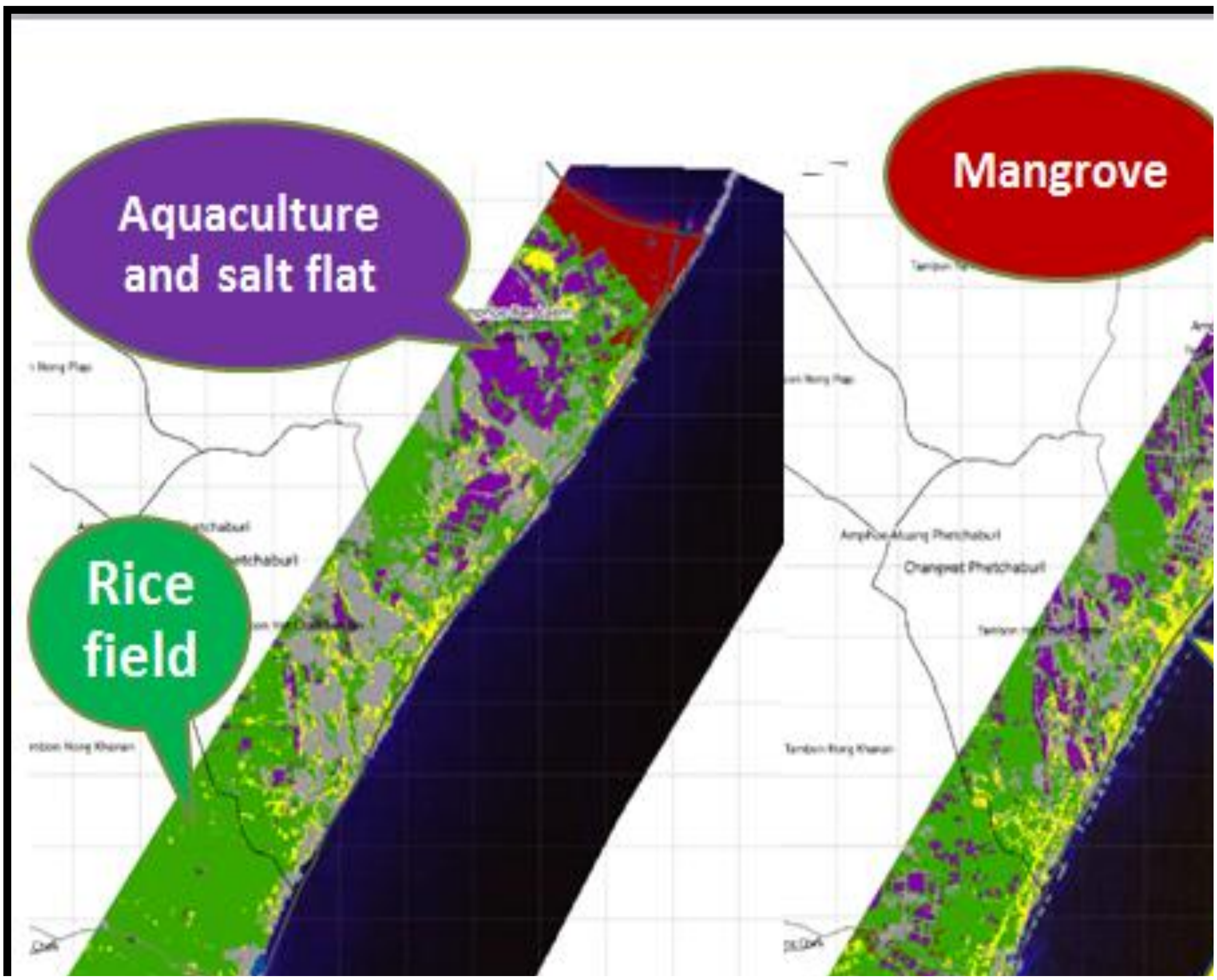

Figure 10. Illustration of the increase in urban area (yellow) along Chao Samran beach between 1999 and 2011

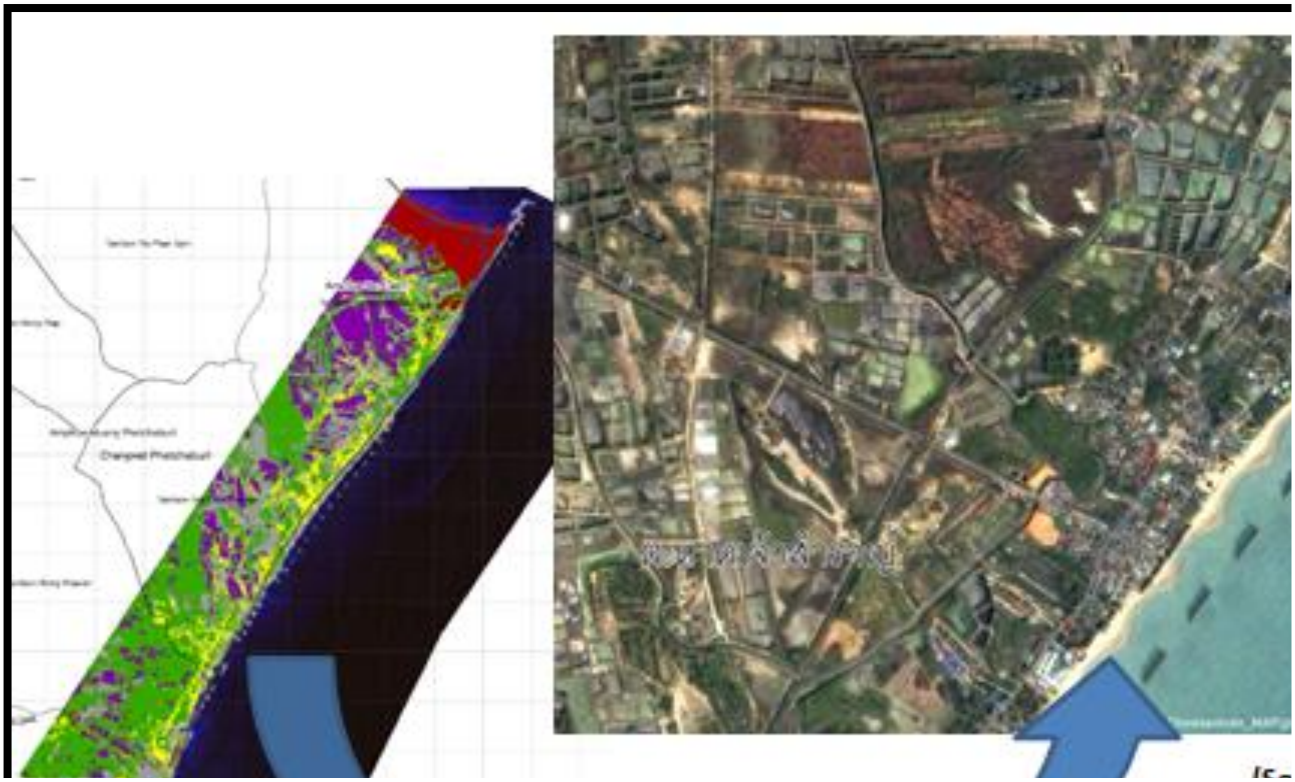

Figure 11. The expanding infrastructure and communities are close to the beach areas (Source: THAICHOTE, 2012)

3.3. Spatial relationships between land use and coastal area changes from 1999-2011

3.3.1. Land use and coastal area changes derived from satellite images

Figure 12 shows the severe erosion that happened in 2005 and 2009. In 2005, the erosion was related to the increases in agricultural area and urban area but decreases in bare land, and aquaculture area. Meanwhile, in 2009, it was related to increases in agricultural and bare land and urban area, while aquaculture was decreasing. The highest accretion levels, in 2004 and 2008, were related to the increases in aquaculture and bare land and urban area but decreases in agricultural area.

3.3.2. Analysis of spatial relationships

3.3.2.1. Erosion and land use relationship:

The regression between erosion area and the type of land use from 1999 to 2011 was calculated using the OLS technique, and the statistical results are presented in Table 2. The statistical correlation of the erosion equation (Y_1) found the highest probability (P-value) for mangroves, which also had the lowest regression coefficient. This indicates a negative relation between erosion and mangroves. Compared with the others, urban and building area had the highest regression coefficient, followed by aquaculture and salt flats area, bare land, and agriculture and rice fields, respectively. This indicates a positive relationship with coastal erosion, which means that as urban and building and aquaculture and salt flats areas increased, coastal erosion increased significantly. This can be summarized by saying that the coastal area change within this period has a negative association with mangroves, that is, more mangroves led to less erosion, and were also positively related to urban and building area, that is, more expansion of urban and building area led to more erosion.

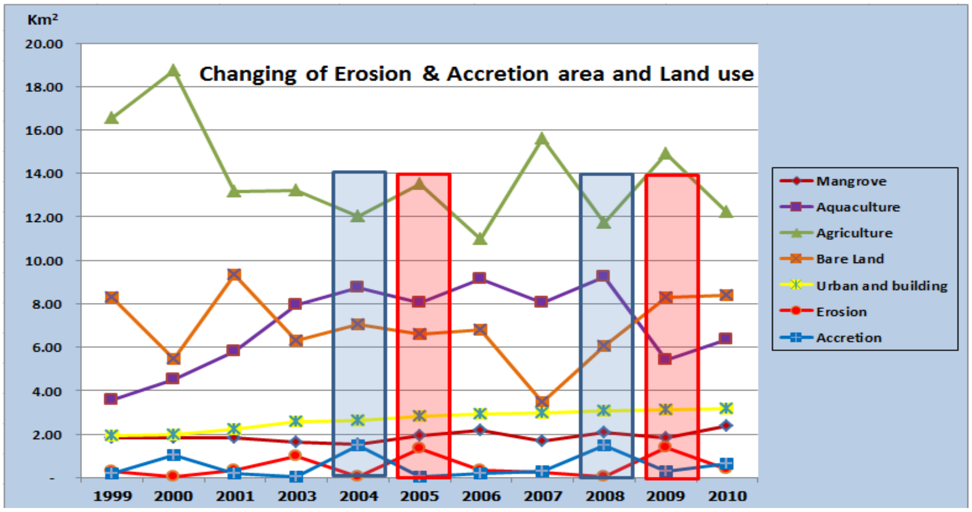

Figure 12. Changes in erosion and accretion areas with land usage from 1999 to 2011

The actual relationships between land use type and erosion, the regression coefficients from 1999–2011, were computed using GWR, as shown in Table 3. The results show that during 2005, which was one of the most erosion-prone years, the regression coefficient for bare land was highest, followed by that for urban and building area. This indicates that erosion during 2005 was associated with bare land and urban and building area. The second highest period of erosion, in 2009, showed a maximum regression coefficient for urban and building area. This represents a positive relationship with coastal erosion. That is, as urban and building area increased, coastal erosion increased significantly. The results in Table 3 indicate that mangroves had no significant impact on erosion during these periods.

3.3.2.2. Accretion and land use relationship:

The regression between accretion area and the type of land use from 1999 to 2011 was calculated using the OLS technique, and the statistical results are presented in Table 2. The probabilities (P-values) reflected high significance for all land use types. Among land use types, bare land had a higher probability than the others. The regression coefficient calculated for the urban and building area had a negative relationship with accretion, while the other land use types had positive relationships. Among the positive relationships, aquaculture and salt flats area had the strongest positive relationship. The accretion within this period was thus associated with all land use types with high probability in both positive and negative relationships.

The relationships between land use type and accretion were computed using GWR and are shown in Table 3. The results show that during 2004, which was one of the most coastal accretion-prone years, the regression coefficient for bare land was highest. This indicates a positive relationship with coastal accretion, which means that as bare land increased, coastal accretion increased significantly. The second highest period of accretion was in 2008, when the regression coefficients for mangroves and urban and building area were highest. This indicates a positive relationship with coastal accretion. That is, as mangroves and urban and building area increased, coastal accretion increased significantly. The results in Table 3 also show that the regression equation for urban and building area and accretion was statistically significant.

Table 2. Statistical correlation from OLS for erosion (Y_1) and accretion (Y_2) with land use types during 1999-2011

	Erosion		Accretion	
	Coefficients	P-value	Coefficients	P-value
Intercept	-19.8929	0.2269	-1.5946	0.9426
Mangroves (X_1)	-0.0025	0.9980	0.1379	0.9267
Aquaculture area & salt flat (X_2)	0.6643	0.2918	0.1657	0.8482
Agriculture and rice field (X_3)	0.6261	0.2288	0.0677	0.9229
Bare land (X_4)	0.6622	0.1905	0.0368	0.9563
Urban and building area (X_5)	0.9221	0.1497	-0.1822	0.8268
Regression statistic (R^2)	0.4946		0.0769	

Table 3. Statistical correlations from GWR for erosion (Y_1) and accretion (Y_2) with land use types from 1999–2011

	Regression coefficient Mangroves (X_1)		Regression coefficient Aquaculture and salt flats (X_2)		Regression coefficient Agriculture and rice fields (X_3)		Regression coefficient Bare land (X_4)		Regression coefficient Urban and building (X5)		Erosion		Accretion	
	Erosion	Accretion	Erosion	Accretion	Erosion	Accretion	Erosion	Accretion	Erosion	Accretion	R^2	P value	R^2	P value
1999	0.1553	0.1006	0.0005	-0.0001	0.0000	0.0000	0.0000	0.0000	0.0007	– 0.0001	0.98	0.011	0.99	0.011
2000	0.0148	0.6301	– 0.00004	– 0.0018	0.0000	0.0000	-0.00003	– 0.00014	– 0.00409	– 0.1746	0.94	0.011	0.94	0.011
2001	0.0947	0.0947	– 0.00005	–0.00005	0.0000	0.0000	0.0000	0.0000	– 0.00028	–0.00029	0.99	0.023	0.99	0.023
2004	-0.0003	-0.0128	–0.00012	–0.0048	-0.0014	-0.0563	0.0876	3.5922	–0.01983	–0.8130	0.2	0.342	0.2	0.342
2005	0.0075	0.0033	–0.0021	–0.00009	0.0030	0.0001	2.4164	0.1061	0.1377	0.0060	0.95	0.786	0.95	0.786
2006	0.0190	0.0102	0.0000	0.0000	0.0042	0.0023	0.0012	-0.0006	0.0000	0.0000	0.99	0.202	0.99	0.202
2007	-0.0003	-0.0002	-0.0013	-0.0069	-0.0002	-0.0001	0.0015	0.0081	-0.0031	-0.0017	0.044	0.183	0.044	0.00003
2008	0.0177	0.7957	-0.0004	-0.0172	0.0000	-0.0006	0.0000	0.0000	0.0000	0.0018	0.99	0.0001	0.99	0.00003
2009	0.3636	0.0360	-0.0064	-0.0044	-0.1268	-0.0311	-0.0663	-0.0845	0.0756	0.4269	0.99	0.264	0.97	0.871
2010	0.2679	0.0088	-0.0007	0.0018	-0.0057	-0.0122	-0.0015	-0.0005	0.0082	0.0097	0.21	0.122	0.137	0.122
2011	0.0010	0.0047	0.0023	0.0049	-0.0020	0.0019	-0.0001	-0.0003	0.0005	-0.0118	0.022	0.065	0.0004	0.739

3.3.2.3. Spatial statistical relationships

The relationships between erosion and accretion with land use can be displayed using the parts of the regression coefficients and standard residuals that vary over space, as shown in Figure 13–16. This indicates that the types of land use that influenced erosion in descending order were urban, aquaculture, bare land, mangroves, and agriculture. Also, the types of land use that influenced accretion in descending order were urban, aquaculture, mangroves, bare land, and agriculture.

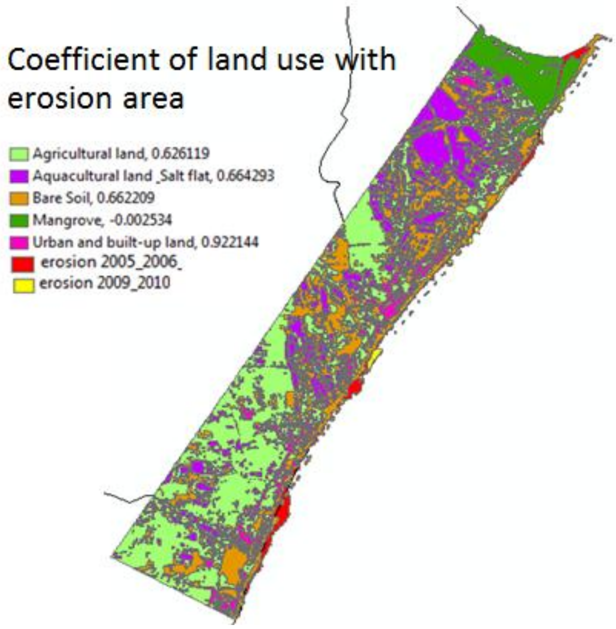

Figure 13. Regression coefficients for land use and erosion during 1999–2011. The maximum regression coefficients were for urban, aquaculture, bare land, agriculture, and mangroves.

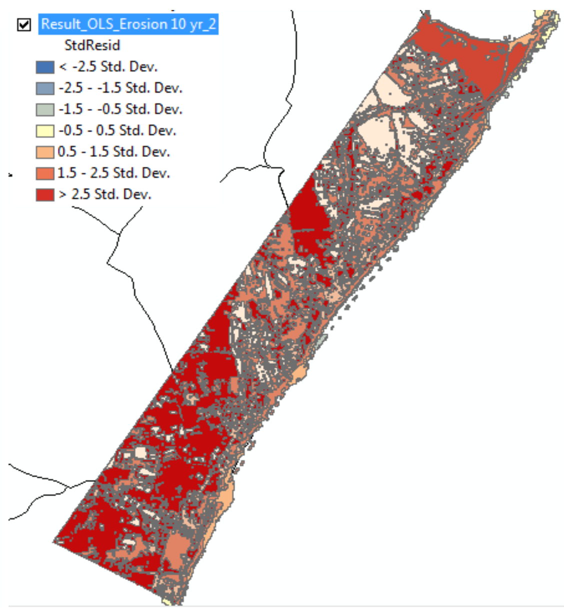

Figure 14. Standard residuals for land use and erosion during 1999–2011. The minimum standard deviations were for aquaculture, urban, bare land, mangroves, and agriculture.

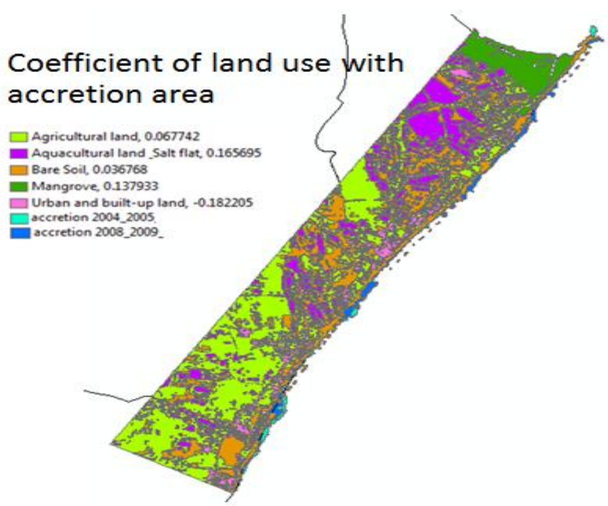

Figure 15. Regression coefficients for land use and accretion during 1999–2011. The maximum regression coefficients were for urban, aquaculture, mangroves, agriculture, and bare land.

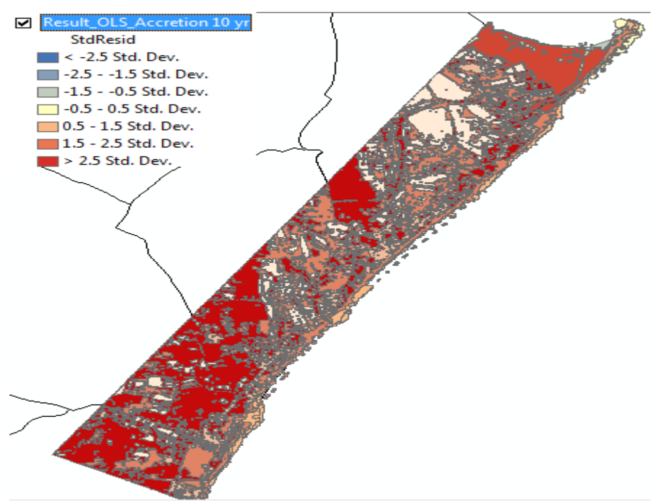

Figure 16. Standard Residuals for land use and accretion during 1999–2011. The minimum standard deviations were for aquaculture, urban, bare land, mangroves, and agriculture.

3.3.3. Spatial autocorrelation

Spatial autocorrelation is based on feature locations and attribute values using the Global Moran's I statistic. The Global Moran's I tool calculates a Z-score and P-value to indicate the validity of the null hypothesis and states whether feature values are randomly distributed across the study area. The spatial autocorrelation between erosion and land use was done using erosion and land use residuals and resulted in a Z score of -1.22 and a P-value of 0.22.This pattern indicates that the regression residuals are spatially random. In the case of accretion and land use, the analysis resulted in a Z score of -0.35 and a P-value of 0.73, which is quite high. This feature pattern indicates that the regression residuals still are spatially random. It also indicates that the OLS results of both events can be trusted.

3.3.4. Performance of the regression model

Erosion regression model: the multiple linear regressions for the dynamics of erosion from Table 2 can be expressed as Eq. 3. The model's performance can be described in terms of the R-squared (R^2) value, which was about 0.49. This is a quite preferable result. The regression coefficient of mangroves represented the lowest value.

Erosion regression equation (Y_1)

$$Y_1 = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \varepsilon$$

$$\text{Erosion} = -19.8929 - 0.0025X_1 + 0.6643X_2 + 0.6261X_3 + 0.6622X_4 + 0.9221X_5, \quad R^2 = 0.49 \tag{3}$$

Accretion regression model: the multiple linear regressions for the dynamics of accretion from Table 2 can be expressed as Eq. 4. The model's performance in terms of the R-squared (R^2) value was about 0.07, which was not preferable. The results included a high probability (P-value) for urban and building area, which had the lowest regression coefficient.

Accretion regression equation (Y_2)

$$Y_2 = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \varepsilon$$

$$\text{Accretion} = -1.5946 + 0.1379X_1 + 0.1657X_2 + 0.0677X_3 + 0.0368X_4 - 0.1822X_5, \quad R^2 = 0.07 \tag{4}$$

3.3.5. Matrix correlation

The matrix correlation between each land use type for erosion and accretion and the correlations among land use types were also calculated for three different periods: the entire years (1999–2011), before the breakwater construction (1999–2007) and after the breakwater construction (2009–2011). This analysis was consistent with the result that found that urban and aquaculture areas were associated with erosion change, while aquaculture, mangroves, and urban area were associated with accretion change. Comparing among land use types, urban and building had a correlation with agriculture (-0.62), mangroves (0.49), and aquaculture (0.48). Bare land had a correlation with aquaculture (-0.47), and agriculture had a correlation with mangroves (-0.50). In summary, there are three land use types that are associated with the changes in erosion and accretion: urban and building area, bare land, and aquaculture. In the cases of mangroves and agriculture, although the analysis indicated low relationships with erosion and accretion change during the 10-year period, it significantly showed a correlation with coastal zone change before the breakwater (mangroves & accretion = -0.49) and after the breakwater construction (mangroves & erosion = -0.70 and agriculture & erosion = 0.53), so these two land use types had relationships with coastal area change and should be kept in regression models.

4. Conclusion

The coastal zone changes related to land use types at Chao Samran beach were analyzed using satellite images from 1999–2011 and spatial regression techniques. Overall, the northern part of the study area, which still has mangroves, experienced the highest deposition, with an accretion rate of over 10 m/yr. The middle part of the beach, with a protective breakwater and an expansion of the urban and building area, had moderate deposition with an accretion rate of 1–10 m/yr. The southern part of Chao Samran beach experienced the lowest rate of deposition. In addition, there is a possibility that erosion in the southern area is increasing, with a severe erosion rate of more than 5 m/yr, and that measures may need to be taken for its protection in the future. This indicates that the responsible agencies should not only focus on the problem area, but also should pay attention to the neighboring area. The factors that influenced the changes in this area indicate that before 2007, the wind-wave characteristics and monsoon intensities clearly affected the beach area. Conversely, the results for after 2008 indicate that protection measures (e.g., the breakwater) and land use could be the major factors influencing coastal zone changes in this area. Among land use types, the largest share of the coastal area was used for agriculture, especially rice cultivation (167.19 km^2). Other usage areas were bare land (84.85 km^2), aquaculture and salt flats (82.04 km^2), urban and building area (32.67 km^2) and mangroves (22.83 km^2).

Spatial relationships between erosion and accretion with land use in each year were analyzed using OLS and GWR. The analyses showed that the relationships were most pronounced in the years 2004– 2005and 2008–2009, when the maximum changes in both erosion and accretion occurred. *During 2004–,2005* erosion was associated with agricultural, aquaculture, bare land, and urban and building areas, and accretion was related to aquaculture, bare land, and urban and building areas. *During 2008–2009*, the occurrence of erosion was associated with agricultural and urban and building areas, and accretion was associated with aquaculture, bare land, urban and building areas, and mangroves. Also, a comparison of regression coefficients and standard residuals that vary over space indicated that the affected land use types were weighted in accordance with erosion or accretion area, so the land use types that were close to the erosion or accretion area were weighted more than the land use types farther away (Fig 13−16). Results from Table 2 indicate that increases in the urban area (0.92) had the most influence on erosion, followed by aquaculture (0.66), bare land (0.66), agriculture (0.62), and mangroves (0.0025) respectively. Also, the types of land use that influenced accretion were, in descending order, urban (1.18), aquaculture (0.16), mangroves (0.13), agriculture (0.06), and bare land (0.03). A spatial autocorrelation analysis between erosion and land use was also done by calculation of erosion and land use residuals, and it found that the regression residuals are spatially random.

The performance of the spatial regression model for the past 10 years concluded that the erosion regression model (R^2=0.49) had a more acceptable level of performance than the accretion model (R^2=0.07). This is significant for using the models for predictions about the coastal zone in the study area. However, the R^2 values for both equations were not high. This indicates that erosion and accretion in the area were due to both natural factors such as the strong wind-wave effects, extreme events especially before 2008, and other land uses, especially the breakwater construction. Thus, including more independent variables in the erosion and accretion models could improve their efficiency.

The findings of this study revealed an alternative method using spatial statistical techniques that can be used to examine or quantify relationships among the land use types that affected the coastal zone changes in the study area. This is a way to enhance a common statistical technique. Thus, using the right tools will allow the study of coastal changes to be more complete and convenient, and they can be combined with other factors related to the analysis of coastal zones in the future.

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