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Original Article

Coastal erosion and accretion in Pak Phanang, Thailand by GIS analysis of maps and satellite imagery

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Abstract

Coastal erosion and accretion in Pak Phanang of southern Thailand between 1973 and 2003 was measured using multi-temporal topographic maps and Landsat satellite imageries. Within a GIS environment landward and seaward movements of shoreline was estimated by a transect-based analysis, and amounts of land accretion and erosion were estimated by a parcel-based geoprocessing. The whole longitudinal extent of the 58 kilometer coast was classified into six kinds based on historical trends of erosion and accretion using agglomerative hierarchical clustering approach. Erosion and accretion were found variable over time and space ranging from 18.4 $mm.yr^{-1}$ to 33.65 $mm.yr^{-1}$, and periodic reversal of status was also noticed in many places. Land loss due to erosion as high as about 3 $ha.km^{-1}$ of shoreline, and land gain as high as about 1.8 $ha.km^{-1}$ of shoreline was estimated in different tambons. As high as 1% of total land of a tambon (Nah Saton) was lost due to erosion, whereas the largest gain was estimated to be slightly over half-percent of the total area in another tambon (Laerm Talumphuk). In general, southern tambons were more affected by erosion. Estimates of erosion were evaluated against field-survey based data, and found reasonably accurate where the rates were relatively great. Smoothing of shoreline datasets was found desirable as its impacts on the estimates remained within tolerable limits.

Keywords: coastal, GIS, shoreline dynamics, erosion-accretion, remote sensing

1. Introduction

Coastal erosion and accretion have long been seen as important processes occurring in many coastal places around the world. Due to their profound social and economic consequences, particularly associated with erosion, much attention has been given to their study. Shoreline is one of the most rapidly changing landforms in coastal areas. Accurate demarcation and monitoring of shoreline over the short and long term is necessary for understanding coastal processes. Increasing population in the coastal areas and diversified economic utilization of coastal resources make the study of shorelines more than just scientific curiosity. Erosion rates are not only used by scientists to study the sediment budgets or the role of natural processes in the shoreline alterations, but they are also used to determine safe construction setbacks, settle property ownership disputes, study the effectiveness of shoreline protection structures and to make land-use decisions (Camfield and Morang, 1996). Coastal status is crucial to people's lives, flora and fauna, to the preservation of properties (Li *et al.,* 1998), and to the understanding of the trends in environmental parameters such as habitat changes (Hardaway *et al,.* 2001). Maintaining the sustainability of coastal land masses is, therefore, very important. It requires a planned and coordinated approach to the measurement of the nature and extent of the changes for

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successful formulation of appropriate responses to achieve certain objectives.

Remote sensing (RS) technology is useful for assessing the coastal environment and monitoring the changes over time in the coastal zone (Green *at al*., 2000). In complement, geographic information systems (GIS) have been successful in analyzing such changes by utilizing from simple to complex modeling and analysis tools. For measuring and monitoring coastal erosion and accretion satellite imagery is useful in extracting the shorelines, and GIS has been used extensively to overlay multi-temporal shoreline maps to detect and visualize changes over time. This paper presents coastal erosion and accretion status in Pak Phanang, Thailand between 1973 and 2003 using topographic maps and Landsat satellite imageries employing new analytical techniques (Chowdhury and Tripathi, 2005) as well as a classical approach. It also investigates the accuracy of the estimates and how much they are affected by cartographic generalization of vector shoreline.

2. Study Area

Pak Phanang in Nakhon Si Thammarat Province of southern Thailand (Figure 1) is known as important basin area considering its economic importance (e.g., paddy rice cultivation and recent shrimp farming activities), scenic beauty as well as a source of locally available livelihood options. Pak Phanang, like many other coastal areas, is faced with conflicts in coastal land and water resources, uncontrolled conversion of critical habitats like mangrove and wetlands to agriculture and shrimp farms, destruction of mangrove and Melaleuca forest for settlement and other uses, and coastal instability due to construction of shrimp farms and physical structures (Coastal Resources Institute, 1991), to name a few. Horizontal dynamics of the shoreline manifested as local erosion and accretion adds to the problems by pressure of protecting private and public properties and of accommodating to the retreat and advance of the sea. The area is situated in the periodic erosion-accretion zone of the Gulf of Thailand, which extends from the tip of Laem Talumpuk in Nakhon Si Thammarat down to the mouth of Songkla Lake (Thaleh Sap Songkla) in the southern isthmus of the Thai Peninsula. Localized erosion-accretion has been a feature of the Pak Phanang coast for decades and coastal protection measures e.g., groins and t-bars to protect coastal land from erosion are attesting to the human appreciation of the problem and bearing the signatures of counter-attempts. Some studies have been carried out to model and predict coastal erosion in the peninsular Thailand (Huq, 1990; Lacoul *et al*., 2001; Wijesekera and Phillips, 2002), as well as to examine the control measures mostly concentrating in Songkla. Coastline monitoring using RS-GIS has been conducted in some parts of the peninsula (Li, 1993; Rattanamanee, 1996), but monitoring coastal erosion in Pak Phanang seems to be inadequate.

3. Data Used

Royal Thai Survey Department (RTSD) topographic maps and available Landsat satellite images between 1973 and 2003 were used to extract and digitize vector shoreline data. Table 1a and b list the multi-temporal datasets used in the study.

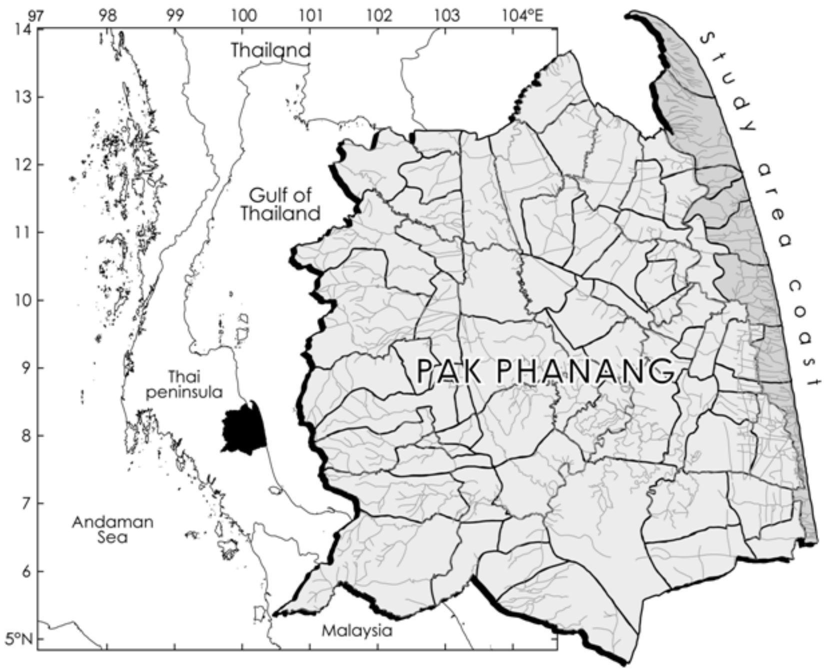

Figure 1. Map of Pak Phanang, Thailand showing the study area for coastal erosion and accretion.

Table 1a. Multi-temporal topographic maps used for shoreline change study.

Year	Topo sheet ID	Scale	Based on	Publisher	Projection
1973	Edition: 2-RTSD, Series: L7017, Sheet: 5025iv	1:50,000	n/a	RTSD	UTM Zone 47, Indian datum, Everest
1989*	Edition: 3-RTSD, Series: 7017, Sheet: 5025ii	1:50,000	Aerial photograph of 1989	RTSD	UTM Zone 47, Indian datum, Everest

* map published in 1991 with map information as of 1990

Table 1b. Multi-temporal Landsat satellite images used for shoreline change study.

Year	Satellite	Sensor	Path/Row	Date	Georeference	Source
1978	Landsat 2	MSS	WRS-2 138/54	Nov 27	GeoCover, WGS-84	GLCF
1994	Landsat 5	TM	WRS-2 128/54	Feb 20	GeoCover, WGS-84	GLCF
2000	Landsat 7	ETM+	WRS-2 128/54	Jul 22	GeoCover, WGS-84	GLCF
2002	Landsat 7	ETM+	Mosaic	Sep 14	Indian datum, Everest	GISDTA
2003	Landsat 7	ETM+	Mosaic	May 28	Indian datum, Everest	GISDTA

GLCF=Global Land Cover Facility (http://www.glcf.org and http://glcf.umiacs.umd.edu)

The longitudinal extent of the studied shoreline was approximately 58 kilometers from near the tip of Laem Talumpuk in the north down to Nah Saton in the south. Geographic extents of the maps and images were, however, inconsistent; some parts of the study area were missing from some of the maps and images thereby resulting in temporal inconsistencies as well. These inconsistencies were dealt with carefully during interpretation of the results.

4. Software

Environment for Visualizing Images (ENVI 4.0) was used for satellite image registration and thresholding of the land-sea boundary for extraction of shorelines, ArcGIS 9.0 was used for digitization of topographic maps and generalization of extracted shorelines, and ArcView GIS 3.2a served as the host software for running the shoreline change analysis extensions discussed later in Sections 7 and 8. FoxBase plus programs facilitated automated bulk processing of intermediate data and S-plus statistical software was used for clustering analysis. The need of the two latter software can be eliminated by scripting in ArcGIS or ArcView, due to time constraints however this was not attempted in the current study.

5. Data Preprocessing and Extraction of Shorelines

Topographic maps were scanned, registered using their own grid reference and GPS data points, and shorelines were digitized on-screen in ArcMap at the map scale of 1:50,000. Satellite images were registered in a hybrid approach (Jensen, 1996), one image being registered against a reference topographic map, and the rest of the images against this reference image to improve feature matching.

Almost all of the near and middle infrared (0.74-3.0 μm) radiation enters deep water and is absorbed with negligible amount of scattering (Jensen, 2000). Owing to this absorption characteristic of water infrared bands in satellite imageries can be used successfully to extract land water boundaries with sufficient accuracies. Band 5 (1.55-1.75 μm) of Landsat TM and ETM+ and band 3 (0.7-0.8 μm) of Landsat MSS were used to extract the shorelines automatically from the images by using a threshold value between the land and the sea, and the boundaries were saved as ESRI shape files for subsequent processing. Threshold value for each image was determined by manually examining average pixel values in near-shore water and on adjacent land. In Landsat TM and ETM any of bands 4, 5 and 7 can be used for coastline extraction, however band 5 is reported to yield better results (Frazier and Page, 2000).

6. Cartographic Generalization

In the vector GIS domain, raster artifacts often unnecessarily increase details in intricate spatial data, and create jagged lines when converted to vectors due to the limited eight neighborhood connectivity of the pixels. Therefore, unprocessed vector data requires more disc space and processing time, and are more difficult to manipulate and display. Moreover, a typical shoreline would appear moderately smooth in a map at a representative factor of 50,000 and above, as they appeared in the topographic maps. Where necessary artifacts in automatically extracted shorelines were corrected in ArcMap, and extracted shorelines were smoothed using parameter values (tolerance) so that the generalized shorelines did not deviate by a maximum of 2 to 3 meters from the extracted lines. The smoothed shorelines thus resemble a manually screen digitized line, or a line drawn by a cartographer on a large printout. Figure 2 shows the extracted and smoothed shorelines in a sample section of the coast, along with the two change detection analyses performed on them.

7. Transect Based Shoreline Change Analysis

A traditional approach for modeling shoreline change and predicting future changes divides shorelines into smaller segments and creates transects at right angles to a master shoreline (Ali, 2003). Shoreline changes along these transect are computed. Corrected and generalized multi-temporal shorelines of Pak Phanang were used in a classical transect based analysis of shore-normal movement using an ArcView GIS Extension named Digital Shoreline Analysis System (DSAS) (Thieler *et al.,* 2003) developed by the United States Geological Survey (USGS). It extends the normal functionality of the ArcView GIS to include historic shoreline change analysis, and contains three main components to assist a user to define a baseline, generate orthogonal transects at a user defined separation along the coast and to calculate rates of change (linear regression, endpoint rate, average of rates, average of endpoints, jackknife). An arbitrary baseline roughly parallel to the shorelines was digitized in this study, and a transect interval of 100 meters was selected based on judgments in Hayden *et al*. (1978), Dusen (1997) and White and El-Asmar (1999). Approximately 58 kilometer long shorelines were in effect divided into 580 discrete transect locations, at which DSAS estimated the landward and seaward changes of the shoreline in different periods.

A detailed signature of the shoreline movement at every 100 meter interval all along the Pak Phanang coast is shown in Figure 3. Clearer trends of erosion-accretion are captured in longer time intervals, but in shorter intervals e.g., 2000-02 and 2002-03 there was no definite pattern. A cumulative shoreline migration rates over about the last decade (1994-2003) is also shown in the figure where generally eroding south (left side) and accreting north (right side) can be recognized.

It was envisaged that coastal zone management objectives requiring administrative actions might often need information not only in geographic coordinates or such linear referencing in kilometers, but also in relation to administrative units of a locality. This paper, therefore, summarizes the overwhelmingly large amount of generated change data into tambon (sub-district) statistics. GIS analyses of shoreline data reveals a complicated scenario of localized and periodic erosion and accretion along Pak Phanang coast, as summarized in Table 2. Movement of shoreline was spatially and temporally variable. Nevertheless, there were conspicuous regimes of erosion or accretion; 1994-2000, as an example in periodic regime, was a spell of erosion all along the coast with some sporadic accretion. As an example in spatial regime, southern tambons were more consistently experiencing erosion than the north. Moreover, most part of the coast experienced periodic changes of status during the study period. Tahpaya exemplifies the case of reduced while Nahsaton a case of recently increasing erosion.

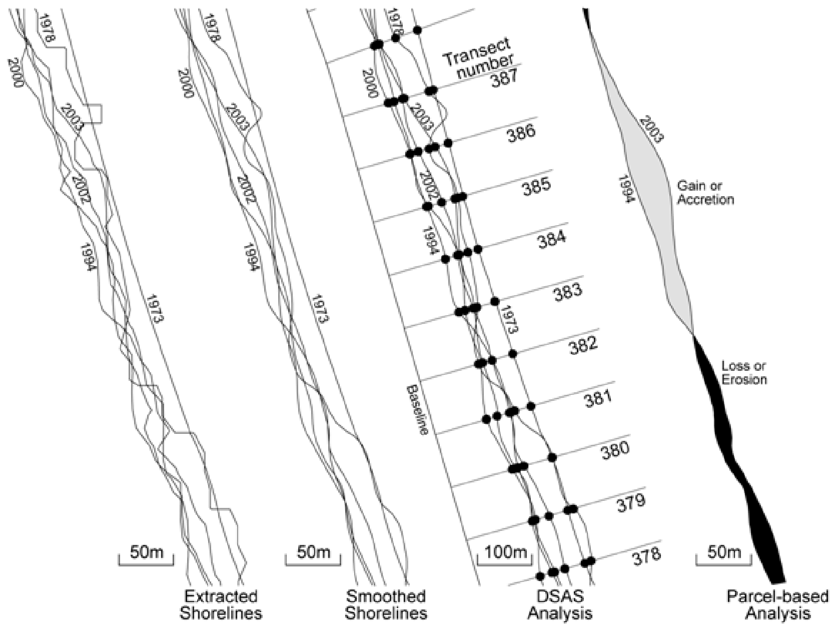

Figure 2. Multi-temporal shorelines of a section of Pak Phanang coast showing thematics of Digital Shoreline Analysis System (DSAS) and Parcel-based analysis performed on them.

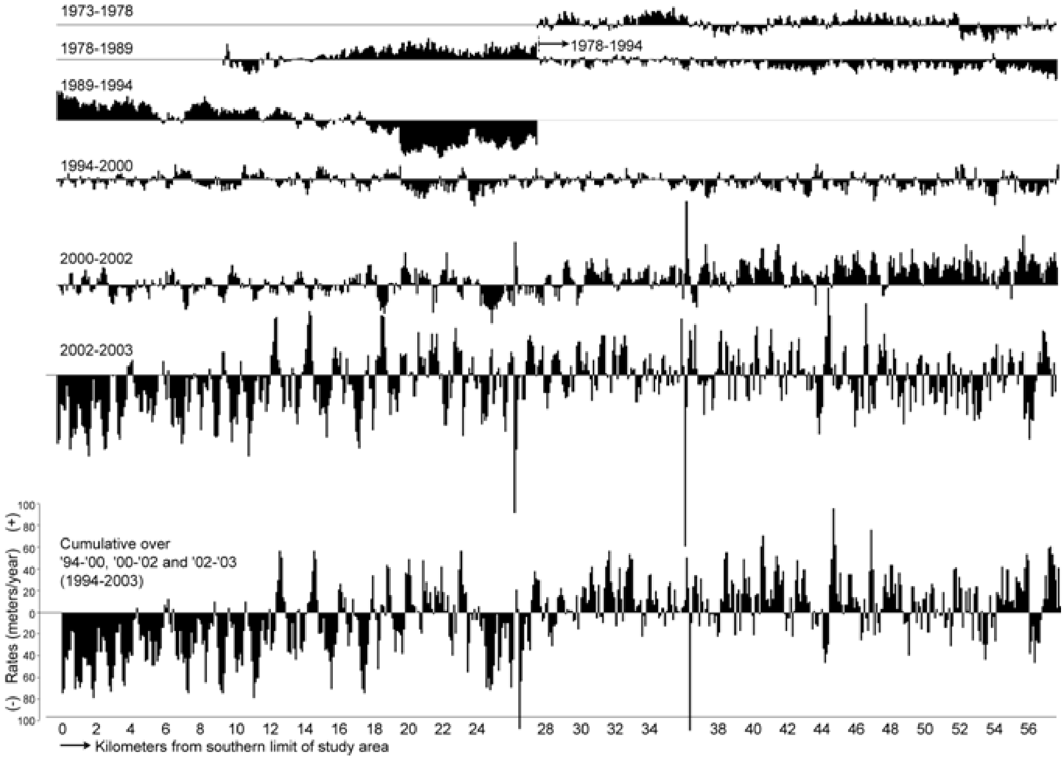

Figure 3. Rates of shoreline movement in different periods along Pak Phanang coast at 100 m–interval (scales for all periods are the same and shown with 1994-2003).

Table 2. Average movement of shoreline in meters along the tambons in different periods, negative indicates erosion and positive accretion.

Tambons	Years					
	73-94	89-94	94-00	00-02	02-03	94-03
Laerm talumpuk	-69.23		-14.05	31.86	-3.10	14.71
East Pak Phanang	-41.36		-11.70	25.59	6.69	20.59
Bang Pra	-48.11		-36.92	39.17	-3.80	-1.55
Bang Paeng	18.96		-12.88	19.43	-0.29	6.27
Tahpaya	6.82	-92.45	-4.15	9.05	-0.22	4.68
Kanabnak		-97.42	-19.15	-2.57	1.85	-19.88
Koh Patch		4.48	-0.46	-1.24	-6.18	-7.88
Nah Saton		55.89	-1.32	-3.92	-20.90	-26.13

7.1 Coast Classification

A set of change values generated by DSAS sequentially for all periods at a transect location was considered the shoreline movement signature over the periods for that location. Signatures of each five consecutive transects were averaged to reduce high frequency spatial variations. 116 signatures with multi-temporal variability thus obtained were then subjected to Agglomerative Hierarchical Nesting/ Clustering (AGNES) in Splus to find groups of coastal places with similar erosion-accretion patterns over years. A dendogram was generated from the operation and classes were manually picked up from the dendogram by examining the distance measure. A more detailed account of the working procedure can be found in Chowdhury and Tripathi (2005). Cluster or group memberships were then propagated back to the original 580 transects. Scriptlets written in FoxBase+ facilitated automated bulk processing of data records.

Visual examination of the dendogram from the clustering analysis revealed that the coast can be broadly classified into six apparent types based on the periodic erosion-accretion patterns, namely, (a) severely eroding, (b) recently eroding from a stable condition, (c) recently eroding from an accreting condition, (d) mildly eroding, (e) accreting, and (f) mildly accreting or with no definitive trend.

A map of the coast according to this classification was created using GIS overlay of the classes on the coast (Figure 4). Due to obvious limitation of scale selection, however, the details of the map cannot be easily discernible in print unless it is blown up in a very large size, or viewed electronically in a highly zoomed state. Assigning appropriate color coding, for example shades of red to all eroding classes, and shades of green to accreting ones, this map became readily understandable information even to laymen. On the map, the study area coast was found to be generally under attack of erosion, as the red shades predominated, and can be seen in Figure 4.

8. Polygon Based Analysis of Erosion and Accretion

As a supplement to transect based analysis, a polygon based change detection of coastal landmass was also performed using a geoprocessing tool named 'Change Analysis across Linear Boundaries' (Chowdhury and Tripathi, 2005) developed as part of the study. It is also an extension to ArcView GIS written in Avenue scripting language, and used to calculate and summarize the amount of land loss and land gain along the coastline over years as the sea proceeds and recedes. Details of the extension can be found in Chowdhury (2006). It supplements the analysis of shift in meters of the shoreline with the results in terms of land area lost to or gained from the sea. While the transect based analysis reports shoreline trends at user defined discrete locations and is at risk of missing trends at intermediary locations, the new parcel based analysis takes into account the continuous shorelines capturing every details on the line. Moreover, this analysis is able to report shoreline change status in units (land area) which is often more meaningful in coastal management perspectives. Figure 5 shows the amount of land lost or gained due to erosion-accretion in each tambon in each period studied. For a better appreciation of the severity or significance, the magnitude of land dynamics is also shown in normalized forms (Figure 6). Erosion and accretion normalized as "per kilometer of coastline" can be a good index of measuring the severity or significance, while the same normalized as "percent of the total land area" of a tambon must also be required for allocation-relocation decisions for the local administration. The implication of these two measures is that a smaller tambon would be facing greater challenge in relocating a lost land use than a larger tambon with the same "per kilometer of coastline" erosion, because due to smaller size a smaller tambon would have a greater percentage of land lost to the sea.

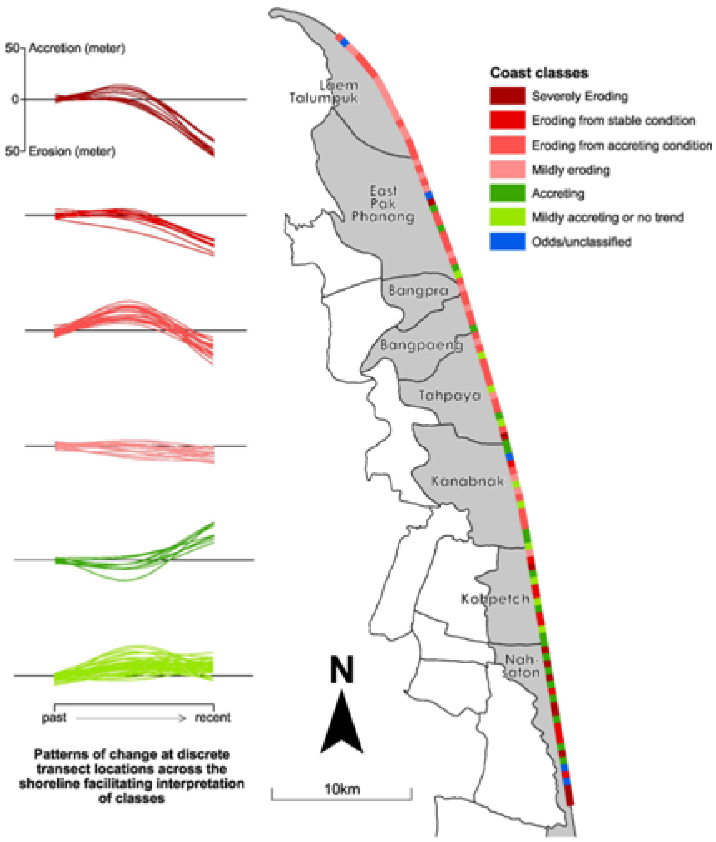

Figure 4. Classified coast map of Pak Phanang (right) with shoreline change patterns used for the classification (left).

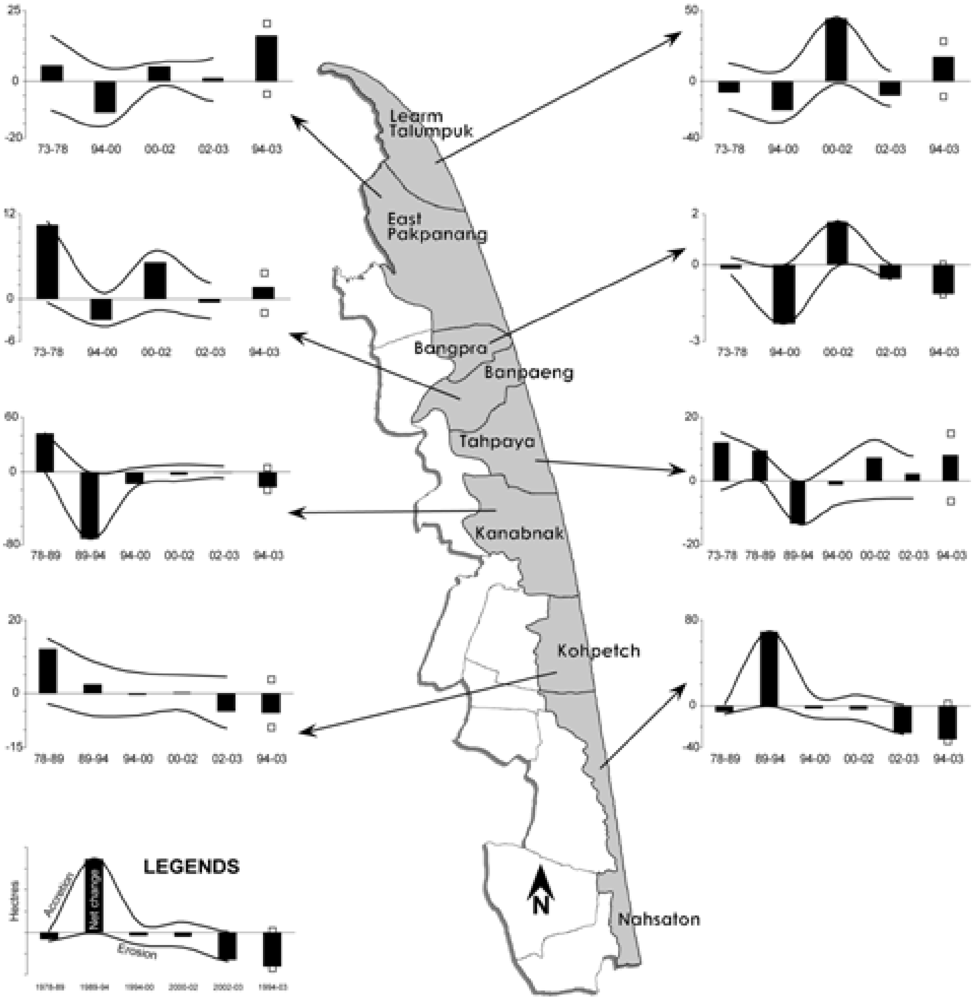

Figure 5. Map of Pak Phanang coast and trends of erosion-accretion in different tambons since 1973, upper and lower lines and markers indicate accretion and erosion respectively, while solid bars denote the net change over the whole amphoe's (district) coast.

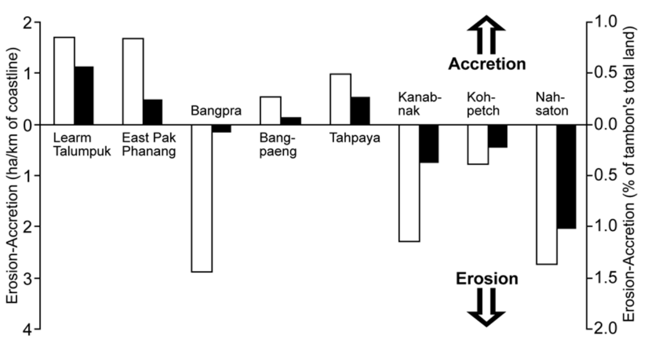

Figure 6. Eroded (downward) and accreted (upward) land areas in hectares in different tambons within the period 1994-2003 normalized as per kilometer of hollow coastline and as percentage of total land solid of the tambons.

9. Accuracy Assessment

Root mean square error (RMSE) is used as a standard measure of positional accuracy for map and image registration. In the current study a set of additional control points was picked up from the topographic maps, and was used to assess the 'lump-sum' registration accuracy of the maps near the coastal areas. RMSE of registration is used as the accuracy statistic for the satellite imageries. Average RMSE of the map and image registrations were found to be 7.82 and 4.08

meters respectively, while the lump-sum positional accuracy of randomly selected points along the coast was 6.94 meters. Considering the pixel size of Landsat image (30 m), such sub-pixel size positional accuracy was considered sufficient for the intended study.

Results of the DSAS shoreline change analysis was finally evaluated for accuracy against data from field survey conducted by the Geological Survey Division of the Department of Mineral Resources of the Government of Thailand during 1989-91 and repeat survey in 1998. Being the only available set of measurements of shoreline positions at an interval of less than a decade and being done only at ten selected eroding locations, the survey results offered very limited opportunity for validation of the present work. The survey suffered from the lack of data in accreting and less eroding areas. It was, however, noticed that at locations of high rates of erosion the results from the survey and the current study agree reasonably well. It was found that the survey locations at Baan Nam Traap, Baan Koh Fai and Baan Na Kot were experiencing high rates of erosion recording 28.9, 26.9 and 18.4 m.yr-1 respectively; while the current study estimated these figures to be 31.2, 33.65 and 22.2 m.yr-1 respectively being about 7%, 25% and 21% overestimations. These overestimations were considered reasonable, because the period of the field survey was 1989-91 to 1998, while the comparable period in the current study was taken to be 1989 to 2000. Shoreline changes in mutually exclusive years are likely to have introduced additional differences in estimates. Extensive field visits and observations were made and local people were interviewed at places not covered by the survey. Erosion-accretion trends at these places were checked with the trends found in the current study, they were in agreement in most places.

At places of low rates of erosion, the current study results were not agreeing with the survey results. This is likely to be because of the coarser resolution of the Landsat images used. White and El-Asmar (1999) pointed out that the effective pixel resolution and RMS error of image registration are the two factors to be considered seriously for accuracy.

Landsat satellite imageries have been used in the past and in recent years in many coastal applications including monitoring of shoreline changes with varying degrees of success (White and El-Asmar, 1999, Kostiuk, 2002, Shifeng *et al.*, 2002, Azab and Noor, 2003, Wang, 2003). Despite the availability of a range of high resolutions imageries today, Landsat satellite imageries over the last three decades still remain the most important remote sensing data among others for studying the changes. Low to moderate resolution images are repeatedly suggested to be useful in regional change analysis (Gao, 2009) often as a quick routine (Wang, 2010) monitoring for qualitative and gross assessment where accuracy can be compromised with to some degrees.

10. Effect of Cartographic Generalization

Transect based shoreline migration analysis and polygon based erosion-accretion analysis were performed on both the original and smoothed shoreline datasets, thus resulting in two sets of estimates for each analysis. Statistical correlations were established between the estimates obtained by using original and smoothed datasets. For transect based analysis, shoreline movement in meters at all 580 transects during 1994-2003 were used to establish the correlation. In this case the number of transects remained same for both datasets resulting in 580 pairs of data. On the other hand, in the polygon based analysis, the number of polygons reduced in case of smoothed datasets due to reduced crossing over of lines than in the original datasets. Change Analysis Across Linear Boundaries ArcView extension's documentation can be seen for a fuller description and illustration of the concept (http://arcscripts.esri.com). Therefore, pairing of change polygons was not possible for the correlation. To overcome this limitation, estimates of net change in land area in each tambon in each period were used. 45 such pairs of data were used for the correlation. It was found that the estimates obtained from the original and the smoothed datasets were very close to each other and highly correlated, values of R^2 being above 0.98 and 0.99 respectively from transect based and polygon based analyses (Figure 7).

Deviations of estimates using smoothed datasets expressed as percent of estimates using original datasets were also investigated in case of the polygon based analysis.

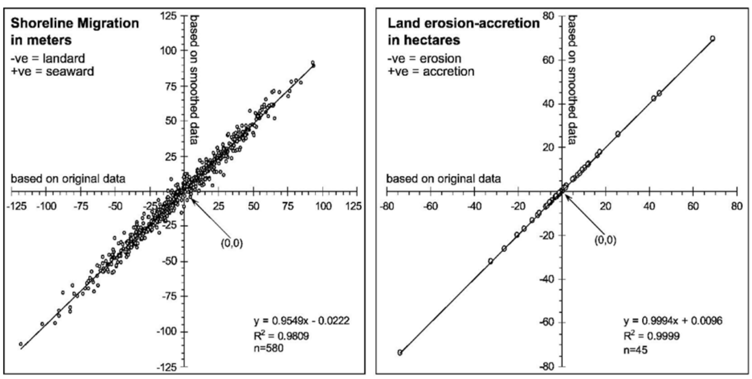

Figure 7. Statistical correlation between results obtained from original (x-axes) and smoothed (y-axes) shoreline datasets.

It was found that smoothing of lines resulted in a mean deviation of 2.06%, with 71% of the estimates showing less than 1% deviation. As a whole, the process of generalization was found desirable as a means of convenience and considering so many other uncertainties that inherently exist in many GIS databases (Zhang and Goodchild, 2002).

11. Conclusions

The aspects of coastal erosion-accretion investigation in this paper are: use of Landsat satellite imagery and topographic maps, semi-automated extraction of shorelines from imagery, GIS database creation, GIS analysis of the changes in two approaches, and cartographic generalization on vector data.

The results show that the approaches can be used for shoreline change analysis of a large area relatively quickly, and are able to generate reasonably acceptable estimates of coastal erosion and accretion. A polygon based approach of shoreline change estimates can be a valuable supplement to the classical transect based analysis, since it is able to capture changes all along the shoreline instead of at discrete transect locations.

Although Pak Phanag coast was selected for this study, an approach for routine monitoring of coastal erosion and accretion has emerged, which may be applied to study changes in other coastal areas.

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