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RESPONSE IN THE MEKONG DELTAIC COAST TO ITS CHANGING SEDIMENT SOURCES AND SINKS

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Abstract

The coastal zone of Mekong delta is suffering under intense pressures from climate change as well as human intervention. Currently, the coastline evolution of Mekong delta is a complex combination of impacts due to (1) relative sea level rise i.e. the sum of eustatic sea level rise, natural and human induced subsidence (2) sediment transport rate changes at some sections due to change of wave condition by climate change (3) change of sediment sources from the Mekong estuaries by dam construction and sand mining and (4) mangrove degradation. A coastline monitoring is the basis to understand and manage coast. This study utilizes integrated techniques of remote sensing, geographic information system and statistics to monitor coastline change over the period of 1973 to 2015 from Landsat images of Multispectral (MSS), Thematic Mapper (TM), Enhanced Thematic Mapper Plus (ETM+), Operational Land Imager (OLI) at coastal area of Mekong delta. An advanced toolbox is developed for the work of atmospheric and radiometric correction of Landsat images as well as influence of tidal range is taken into account to obtain mean water level. Tasseled Cap and Normalized Difference Water Index (NDWI) algorithm is applied to separate land-water interface for extracting shorelines. Besides, a digital shoreline assessment system (DSAS) tool is used to analyze shoreline rate by statistic parameters as Shoreline Change Envelope (SCE), End Point Rate (EPR) and Linear Regression (LRR). Furthermore, uncertainty assessment for this methodology based on topographic surveying and Google Earth images. Moreover this research explored relationships between the accretion and erosion of land and the sediment load of the Mekong River. The results revealed a general pattern of accretion and erosion. The eastern coast, which is fragmented by 9 estuaries, was significant accretion and erosion, especially annual erosion rate of around 40 meter at Bo De estuary is noted. Meanwhile the western coast is rather stable, particularly annual accretion rate of up to 90-95 meter at Datmui commune of Camau province. This study indicated there is relative difference of coastline change rate among periods of 1973-1990, 1990-2005 and 2005- present. And the study illustrates the rate of shoreline change is significantly associated with sediment discharge on Mekong River through statistic approach, especially the phase of sediment flow decrease by dam and sand mining on Mekong River in recent 15 years. The results of methodology and maps from this research may be useful in planning and management of this exposed coastline.

Key words: Mekong Delta, coastline evolution, remote sensing, Landsat images, sediment load, accretion, erosion.

1. Introduction

The coastal zone encompasses that area where the land is significantly influenced by the sea and the sea is notably influenced by the land vice versa. 75 per cent of the mega-cities are located in coastal zones and 90 per cent of the global fishery activity occurs in coastal waters. The coastal zones of the earth are extremely diverse and tremendously important, not only for human beings. Coastlines are shaped by natural forces, often changing greatly in response to changing environmental conditions and anthropogenic disturbances (Manoj et al., 2015). The shape of a coast is influenced by many factors which are (1) relative sea level rise i.e. the sum of eustatic sea level rise, natural and human induced subsidence (2) wave action and (3) sediment source from rivers (Syvitski & Saito, 2007). The sediments are primarily transported by wind-

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induced waves and water currents – either tidal currents, or rivers that flow into the sea. Depending on the currents, sediments are either eroded, redistributed or deposited (accumulation), hence the shape of the coast will change over time.

A large portion of the world population lives in flat coastal areas that can drastically change their shape in complex, unsteady and dimensionally different from spatial to temporal scale by above mentioned factors. Therefore, detection and measurement of coastal changes is of great importance for environmental monitoring and coastal management (Addo et al., 2011) and as part of the coastal zone management, regular monitoring of shoreline changes plays an important role. Hence, coastal maps should be continuously updated and the changes should be monitored (Alesheikh et al., 2007).

The Mekong River system is the world's second richest river basin in terms of biodiversity (WWF, 2004) with a total length of 4,800 km and an area of 795,000-800,000 km2. The Mekong River flows are collected from many sources and shared by six countries: China, Myanmar, Lao, Thailand, Cambodia and Vietnam. More than 60 million people from more than 95 distinct ethnic groups (WWF, 2004) live along the main river and its tributaries.

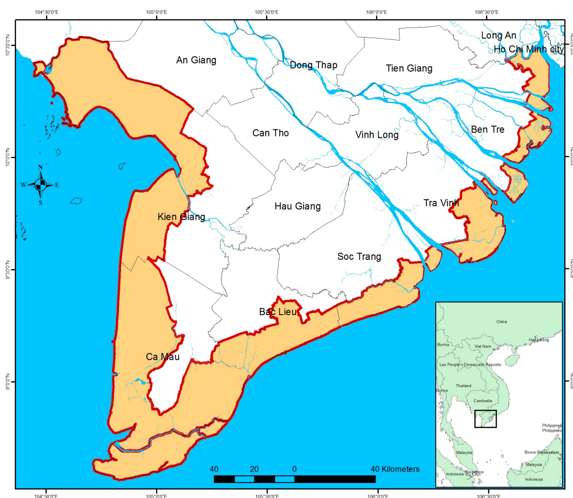

Figure 1: Map of study area in Mekong deltaic coast

In recent years, the coastal Mekong delta is facing erosion process severely and living condition of local people is affected extremely. The occurrence of erosion or accretion of the coastal Mekong delta is still an unclarified issue. In 2005, Southern Institute of Water Resources Research of Vietnam implemented analysis of shorelines in 1965, 1989, 2002. The method used to extract shorelines from satellite images for this work is only the on-screen digitizing as a manual method using visual interpretation. This method depends largely on the subjective of implementer and it leads to high manual error for shorelines result. Besides, none of these studies has fully assessed the accuracy of the derived shorelines through comparison with simultaneous and independent in situ observations. The approach used in this study to identify coastline and detect changes was based on the combination of water indices approach, called automatic shoreline extraction and on-screen digitization. And shorelines result from this method is compared with ground survey data at some locations which collected in the framework of Vietnam government projects.

In spite of the development of relevant techniques that have now reached a level of maturity, there are only a limited number of literature references quantitatively linking shoreline change to river sediment load (Gens, 2010). Some limited studies have provided a quantification of the relationship between shoreline change and river discharge on a coarse spatial scale. The primary purpose of this paper, therefore, is to quantify the shoreline change in Mekong deltaic coast and relationship between shoreline change rates and the river sediment discharge on different spatial scales. This approach will facilitate the research of more detailed and in-depth shoreline responses to river sediment discharge using remote sensing and GIS techniques. Exploring spatiotemporal dynamics of the changing coastline and the drivers of those changes is essential to understand how the delta front is responding to the natural and anthropogenic changes.

2. Study area

The study area which is coastal zone of Mekong Delta extends for about 600 km length and lies between 8o32’-10o22’ N latitude and 104o26’-106o47’. The complex character of the tidal regime is dominated by the M2- and K1-tidal-constituents which extend from northeast to southwest in the South China Sea (Zu et al., 2008). A pronounced meso-tidal regime prevails in the South China Sea, while in the Gulf of Thailand a micro-tidal system occurs. In the South China Sea it leads to tidal ranges of 2.5–3.8 m in a semi-diurnal to mixed-tidal system (Nguyen et al., 2000). However, the Gulf of Thailand has diurnal tides with tidal ranges between 0.5 and 1.0 m. Tidal ellipses of the dominant tidal constituents with its according currents extend in the subaqueous Mekong Delta mainly in a shore-parallel direction (Zu et al., 2008).

The present morphology of the lower Mekong Delta developed over the last 6000 years. During this period the delta advanced 200 km over the continental shelf of the South China Sea, covering an area of more than 62,500 km2 (Nguyen et al. 2000). From 5.3 to 3.5 ka the delta advanced across a broad embayment formed between higher ground near the Cambodian border and uplands north of Ho Chi Minh City. During this period of its development the delta was sheltered from the wave action of longshore currents and was constructed largely through fluvial and tidal processes (Ta et al. 2002b). At this time the delta was advancing at a rate of 17–18 m per year. However after 3.5 ka the delta had built out beyond the embayment and became subject to wave action and marine currents. These deflected deposition south-eastwards in the direction of the Camau Peninsula, which is one of the most recent features of the delta.

Figure 2: Field survey in Mekong deltaic coast in 2013.

Figure 3: Erosion in 2010 (left) and 2011 (right) in coastal Travinh province, Vietnam

Currently, reduced sediment supply to the Mekong delta is likely to have serious consequences, particularly with regard to increased coastal erosion, a situation which is aggravated by possible sea level rise due to climate change. The sensitivity of the area to the available sediment budget is illustrated by increased bank erosion downstream of areas associated with sand mining from the river bed. The impacts of upstream sediment trapping are likely to be long term, however, since the supply from bank erosion downstream of the reservoirs will only compensate in part.

3. Materials and methods

Shoreline change analysis is one of the important means for understanding the evolution of the subaerial delta. The analysis of shoreline changes helps determine coastal danger zones and detect short-, medium- and long-term uncontrolled changes in coastal areas (Ford, 2013). The erosion risk and change trends can be estimated in coastal areas by monitoring spatiotemporal changes in coastal areas and providing important data for necessary intervention policies (Addo et al., 2011). Due to the importance of the processes that occur along the coastline, rapid and reliable techniques are required to monitor and update coastline maps. It is also necessary to quantify the rates of environmental retreats. The sources of data for shoreline change analyses are historical photographs, coastal maps and graphs, aerial photographs, ground surveying, GPS surveying, satellite images and video images (Ford, 2013). Each of these methods has specific advantages and disadvantages. However, the general availability and easy accessibility of the data are decisive criteria for whether the data can be used in the study (Kusimi and Dika, 2012). Aerial photo and ground survey techniques are conventionally used for coastline monitoring. Classical topographic surveying and GPS surveying produce high precision results; however, they are demanding, time-consuming and high-cost procedures (Alesheikh et al., 2007;). Aerial photogrammetry can also provide high-precision information; however, this is also a high-cost method for large areas. Additionally, the extraction of photogrammetric data and the production of maps are highly time consuming (Alesheikh et al., 2007). Futhermore, these techniques are inherently limited in temporal coverage, typically being either too short to identify long term trends or too widely spaced in time to distinguish short term, seasonal changes.

Recent advances in remote sensing and geographical information system (GIS) techniques have enabled the acquisition of high-accuracy shoreline information and shoreline analysis on finer spatial and temporal scales (Pardo-Pascual et al., 2012). These techniques are cost-effective and minimize the need for laborious fieldwork and it covers larger areas than traditional methods (Alesheikh et al., 2007). Considering the lack of data on wetlands and coasts, particularly in developing countries, the use of satellite images is considered the most economically and temporally appropriate method because it provides access to current and archived data (El-Asmar et al., 2013).

NASA's satellite in the Landsat series has critical role in monitoring, understanding and managing the resources needed for human sustainment such as food, water and forests. With the longest continuous data stream of Earth's surface as seen from space, NASA's Earth-observing Landsat fleet has provided the world with unprecedented information on land cover changes and their residual effects since 1972. The knowledge gained from 40 years of continuous data contributes to research on climate, carbon cycle, ecosystems, water cycle, biogeochemistry and changes to Earth's surface, as well as our understanding of visible human effects on land surfaces.

The normalized difference water index NDWI algorithm was generated by combining the green with near-infrared to extract waterline (McFeeters ., 1996). The green band (0.52–0.6 lm) is sensitive to water turbidity differences as well as sediment and pollution plumes because it covers the green reflectance peak from leaf surfaces. It can be useful for discriminating broad classes of vegetation. The near-infrared band (0.7–1.1 lm) exhibits a strong contrast between land and water features due to the high degree of absorption by water and the strong reflectance by vegetation and natural features in the range. Thus, the NDWI algorithm, which is a combination of green and near-infrared bands, is ideal for discriminating between land and water at their interface.

However, the application of the NDWI dealt with calm water environment as lake, rivers, lagoons. In water regions with the chaotic nature of wave environment in the near shore surf zone resulted in a high variability in the reflectance values in the green and IR bands does not achieve its goal as expected. Consequently, the NDWI ratio alone were unable to adequately separate beach from the surf zone.

The Tasseled Cap has been shown to be a suitable candidate for shoreline extraction by using principal components analysis function for converting the original bands of an image into a new set of bands as brightness, greenness and wetness. Tasseled cap did a good result of differentiating between waves and beach, especially when the classifier option to leave 0.5% of the pixels unclassified was chosen. However, in image with stratus clouds the differentiation between land and sea was often lost resulting in wet soil and beach being grouped into the same category as clouds. To solve this matter the NDWI band was added to band combination with the Tasseled Cap bands. Tasseled Cap and NDVI bands input was taken and create a 10 class land cover data set. Then, land cover data set continue to classify from 10 to 2 classes of land and water and finally shorelines is created from 2 classes by using contour and smooth line commands.

Our study examines the changes in the shorelines of the Mekong deltaic coast that occurred over 43 years from 1973 to 2015. Shorelines were determined using Landsat data for 1973, 1979, 1990, 1995, 2000, 2005, 2010, 2015. Shoreline changes of the case study were determined for the periods and the effects of shoreline changes on the lagoons were analyzed. ArcGIS 10.3 software was used for the satellite images processing, shoreline extraction and DSAS tool was used to analyse shoreline change by some statistic parameters. The steps of methodology of the study is presented in table 1.

Table 1: Methodology in process steps for shorelines change detection.

Process Step	Process Name	Description
1	Download and Extract Images	USGS EROS DATA CENTER
2	Atmospheric correction	Sun + radiometric correction
3	Normalized Difference Water Index (NDWI)	Green and Near Infrared Bands
4	Tasseled Cap (Brightness, Greenness, Wetness)	Some bands depending on types of Landsat images
5	Developing approach for Land and Sea creation by combining NDWI and Tasseled Cap (10 classes)	Unsupervised classify by maximum algorithm to create 10 classes
6	Classify Land and Sea (2 classes)	10 classes to 2 classes
7	Create Shore Boundary	Majority filtering, contour and smooth line commands
8	Tidal Correction	Mean Sea Level
9	Shorelines Change Detection	Digital Shoreline Assessment System (DSAS Tool)

Possible error sources can be identified in the process of the modeling shoreline change and these are as follows: (1) error resulting from the geometric correction of Landsat images; (2) error arising with the shoreline extraction process; and (3) error caused by a variation in some factors affecting shoreline change. Topographic surveying at Travinh province from 2011-2012 and Camau province from 2011-2013 by Vietnam Institute of Coastal and Offshore Engineering was used as a reference map to analyse accuracy shoreline extraction methodology.

Besides, the high spatial resolution images provided by Google Earth™ were used as reference for the image from 2000 to 2015. The dates of the reference data and the analyzed images were closely matched to minimize bias in the surface water boundaries that could arise because of large differences in time. For the validation of extracted shorelines the ‘‘true’’ boundaries between land and water were digitized manually on-screen from all the reference data. Then total areas were calculated for each newly generated reference data and compared with classified Landsat images. To assess the accuracy of the land/water classification for all classified maps RMSE was used. The RMSE between the shoreline change by topographic survey and result of shoreline change by extraction from satellite images was calculated roughly 10m to show the difference of the obtained shorelines.

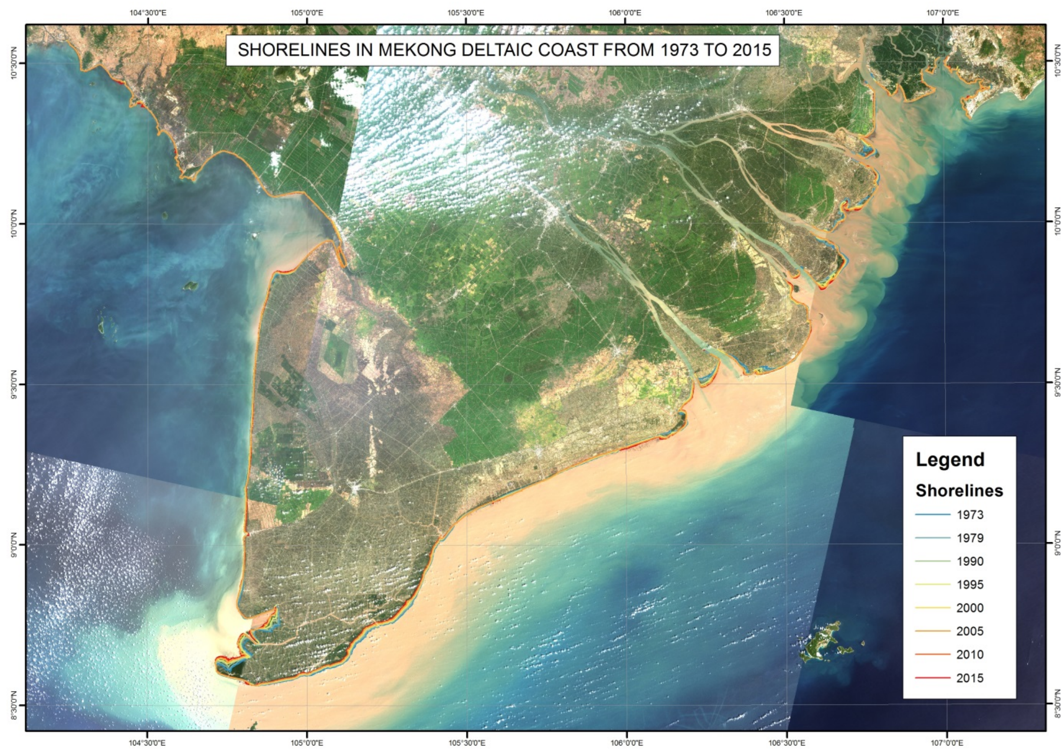

Figure 4: Final shorelines extracted from Landsat images from 1973 to 2015

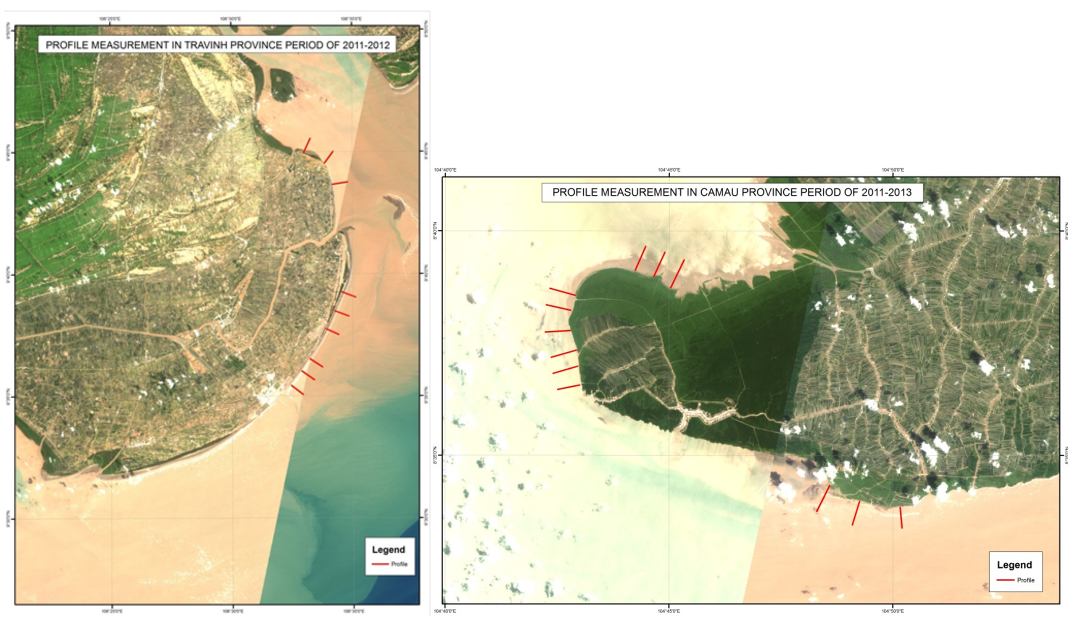

Figure 5: Topographic surveying at two zones including Travinh province from 2011-2012 and Camau province from 2011-2013.

4. Results and discussion

4.1 *Results*

Our results showed a variation in the shoreline change rates during the different periods, with a generally decreasing trend. Coastal area is extended steadily average 21 km^2 in 5 year period before 1990. However, since 1990 accretion area started to decrease to only 0.5 km^2 in 5 year period of 2000-2005 and in the recent years annually rate of accretion in Mekong deltaic coast approximately 1-2 km^2. Although there is relatively difference of shoreline change over 43 years, in general sedimentation is still dominated in Mekong deltaic coast with annually average accretion of 1.2 km^2. The maximum average accretion rate in over 43 years from 1973 to 2015 is 105 m/year at western Datmui commune of Camau province, meanwhile maximum average erosion rate is 55m/year at Tamgiangdong commune of eastern Camau province.

According to characteristic of morphodynamics, the Mekong deltaic coast is divided into 3 areas as figure: estuaries area from Vungtau to Soctrang, the eastern coast from Soctrang to Camau and the western coast from Camau to Kiengiang.

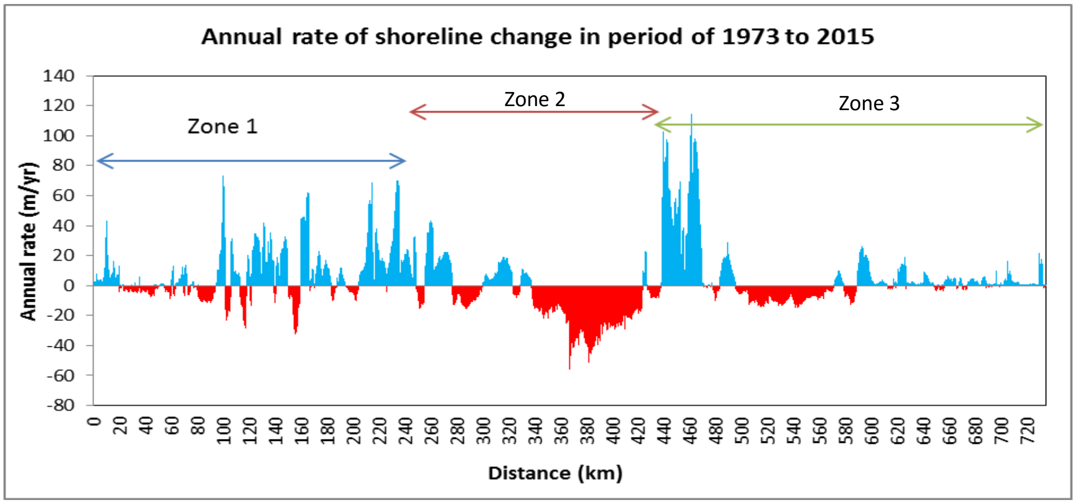

Figure 6: Annual rate of shoreline change in period of 1973 to 2015

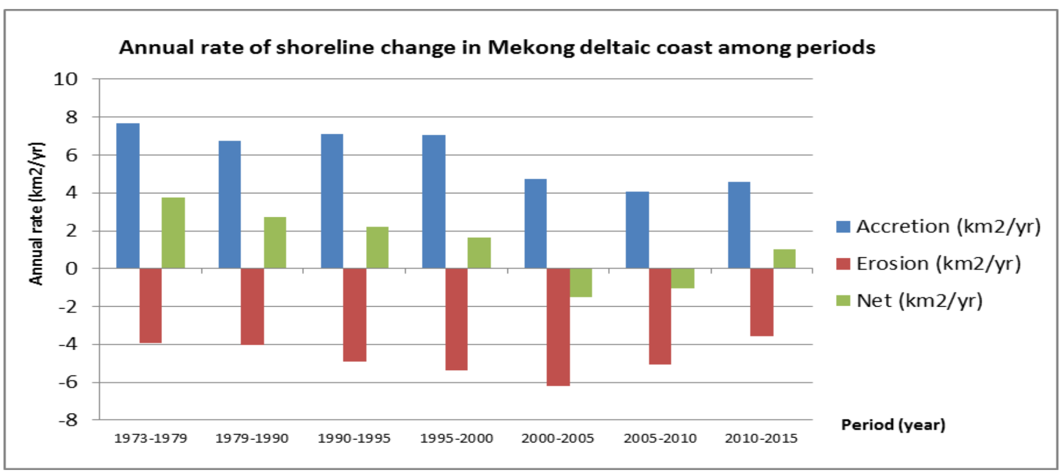

Figure 7: Annual rate of shoreline change in Mekong deltaic coast among periods

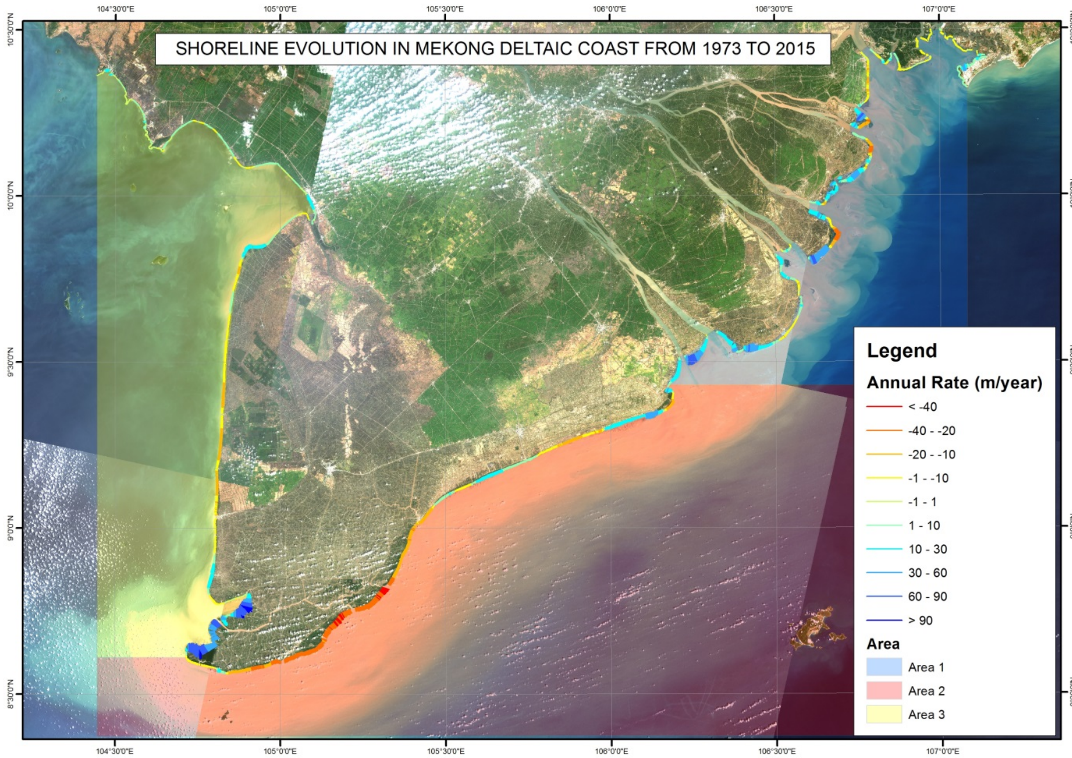

Figure 8: Shoreline evolution in Mekong deltaic coast from 1973 to 2015

4.1.1. *Estuaries in eastern area*

These distributary mouths where Mekong river running to the sea is received huge sediment from this world's 12th longest river, therefore accretion prevail in this area. Mostly accretion occurs in left estuaries and erosion takes place in right estuaries vice versa. It can be explained that monsoon climate with north-east ward dominated affect to sediment transport in this area. There are some locations with accretion greater than 30m/yr as Anthanhnam commune of Soctrang province, Donghai commune of Travinh province, Thanhphong commune of Bentre province and Phutan commune of Tiengiang province. Meanwhile erosion occurs seriously more than 20 m/yr at two places as Thanhhai commune and Thuaduc commune of Bentre province.

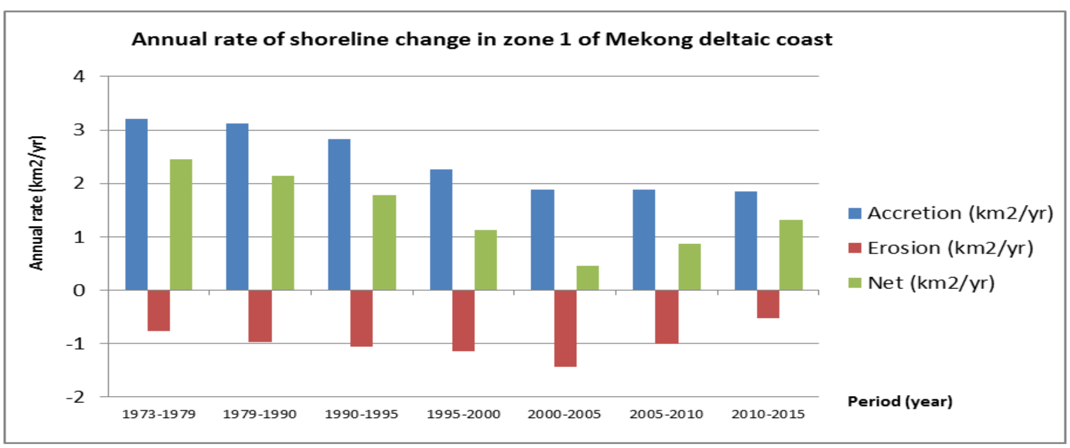

Figure 9: Annual rate of shoreline change in zone 1 of Mekong deltaic coast

There was annual decrease rate of accretion area from 3.5 km^2/yr in period of 1973-1979 to approximately 1.9 km^2/yr in 2000-2015 and it has kept steadily nearly 1.8 km^2/yr so far. Besides, the result of shoreline change from satellite images showed that there is annual increase rate of erosion area in area 1from 0.7 km^2/yr in period of 1973-1979 double at 1.4 km^2/yr in period of 2000-2005. However, erosion area started to decrease at 0.5 km^2/y in period of 2010-2015. Consequently, period of 1973 to 2015 in area 1 resulted in a net land gain by average 1.3 km^2/yr with lowest value of net gain in land in period of 2000-2005 at nearly 0.5 km^2/yr. One of the reason for this phenomenon comes from some bank protection works built from 2004-2005 as jetties in Cangio district, revetments in Gocong district, Duyenhai district, seadike systems in Mekong deltaic coast.

4.1.2. *Eastern coast*

The sedimentation area in period of 1973-2000 in this region is average 1.23 km^2/yr, however in next 15 years it decreases to 0.81 km^2/yr in which lowest accretion area occurs in period of 2000-2005. Vinhhai commune of Soctrang province is where takes place highest accretion more than 30m/yr in this zone. Meanwhile from 1973 to 2015 erosion area is range between 2.3 and 3.1 km^2/yr in which period of 1990-2005 had erosion rate larger than 3 km^2/yr. Compared with remaining two area 1 and 3, the erosion dominates this area with average net land loss rate of 1.6 km^2/yr, especially in Tamgiangtay and Tamgiangdong communes of Ca Mau province with erosion rate higher than 40 m/yr.

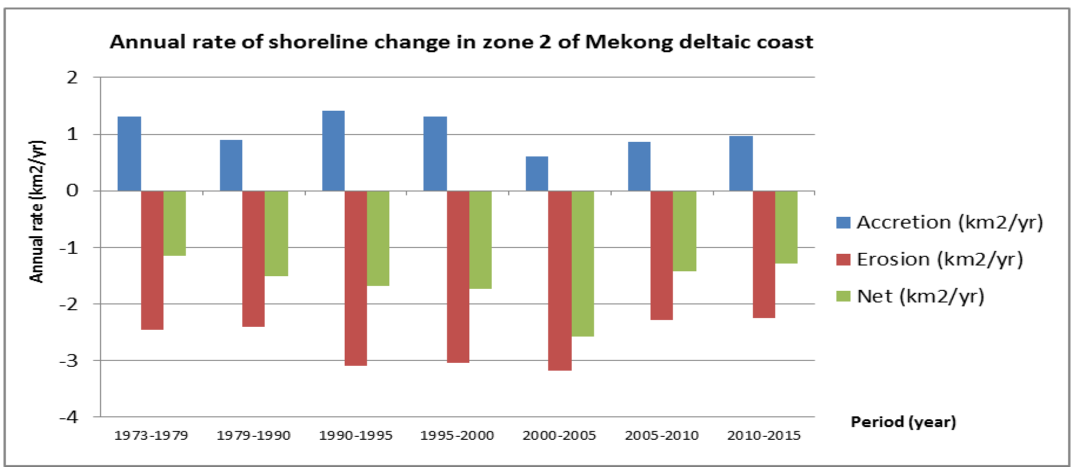

Figure 10: Annual rate of shoreline change in zone 2 of Mekong deltaic coast

4.1.3. *Western coast*

It can be said that compared with zone 1 and 2, coastline in this zone 3 is more stable with high accretion and low erosion in period of 1973-2000 with net land gain rate of almost 2.3 km^2/yr. With distinctive place as interaction between irregular semi diurnal tide of ranging 4 meter in eastern ward and irregular diurnal tide of ranging 1 meter in western ward, there is large amount of sediment including mainly fine silt and clay depositing in western part by accretion up to 110m/year as Datmui and Lamhai communes of Camau province. However there was complicated happening of shoreline in next periods when accretion area rate decreased suddenly from nearly 3.7 km^2/yr in period of 1995-2000 to 1.2 km^2/yr in 2005-2010 and erosion area rate increased rapidly to 2.8 km^2/yr in 2005-2010. Net land loss rate in this zone of 0.4 km^2 took place only in period of 2005-2010 and net land gain rate increases again in so far by some groynes built in this period.

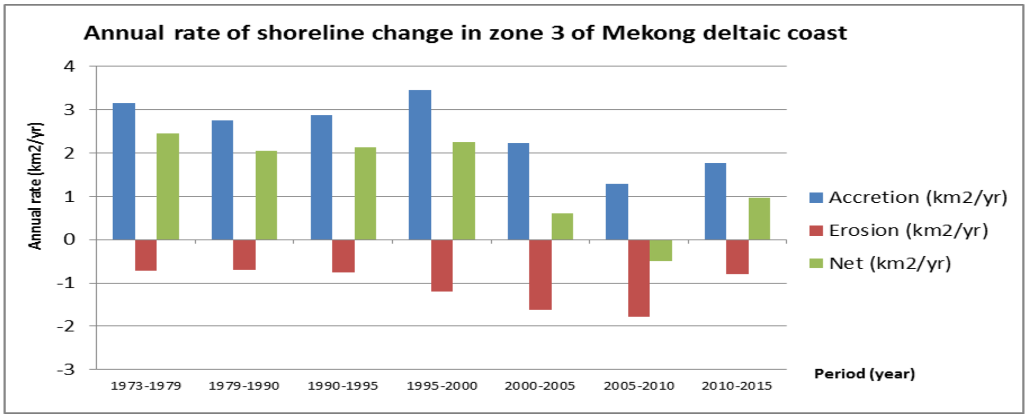

Figure 11: Annual rate of shoreline change in zone 3 of Mekong deltaic coast

4.2. *Discussion*

The sediment flow from Mekong river is the one of some significant elements affecting to the retreat of Mekong delta coastline. Measurements of suspended sediment concentration data at Tanchau permanent station showed that there is a difference markedly among period of 1988-1995, period of 1996-2000 and period of 2001-2012. Among 1988 between 2012, suspended sediment concentration in period of 1996-2000 declined significantly to average 85 mg/l from average 124 mg/l in period of 1988-1995 at Tanchau station. In the next periods, there is slight growth of suspended sediment concentration to 110 mg/l and 115 mg/l in period of 2000-2005 and 2005-2012 correspondingly at Tanchau station. Therefore, total sediment load of Mekong river in the Vietnam zone is estimated average ranging 45 to 55 million ton/year. Furthermore, combined with Landsat images on flood season, it can be seen easily that allocated sediment area in Mekong deltaic coast is estimated approximately 6000-7000 km^2. According to Linsley et al. (1982), the dry density of most soils varies within the range of 1.1-1.6 g/cm^3 then the amount of Mekong sediment load supplying for subaqueous delta system is equivalent to the depth average 7-8 mm/yr.

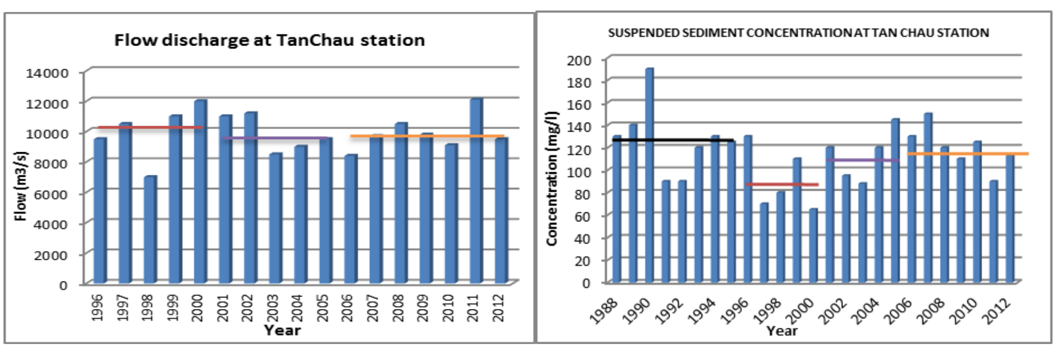

Figure 12: Suspended sediment concentration and flow discharge at Tanchau (left) from 1988 to 2012.

Based on the data between 1979 and 2007 of Vungtau gauge station, it showed that the HHWL of sea level at this station has risen by 13 cm, e.g. nearly 4.0 mm/year. Besides, subsidence caused by natural reasons as compaction of fresh deltaic deposits and human impact as groundwater extraction in Mekong delta taking place rather severely average 1.6 cm/year (Erban et al., 2014). Therefore, it can be seen that sediment from Mekong river in the present is insufficient to compensate by relative sea-level rise, i.e. the sum of eustatic sea level rise, natural and human induced subsidence.

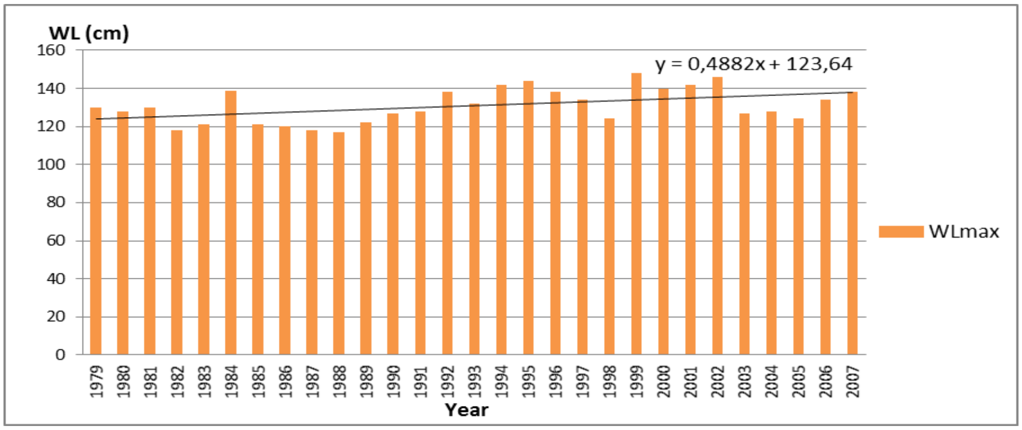

Figure 13: Trend of highest water level in the period 1979 to 2007 at Vungtau station.

5. Conclusion

Our study demonstrates the applicability of remote sensing, GIS and statistics techniques for enabling more detailed and in-depth assessments of shoreline changes in coastal area. Landsat MSS/TM/ETM+/OLI images from 1973 to 2015 were used for shoreline extraction and an orthogonal transect method was used to model the shoreline changes. Two advanced toolbox are developed to be convenience for correcting atmosphere as well as extracting shorelines. Topography survey from 2011 to 2013 in Travinh and Camau province is used to evaluate accuracy of shoreline change rate result.

Our work presents detailed spatiotemporal dynamics of the shoreline change of Mekong delta with three distinctive areas in Mekong deltaic coast including sedimentation of zone 1, erosion of zone 2 and rather stability of zone 3. However sedimentation is still dominated in Mekong deltaic coast with annually average accretion of 1.2 km^2 in general. This is a first study to reveals a fairly close relationship between the shoreline change in Mekong deltaic coast itself, especially zone 1 with Pearson coefficient as 0.46 and the sediment load in Mekong river.

The results reveal that the shoreline change in lower Mekong delta have mainly been controlled by the river sediment load, hydrodynamics, mangrove area, relative sea level rise and coastal engineering projects. From above mentioned causes, consequently there is relatively difference of coastline change rate among periods of 1973-1990, 1990-2005 and 2005- present, of which erosion phenomenon in period of 1990-2005 took place most serious situation.

This study may contribute to providing relatively comprehensive knowledge related to the evolution of the entire Mekong deltaic coast in recent 43 years. Integration of aerial photography with high resolution imagery from other satellites (e.g. Quickbird, Ikonos, Spot) could further improve the accuracy of shoreline change result.

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