Coastal Erosion Risk – Rapid Shoreline Assessment of the Western Mekong Delta Coast

Jan-Peter MUND

Abstract

Rapid Shoreline changes and movement of sediment caused by erosion and deposition is a major concern for managing the coastal zone in the Mekong Delta in Southern Viet Nam. Such morphologic processes are the result of natural and man induced processes of erosion, summing up to 50 km² of eroded coastal areas in Cau Mau Province, already in 2005. The aim of this paper is to present rapid assessment methods to detect shoreline movement employing the combination of high-resolution satellite imagery and topographic maps. Semi-automated measurements of very high resolution satellite and aerial imagery were integrated with topographic maps to compare shoreline locations during the last decade.

Historical changes of the shoreline location have been mapped along a 25 km strip on the western coast of Cau Mau Province. Shoreline positions have been compared to interpret rates of shoreline changes using the Digital Shoreline Analysis System Application (USGS, DSAS 4.1). The presented rapid assessment of the western shoreline shows that minimum 30% of the shoreline is in endangered by strong to severe erosion patterns during the last decade. Measured average change in shoreline position show large variability ranging from + 5.6 m to – 290.1 m net shoreline movement over 2001 to 2009. Coastal erosion risk and abrasion exposure analysis showed 9.8% of surveyed coastlines (equivalent to 2.46 km) are ranked as having a very high erosion exposure risk. Further 31.6 % of shorelines (equivalent to 7.91 km) are ranked as highly vulnerable to erosion and 58.6% (equivalent to 14.63 km) show a moderate or low vulnerability to coastal erosion.

According to the presented results a substantial loss of mangrove forests and tidal wetlands along highly dynamic coastlines are caused by sea level rise combined with high erosion energy of tidal waves, storm surges and a significant reduction of sediment deposits by the Mekong discharge regime. The detected shoreline movement poses considerable vulnerability for regional human livelihoods. Rapid assessment techniques combining remote sensing approaches with GIS based cartographic surveys are required to update shoreline maps of affected areas in order to monitor rates of change and suggest areas of urgent intervention.

Keywords: Costal Erosion, Vulnerability, Rapid Assessment, Mekong Delta, Viet Nam

Jekel, T., Car, A., Strobl, J. & Griesebner, G. (Eds.) (2012): GI_Forum 2012: Geovizualisation, Society and Learning. © Herbert Wichmann Verlag, VDE VERLAG GMBH, Berlin/Offenbach. ISBN 978-3-87907-521-8.

1 Introduction

A shoreline, the variable intertidal boundary between land and sea, keeps changing its shape and position continuously due to dynamic environmental conditions of the tidal floodplain. Beach erosion or shifting shorelines and sea level rise are a chronic problem along most open-ocean shorelines in the Mekong Delta since centuries disturbing a dynamic equilibrium. Coastal erosion and shoreline movement is considered as a natural hazard that occurs frequently due to various geophysical, climate chance and man induced reasons causing severe threats to the vulnerable societies of coastal dwellers. There is increasing demand for rapid and detailed information regarding past and present shoreline changes in the Mekong Delta region. Coastal erosion in Viet Nam has been in the focus of many topographic surveys and modelling attempts since the late 1980ies (NGU & HIEU 1991). With increasing population and changing land use in the low-lying coastal areas of the Mekong Delta, communities and infrastructure became vulnerable to continuous shoreline shifts and permanent erosion protection measures become essential. Increasing economic values, and stronger loads on the coasts caused by effects of the global climate change demand an improved sustainable and holistic management of the shoreline including the implementation of adequate erosion protection measures.

Along dynamic coastlines a substantial loss of mangrove forests and tidal wetlands has been reported due to sea level rise combined with high erosion energy of tidal waves and a significant reduction of sediment deposits have caused (WALLING 2008). The Ministry of Natural Resources and Environment in Vietnam calculated a projected sea level rise of about 30cm and 75cm respectively in 2050 and 2100 (MONRE 2009). In particular the complex and highly dynamic process of erosion, sediment transport and accretion, occurs frequently along the coastline of western Cau Mau Province on the southernmost tip of the Mekong Delta in Southeast Asia (NGUYEN 2009). This process driven by prevailing monsoon winds and regional ocean currents is influenced by a complex interaction between the tidal regime and sediment transport and accretion equilibrium of the Mekong Delta discharge regime (OLIVIER & SCHMITT 2011). Morphological erosion processes summing up to 50 km² have been reported from Cau Mau Province, already in 2005 (TIEN et al. 2005). The sediment movement and deposition balance has changed over time influencing indirectly the shape of the coastline and the compactness of the natural mangrove cover in the area (WALLING 2008). Applied experiences have shown that areas with mangrove forests can effectively detain ocean currents, tidal waves thus preventing coastal erosion and shoreline movement (PHAM 2011). Various attempts to determine intertidal mean shoreline location were carried out using different geospatial methods ranging from aerial photo interpretation and medium scale multispectral imagery to video-gps surveys of the coastline (VAN & BINH 2008, BROWN et al. 2010, HOA et al. 2007, YANG et al. 2009, ALESHEIKH et al. 2007).

2 Study Area

The satellite based analysis of the mean shoreline movement was carried out on a 25 km strip of the western Cau Mau province coast bordering the Gulf of Thailand (Fig. 2). Cau Mau is flat coastal province on the southernmost tip of Viet Nam in the western part of the

Mekong Delta with an average population density of 231.1 person/km². It is situated from 9°32’ North and 104°50’ East to 9°31’ North and 105°25’East. The province is surrounded by the Gulf Thailand and the South China Sea and is bordered in the North by the Kiên Giang and in the East by Bạc Liêu province. Cau Mau Province has a 252km long coastline, the longest of all Mekong provinces. Even though it is reported that the area of erosion in Cau Mau Province has decreased by 40% between 2000 and 2007 and accretion strips have increased by 20% (BROWNE et al. 2010). The presented rapid assessment of the western shoreline shows that minimum 30% of the shoreline is in endangered by strong to severe erosion patterns during the last decade. In 1993, the shoreline of Cau Mau Province had more than 66.873 ha of mangrove area (MINH 2006), forming a thin line 600-800m wide along the study area that buffers and protected valuable farming lands from rising seas and storm surge damages. Field survey and remote sensing image interpretation showed that between 2001 and 2009 nearly 85% of the mangrove area has been lost. Up to 26 m wide strips of mangroves and coast lines are lost annually (DUKE et al. 2009).

Fig. 1: Mangroves in the Mekong Delta 1943 (HONG 1993)

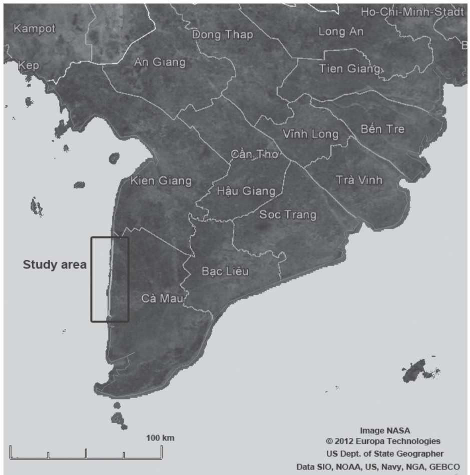

Fig. 2: Overview Study area (GE 2000)

3 Data Used

Three band optical very high resolution satellite imagery from the sensors World View 1 and Quickbird (1; 2) with an average panchromatic resolution of 0.5 m offer excellent opportunities to map and analyze recent shoreline movements and erosion pattern during the last decade. Two Quickbird images from 02/03/2001 and 08/06/2009 were available in standard georeferenced color products. The selected satellite images represent a comparable normal hide tide period. Additional topographic charts in 1:200.000 and 1:50.000 were used to extract mean shoreline positions and exact location of hinterland dykes and canals which were constructed during the last 20 years. Aster and Landsat imagery from 1989 and 1995 were integrated in order test rough extrapolation of historical shoreline positions.

4 Methodology

Developing a consistent historical data set requires various data ranging from historical analogue maps (Fig. 3), via aerial photos up to most recent marine borne GPS-video mapping approaches in order to determine the most detailed mean tide shoreline position at a certain discrete point in time. The regular intertidal variation of the submerged coastal strip were not calculated or surveyed in detail within this study. Only significant visual coastal erosion, like beach cliffs, the loss of mudflats and sandy beach zones or similar obvious erosion patterns were taken into account for the change detection with regards to methodical interpretation reasons. Rapid assessment and visual interpretation methods to detect shoreline movement combined with very high-resolution satellite imagery (VHR) and topographic maps have been used to detect large scale shoreline shifts and shrinking of mangrove forest area along the western Cau Mau coast. Due to the complexity of tidal landscapes and a difficult accessibility of the terrain the visual optical satellite interpretation method were chosen to provide rapid and detailed information about the movement of the shoreline during the last decade. The Digital Globe Quickbird optical color image products from 2001 and 2009 were georeferenced and co-referenced to UTM WGS 84, and overlayed with scanned regional topographical maps of 1:50.000 circumventing projection difficulties with the national geodetic datum of Vietnam (VN 2000). As co-referenced images were later compared using change detection methods, geometric rectification and mismatching errors should not exceed pixel accuracy. Aster and Landsat imagery, analysed with the band ratio method were integrated later into the shoreline determination process to extrapolate roughly prior shoreline positions.

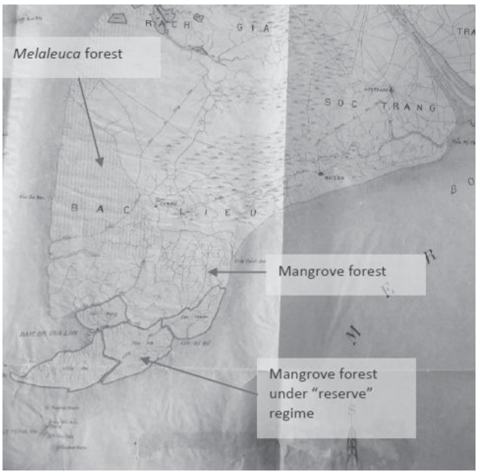

Fig. 3: Historical Forest map of Cochinchine (Carte Forestière de la Cochinchine 1917) (JOFFRE 2010)

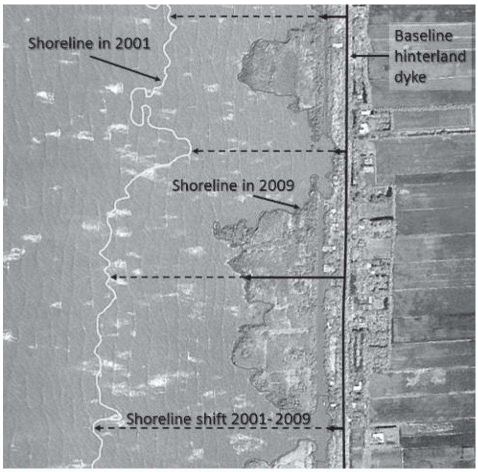

Fig. 4: Visual shoreline shift measurement Shoreline 2001 in yellow, 2009 in orange

The visual interpretation and extraction of two different shoreline locations were executed on a time series of two Quickbird images from 02/03/2001 and 08/06/2009. Several structural features of the shoreline were easily identified and categorized according observations. The following coastal habitat assessment categories (Table 1) were used separating visual assessment parameters in a rapid coastal habitat mapping (Table 3). Additionally, three qualitative erosion classes have been separated along 25 km of shoreline (Table 2).

Table 1: Visual assessment categories of coastal habitats

Parameters	Assessment categories
Coastal habitat type	Mangrove, Terrestrial Fringe, Rocky Shore, Mud, Sand, Canal
Physical coastline conditions	eroded, stable, depositional, wall, dike, fixed
Qualitative erosion assessment	Active, inactive, fixed, severe
Mangrove situation	closed mangrove cover, interrupted, patchy, destroyed

Extracted shoreline movement was validated measuring manually orthogonal distances to a basis line along the fixed position of the hinterland dyke (Fig. 4). In a parallel effort the DSAS 4.1 shoreline extraction tool (USGS) was applied calculating average shoreline movement in a selected spatial distance of 150 meter each resulting in more than 165 orthogonal vector lines. This open source GIS tool generates perpendicular transects to a selected baseline at a user specific spacing alongshore. The distance from the baseline to each measurement point is used in conjunction with the corresponding shoreline date to compute the change-rate statistics. Other high resolution imagery of intermediate date was accessed via the Google Earth online viewer in order to compare shoreline positions via KML overlay. In order to separate mangrove forest from open tidal wetlands and other landuse patterns different coastal habitats were assessed. The satellite images were classified using a region growing segmentation algorithm based on five different land cover classes: open water, tidal sand- and mudlands, mangrove forest, and other vegetation cover.

5 Results and Discussion

Time series of historical shoreline datasets with different tidal datum influence also the ex-post analysis of shoreline shifts and sediment movement as well as the total extent of the considered shoreline. In order to identify individual or systematic errors in the data, extracted shorelines must meet certain criteria for example matching map datum and projection and successful plausibility tests of immobile point of reference, e.g. rock outcrops, groins, piers or jetties. The rates of shoreline movement statistically derived from analogue shoreline extraction were improved using the DSAS calculation tool to an average resolution of +/- 0.45 meters which meets the image pixel accuracy requirement. The overlaid shorelines of 2001 and 2009, subtracted using a geospatial analytics resulting in a significant inland shift of 179.8 m in average along the surveyed 25 km coastal area (Fig. 5; Fig 6).

Historical shoreline positions were spatially compared to interpret rates of shoreline changes. Measured and calculated average movement in shoreline position show large variability ranging from + 5.6 m to – 290.1 m net shoreline movement over 2001 to 2009 with a standard deviation of 87.81 m. Evaluation of spatial positioning error suggests that the extracted shoreline positions of 2001 and 2009 are generally accurate to within +/- 2.4 meters.

Table 2: Qualitative erosion categories along 25 km of coastline

Erosion category	**Description**	**2001 km**	**2001 %**	**2009 km**	**2009 %**
Severe erosion	Total loss of dike foreland	0.48	1.9	2,46	9.8
Active erosion	Sharp eroded shoreline	3.66	14.6	7.91	31.6
Moderate erosion	Close terrestrial fringe	20.86	83.4	14.63	58.6

Coastal erosion risk and abrasion exposure analysis showed 9.8% of surveyed coastlines (equivalent to 2.46 km) are ranked as having a very high erosion exposure risk. Further 31.6 % of shorelines (equivalent to 7.91 km) are ranked as highly vulnerable to erosion and 58.6% (equivalent to 14.63 km) show a moderate or low vulnerability to coastal erosion. There is a significant decline of the mangrove forest cover and muddy shoreline segments detected between 2001 and 2009, comparable to similar reports of land cover change and erosion along the Mekong Delta Coast (HIROSE et al. 2005, JOFFRE & SCHMITT 2011). The coastal front in the central and the southern section of the surveyed coastal area show severe erosion patterns of about 250 m maximum perpendicular to the shoreline. Muddy shoreline segments and mangrove covered areas along the coast have declined while terrestrial fringes and sandy segments of the coast have increased up to 20% from 2001 to 2009.

Table 3: Results of rapid costal habitat mapping of 25 km coastline

Coastal habitat type	**Description**	**2001 km**	**2001 %**	**2009 km**	**2009 %**
Coastline	strait length in total	25.0	100	25.0	100
Mangrove	mostly dense mangrove forest	12.31	48.9	8.62	34.5
Terrestrial fringe	Mostly covered terrestrial vegetation (trees & grass)	2.73	10.9	8.31	32.4
Muddy shore	shoreline with muddy substrate	6.63	26.6	1.58	6,4
Sandy shore	shoreline with sandy substrate	2,48	10	3.88	15.6
Human construction	Canal, dike or other human construction	0.85	3,6	2.61	10.5

Fig. 5: Shoreline shift from 2001 to 2009 north of Khanh Hoi; visual interpretation

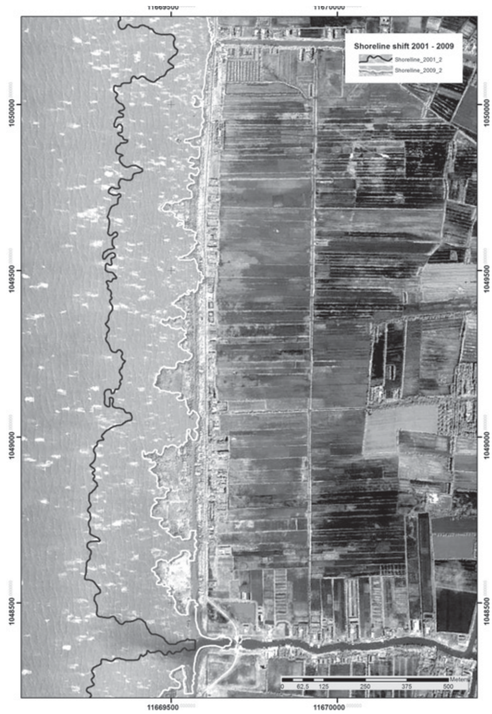

Fig. 6: Severe erosion pattern along the shoreline north of Khanh Hoi in 2009

Since the late 1980ies, large mangrove areas of the thin coastal fringe between the tidal wetland and a hinterland dike some hundreds of meter of the coast have been logged continuously due to inadequate mangrove forest management systems and land use change pattern converting natural mangrove forest areas into mixed aquacultures and plantations. Possible causes of receding mangrove fronts are also related to strong ocean current parallel to the coast as well as mudflats and sediment erosion next to man-made canal inlets and pumping stations. The combined impact of storm surges and of a potential sea level rise may increase strong erosion risk along the North-South oriented Western coast of Cau Mau Province (HOA et al. 2007).

This regional survey confirms other findings from neighbouring provinces Kiên Giang and Bạc Liêu (BROWN et al. 2010, CAREW-REID 2007, DUKE et al. 2009). It proves that coastal mangrove forest area, mudflats and mudland marshes and other terrestrial fringes are particularly vulnerable to shoreline erosion. Along the southern section of the survey area, north of Khanh Hoi village, already in 2009 coastal erosion has extended beyond the mangrove fringe and now threatens the hinterland dikes, homes of coastal dwellers, their farmland, local infrastructure and some commercial enterprises in aquaculture and rice farming. During the last decade large areas of dike foreland has been lost in along the

Western shore of Cau Mau Province. The outer boundary of remaining coastal marshes and wetlands are severely vulnerable to shoreline erosion with the predicted sea level rise.

Academic and methodological discussions about visual interpretation techniques and analyses of very high resolution satellite imagery in combination with mostly qualitative rapid assessment methods consider limited to unsatisfying spatial accuracy in comparison to digital dGPS terrestrial surveying methods. However, results of the presented study provide promising overview data about local spatial pattern, regional trends and physical symptoms highlighting the most vulnerable coastal fringes in the studied area. Results of this study with spatial accuracy below 2 m are considered sufficient for regional planning strategies discussing various options of coastal protection measures in order to reduce the risk exposure and vulnerability of the local population. The presented method in combination with other rapid assessment techniques like marine borne GPS video mapping could substitute the time consuming and tough terrestrial access to remote shoreline areas and tidal mudlands. With regards to expansive technical constructions or regional planning decisions further terrestrial surveys and physical analysis of spatial erosion pattern are recommended anyhow.

6 Conclusion

The coastal morphology of the western Cau Mau Province coast changes continuously over time due to increased erosion of the coastal area and sea level rise. This influences severely the physical shoreline structure and pattern as well as the decline of associated shoreline mudlands and mangrove forest fringes. The consequences are complex and manifold with regards to the risk exposure of coastal protection measures and the vulnerability of local population and their livelihood. The presented visuals interpretation methods of VHR satellite imagery have shown opportunities, improvements and challenges of rapid shoreline assessment methods. Several structural shoreline features were easily identified in the imagery and compared over time. Combing historical data, precise spatial information derived from satellite data and digital shoreline analysis tools could successfully provide regional overview data. The results may be used to risk exposure and foster adaptation options to prevent coastal erosion with acceptable financial inputs. Findings and interpretations could be integrated into further research, hydrological modeling approaches and coastal protection as well as climate change and risk reduction adaptations measures, which are discussed in several integrated coastal management planning schemes, already.

References

ALESHEIKH, A. A., GHORBANALI, A., NOURI, N. (2007), Coastline change detection using remote sensing. Int. J. Environ. Sci. Tech., 4 (1), 61-66.

BROWN, S. et al. (2010), Coastal planning and management for climate change in Kien Giang province, Vietnam. Conservation and development of the Kien Giang Biosphere Reserve Project web paper: http://www.kiengiangbiospherereserve.com.vn/project/index.php?content/1/8/5, accessed on 05 January 2012.

CAREW-REID, J. (2007), Rapid Assessment of the Extent and Impact of Sea Level Rise in Viet Nam, Climate Change Discussion Paper 1, ICEM – International Centre for Environmental Management, Brisbane, Australia. 74 p.

DUKE, N. C, WILSON, N, MACKENZIE, J. & NGUYEN, H. H. (2009), An Interim report on the current status of GTZ Kien Giang Shoreline and management projects for periods up to July – August 2009. Kien Giang Province, Vietnam. 45 p.

HIROSE, K. et al. (2005), Satellite Data Application for Mangrove Management, conference proceedings of the The Sixteenth Workshop of OMISAR. Jakarta 2005.

HOA, L. T. V. H. et al. (2007), The combined impact on the flooding in Vietnam's Mekong River delta of local man-made structures, sea level rise, and dams upstream in the river catchment. In: Estuarine, Coastal and Shelf Science, 71 (2007), 110-116.

HONG, N. P. & SAN, H. T. (1993), Mangroves of Vietnam, in IUCN Wetland Programme. IUCN Bangkok.

JOFFRE, O. M. & SCHMITT, K. (2011), Research on historical changes in mangrove distribution and coastline development in Soc Trang Province (Vietnam): an important input for the development of climate change adoption measures.

JOFFRE, O. M. (2010), Mangrove Dynamics in Soc Trang Province 1889 – 1965, Published by GTZ GmbH. Management of Natural Resources in the Coastal Zone of Soc Trang Province.

MINH,T. H., YAKUPITIYAGE, A. & MACINTOSH, D. J. (2001), Management of the Integrated Mangrove- Aquaculture Farming Systems in the Mekong Delta of Vietnam. ITCZM monograph series, 1/2001.

NGU, N. D. & HIEU, N. T. (1991), A review of climate changes in Vietnam over the past 100 years. Intern. Conf. Climate Changes Sea Level Rise Impact, Hanoi, 40-42.

NGUYEN, T. T. (2009), Surface sediment characteristics and sediment transport from Bassac River mouths to Cau Mau Peninsula (Mekong Delta). Institute of Geosciences, University of Kiel, Germany.

PHAM, T. T. (2011), Mangroves of Soc Trang 1965 – 2007. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, Management of Natural Resources in the Coastal Zone of Soc Trang Province, Vietnam. 57 p. http://czm-soctrang.org.vn/en/Publications.aspx, accessed on 12 December 201.

THE MINISTRY OF NATURAL RESOURCES AND ENVIRONMENT (MONRE) (2009), Climate change and sea level rise scenarios. Hanoi, Vietnam.

VAN, T. T. & BINH, T. T. (2008), Shoreline change detection to serve sustainable management of the coastal zone in Cuu Long estuary. International Symposium on Geo-informatics for Spatial Infrastructure Development in Earth and Allied Sciences 2008

WALLING, D. E. (2008), The Changing sediment Load of the Mekong River. Ambio, 37 (3), 150-157.

YANG, J.-Y. et al. (2009), The study of coastal change from using digital aerial photo and hydrographic survey: the erosion land under sea.