SPACE APPLICATIONS & EARTH OBSERVATION TECHNOLOGIES FOR COASTAL MONITORING FOR COMMUNITY BENEFITS, KALPITIYA COASTAL WINDOW, SRI LANKA

Bandula Wickramaarachchi

Coastal Research & Design, Coast Conservation Department,
New Secretariat, Maligawatta, Colombo 10, Sri Lanka;
Tel: +94 77 779 2966
E-mail: engwicky@sltnet.lk

Lal Samarakoon, Kavinda Gunasekara

Geoinformatics Center, Asian Institute of Technology
PO Box 4, Klong Luang, Pathumthani, Thailand 12120
E-mail: lal@ait.ac.th

Yoshimitsu Tajima, Shotaro Funatake

Coastal Engineering Lab, Department of Civil Engineering, University of Tokyo
7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan
E-mail: yoshitaji@coastal.t.u-tokyo.ac.jp

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Abstract: In nature, coastal regions are dynamic due to the natural and anthropogenic drivers. The dynamics would have both positive and negative impacts on the coastal communities and environment. The negative impacts might adversely affect on the livelihoods of communities, and harmful to the healthiness of the environment. Hence it is vital to explore and monitor the dynamic coastal environments for decision making on community developments and environment enhancement. The dynamics in the coastal areas are due to the drivers, which are spatially spread over vast coastal regions with temporal variations. Therefore the space technologies are much appropriate for the exploring coastal dynamics and monitoring them in both spatial and temporal domains.
The coastal dynamics mainly describe by the temporal changes of shoreline. This study examined the use of imageries captured by different sensors on board airplane and satellites in estimating shoreline changes. Based on historical imageries captured in 1956 up to images captured by modern sensors were used to examine these changes. During the study entire west coastline were investigated and modeled for the interpretation of the changes at Kalpitiya Coastal Window. However some of the changes could not be interpreted due to the limited temporal resolutions of the imageries. Since such areas are limited to small spatial domains, special imaging techniques with outdoor sensors mount on towers were used with high temporal resolutions.
The end results of the study was shared with various stakeholders who are directly or indirectly involved and affected by the changes that are happening in the coastal region and that could possibly effect the livelihood of the communities in time to come. Technical & scientific findings were shared with intellectual communities; possible causes and appropriate adaptation strategies were shared to utilize in national & local administration policy updates, regulations & guidelines; and finally communicated with the general public & private developers for sustainable developments & secured livelihoods.

1. INTRODUCTION

Coastal systems, where the structure of the system includes interactive elements with dynamic relationships, are complex in nature. Any interventions to the system may results unintended consequences. The sediment system, which is one major natural process in the coastal region, is a subset of the coastal system. The sediment processes provide the infrastructure for the existence of coastal habitat & ecosystems. The sediment processes are driven by natural and anthropogenic drivers and the ultimate state of the sediment system is accretion or erosion. Primarily the natural sediment dynamics of the system is driven by the drivers of meteorological (wind, wave, tide etc), climate (monsoon), geomorphologic (bathymetry, geological structure) etc. Anthropogenic drivers that are generated due to the development pressures in the coastal regions, adversely collide with the natural system. In managing the coastal resources sustainably, the systems shall be monitored, analyzed and forecasted.

1.1. Kalpitiya Coastal Window

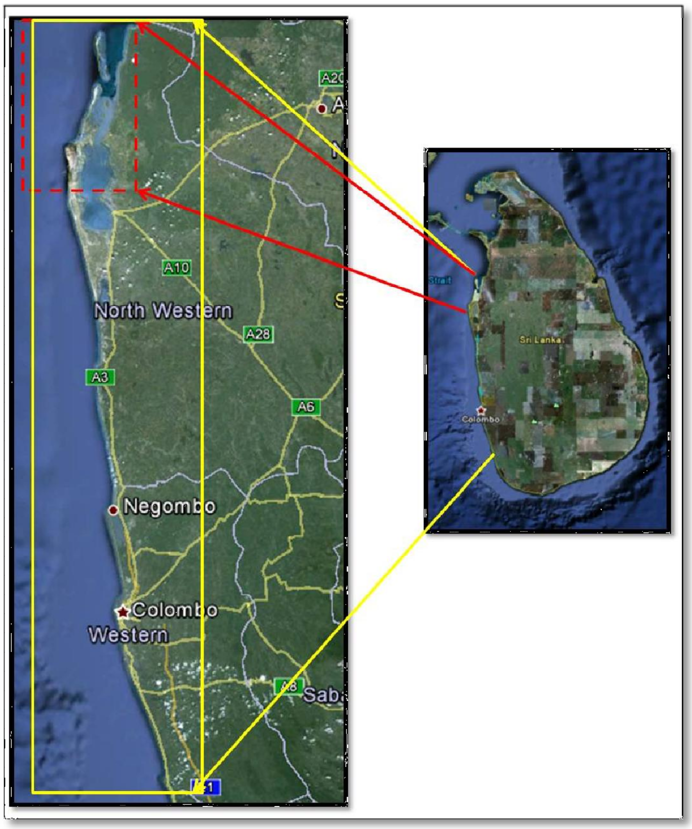

Figure 1-1 Kalpitiya Coastal Window (Red) in West Coast
Google Earth

Being an Island Nation in the tropics of Indian Ocean, Sri Lankan coastal dynamics are mainly driven by the monsoonal waves. The dynamics of the south & west coastal regions are derived by the southwest monsoon with net sediment drift from south to north. Kalpitiya coastal region is the most north word in the west coast. Kalpitiya peninsula, which is west of Puttulam lagoon, is a sand spit, shaped like a beckoning finger. Its landform includes beach, dunes, saline flats, salt marsh, mangrove, and water bodies etc. The peninsula has a concave shoreline oriented west up to Kandakuliya, and north of Kandakuliya is largely convex. North of kandakuliya is assumed to be more vulnerable for coastal dynamics. It was further examined through transact walk and decided to confine the studies to the 'Kalpitia Coastal Window' as shown in **Figure 1-1**. Since the coastal dynamics are continued over the entire west coast, models were forced to the Kalpitiya Coastal Window through the west coastal region.

1.2. Coastal Communities

Coastal resource & communities in Sri Lanka are more significant in socio economic means of the country. As per the study on the Coastal Economy, done by the Coast Conservation Department in 2006, it is found that the 44% of the National GDP is generated in the coastal regions. Further with the current rapid development process in the country, coastal tourism is at its utmost. Kalpitiya Coastal Window is specifically proposed as a tourism resort with major investments. However the Kalpitiya coastal areas are occupied by traditional fishermen from the olden times. The both sectors have now shared the coastal resources for livelihood and economic benefits. Resources sharing in the dynamic coastal environment are an enormous challenge for the planners and administrators in the region. Since the Kalpitiya coastal region is rich with biodiversity and dynamic physical processes, the scientists shall be dealt with many researches, which are linked to engineering and management applications. The study aimed to explore the significance of sediment system and their dynamics to the coastal communities of General Public, and Private Developers and in the meantime to provide decision support tools for National & Local Planers, Administrators & Managers.

1.3. Space Applications

Space applications and earth observation technologies have vital advantages in studying long coastal stretches in a timely and cost effective manner as satellite data could provide a large spatial coverage on temporal basis through vast amount of satellite sensors. In the assessment of dynamics, the temporal resolutions of satellite images could be found in line with the natural climatic cycles. Further airborne imageries are the best mode of archiving the system information for analysis to be required by future generations. Therefore space based earth observation system is an ideal model for exploring and monitoring dynamics in the coastal systems.

2. METHODOLOGY

The healthy coastal resources, habitats & ecosystems are determined by the healthiness of coastal sediment structure. Therefore it is vital to maintain healthy sediment system for the existence of rich coastal environments, resulting livable coastal regions. Hence the coastal sediment systems and shoreline shall be indicative measures of the environmental productivity and sustainability of the coastal regions. The Coastal Managers shall monitor the healthiness of the sediment system for decision making in sustainable coastal management. Further, the systems shall be explored for their entire system life in spatial and temporal domains, describing the continuity and dynamics.

The study was done in following steps;

1. Explore the alongshore sediment drift
2. Long-term & short-term coastal dynamics
3. Coastal administration and development planning applications

2.1. Exploration of Alongshore Sediment Drift

The wave driven sediment process continues on long coastal stretches. In exploring the system, the entire sediment unit shall be studied. The sediment system in the west coast is driven by the southwest monsoon and it is presumed that the sediment process continued from Kalu River, towards north, up to the tip of Kalpitiya peninsula. The system spread over about 250 km coastal stretch. In analyzing the sediment particle movement along the coastal stretch, the thermo-luminescence principles were applied. Since no airborne sensors could measure the energy decay of sediment particles in exposure to the sun, ex-situ laboratory sensor were used. Sand samples collected along the entire coastal stretch were tested in Ris□ TL/OSL DA-20 emission spectrometer (**Figure 2-1**) at Coastal Engineering Laboratory of The Tokyo University.

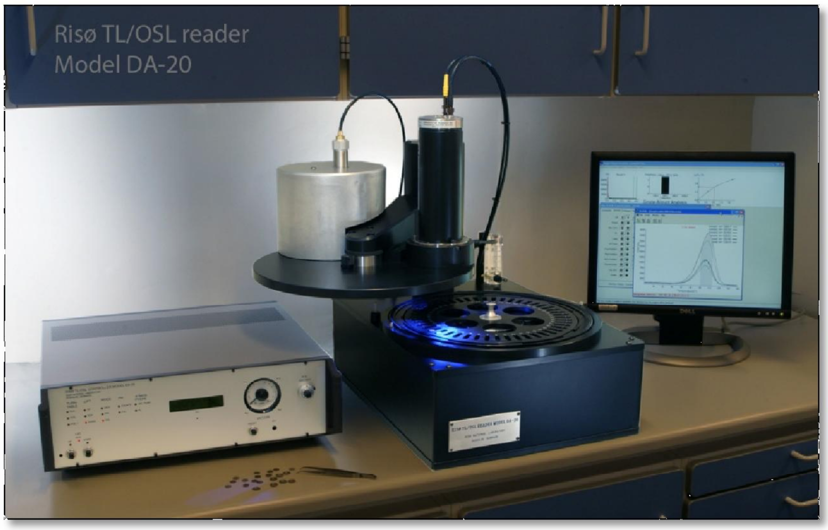

Figure 2-1 Riso TL/OSL Reader
Riso National Laboratory

2.2. Long-term & Short-term Shoreline Dynamics

The stability of shoreline is one measure of the healthiness sediment system. In analyzing the shoreline dynamics, the study was confined to the Kalpitiya Coastal Window, which has coastal length of about 50 km. There are many ways of measuring the shoreline with ground technologies. When considering the area of interest, ground technologies would be time consuming. Further no historical shoreline ground measurements have been done in the past. Hence the airborne techniques provide more realistic ways in capturing shorelines in temporal domain.

In Sri Lanka the historical images could be found in aerial photographs. The first aerial survey has been done in 1956 and it has been repeated in nearly 10 year intervals. The entire coverage of the island is available in 1956 and selected areas have covered in 1972, 1984, 1992 and 2000. For capturing the recent shorelines, satellite images are available from optical and Synthetic Aperture Radar (SAR) sensors.

Long-term Shoreline Dynamics: In the study of long-term dynamics of Kalpitiya region, shorelines captured from 1956 scanned aerial images, 1988 Landsat image, 2005 Google Image and 2010 ALOS PULSAR images were used. The shorelines in different years were digitized on screen manually. Since the images are from different sensors with varying spatial resolutions, the analysis is much qualitative then quantitative.

Shore-term Shoreline Dynamics: In analyzing the short-term shoreline dynamics, the frequency of imaging is important. For short-term analysis, the images shall be captured in monsoon, inter-monsoon and off monsoon periods. The ALOS PALSAR provides images with revisit time of 46 days and hence it can be captured seasonal dynamics of the shoreline. Since the SAR techniques are ready for all-weather, it is much appropriate using PALSAR images. In the study shorelines were captured from the ALOS PALSAR images of 3 years from 2007 to 2009. The intensities of backscattering of SAR images are derived from the ground features such as roughness and moisture. The phenomena were used in ground truthing the shoreline, where dry lands and water surface are at either side. For ground truthing, the GPS tracks of shoreline were captured on ground and compared with the corresponding satellite image. The shoreline captured was overlaid on PALSAR images, and it was investigated the backscattering characteristics along the shoreline. The shoreline locations were plotted on the cross-section of the normalized backscattering intensities, as shown in the **Figure 2-2**, and following relationships were observed.

From sea to the land,

- the offshore area is much darker with low backscattering
- the near shore with breaking waves has slightly higher backscattering
- smooth sandy beach surface with moisture backscattered very low
- vegetation and dunes results relatively high backscattering

Hence the shorelines were extracted by using the above characteristics on the image.

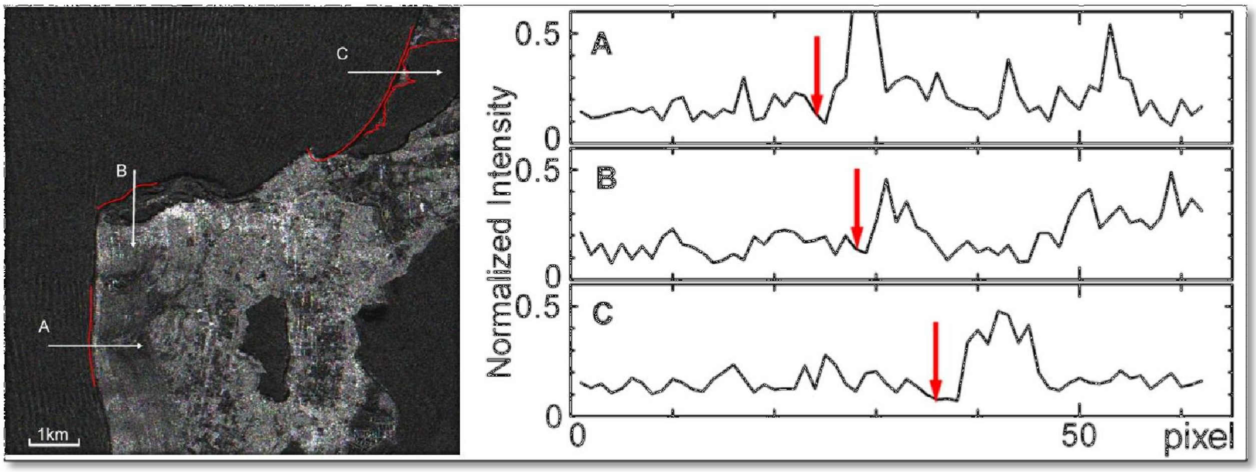

Figure 2-2 GPS Tracks (left), Backscattering Intensities (right) and shoreline Location (red arrow)

In short-term dynamic analysis, selected few smaller spatial domains were considered. The variations of shorelines at these localities were observed on the images. The shoreline dynamics with the alongshore sediment transport were analyzed using the shoreline plots with reference to 2007 shoreline. Further shoreline variations with reference to the 2007 shoreline were plotted at the selected locations and the seasonal changes with the monsoonal waves were investigated.

Micro Scale Dynamics: The long coastal stretches shall be divided in to micro cells with their characteristics. Kudawa sand pit has been identified as one micro cell, which has complex behavior. Micro scale dynamic analysis approaches were applied in understanding the behavior of Kudawa sand pits. The spatial domain of Kudawa sand pit is limited to 3 km, and within the cell, micro scale observations were carried out. Since the temporal scales of the dynamics are too rapid, the micro processes taken place with the wave periods have to be observed. No satellite images shall help with the temporal resolution required at micro scale. Hence an outdoor optical sensor was deployed at 21m above the ground. Since the wave periods are varied from 2 - 15 sec the images were captured at 1.2 sec intervals. Few ground control points were used for geo-cording the images. Images were captured continuously for six months during day time for 20 minutes per an hour.

Figure 2-3 Optical sensor arrangement & Kudawa sand pit
Google Earth

2.3. Coastal Administration and Development Planning Applications

The dynamics of the coastal areas would have both positive and negative impacts on the coastal communities and environment. The negative impacts might adversely affect the livelihoods of communities, and harmful to the healthiness of the environment. If the positive impacts are not administered or managed properly, there might be possibilities of creating many issues. Hence it is vital to develop applications, by linking the derived coastal dynamics, for decision making on community developments and environment enhancement. For understanding the relationships of developments, community livelihoods, habitat and ecosystems, with the dynamic coastal nature, ALOS AVNIR 2, ALOS PRISM and Google Earth imageries were used.

From the commencement of the study, the coastal community consultations were done in identifying specific issues linked with the coastal dynamics. Fisheries activities have well distributed over the coastal region in Kalpitiya, from long ago. Recently the area is proposed to develop as a tourist resort area. Then the sharing resources on a dynamic environment create the systems more complex. As decision support through the sturdy, stakeholder meetings were conducted throughout. Tourism authorities, hoteliers associations, fisheries management authorities, fishing community organizations, local government and division administration were closely associated with the study.

3. RESULTS & DISCUSSION

The study results were grouped and analyzed for the conclusions on the coastal dynamics in the Kalpitiya Coastal Window. The results & conclusions are made on the following.

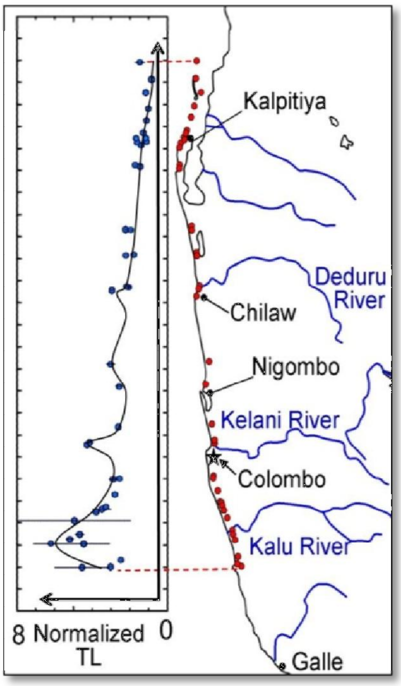

Figure 3-1 TL results in west coast

1. Alongshore sediment drift
2. Long-term dynamics
3. Short-term dynamics
4. Multiple sensor approach
5. Decision support

Since, the results itself could not be concluded in analyzing the system, further observations and investigation on the geomorphology were conducted.

3.1. Alongshore Sediment Drift

The TL study results for the west coast are shown in **Figure** 3-1. The Normalized intensity distribution alongshore indicates peaks at the river mouths and also intensity decay towards the north up to Kalpitiya. It can be noticed that the peaks are due to the addition of newly eroded sediments, which have less exposure to the sun with high energy remittance. While the sediment particles move over the shore, the particles are exposed to the sun and hence the TL signal intensities have been reduced. It concludes that the sediments are supplied to the beaches from rivers and move along the west coast with net drift towards northerly direction. Finally the sediment accumulates in the Kalpitiya region.

3.2. Long-term Dynamics

The long-term dynamics of the Kalpitiya Coastal Window was investigated through the analysis of image since 1956 to 2010 with four temporal tags of 1956, 1988, 2005 and 2010. The entire temporal domain is 55 years. The results were explained at four critical micro cells, namely 1. Kandakuliy, 2. Kudawa, 3. Uchchumunai, 4. Vellai **(Figure 3-3)**.

Kandakuliya (1): Huge sediment accumulation has been taken place for the past period. 1956 – 1988, 60 hectares of land has been accreted at the rate of 1.86 hectares/year, and 1988 – 2005, 102 hectares at 6 hectares/year, 2005 – 2010, 30 hectares at 6 hectares/year. In total for last 55 years 192 hectares has been added. It can be concluded that the shape of the shoreline proves that the geomorphologic features such as reef outcrop in the sea bottom might be the reason for the accumulation.

Kudawa (2): At the Kudawa sand pit, there is a considerable retreat but accelerated over the period of last 55 years. The maximum total retreat is about 600 m. By exploring the geophysical features of the area, it can be observed that the Groyne series constructed in 2002 for the purpose of protection of coastal communities, could account for the acceleration of the erosion.

Uchchumunai (3): In Uchchumunai huge accumulation has been detected and it has also been accelerated over the period. Acceleration is further proved by the observations made on the sand dunes **(Figure 3-2)**. It can be seen that heights of the sand dunes are reduced towards the sea. Slower the accretions grow the sand dune and increase the heights. In observations made on geomorphology, the presence of bar reef has sheltered the Uchchumunai, reducing wave energies and then the rate of sediment drift.

Figure 3-2 Sand dunes

Vellai (4): Vast change of shoreline was detected in Vellai. The long sand bar has been detached in to small islets and the islets have moved towards the mainland. As determined, the sediment drift in the coastal areas in northerly direction. Since the sediment is accumulated at Uchchumunai, no sediment passes towards Vellai. Further the islet is at very low elevations. Hence the wave overtops the islet by moving sediment from foreshore to the back of the islet resulting movement of the position of islet towards mainland. It shall further conclude that in this no sediment supply scenario, there is no possibility of long existence of Vellai Islet.

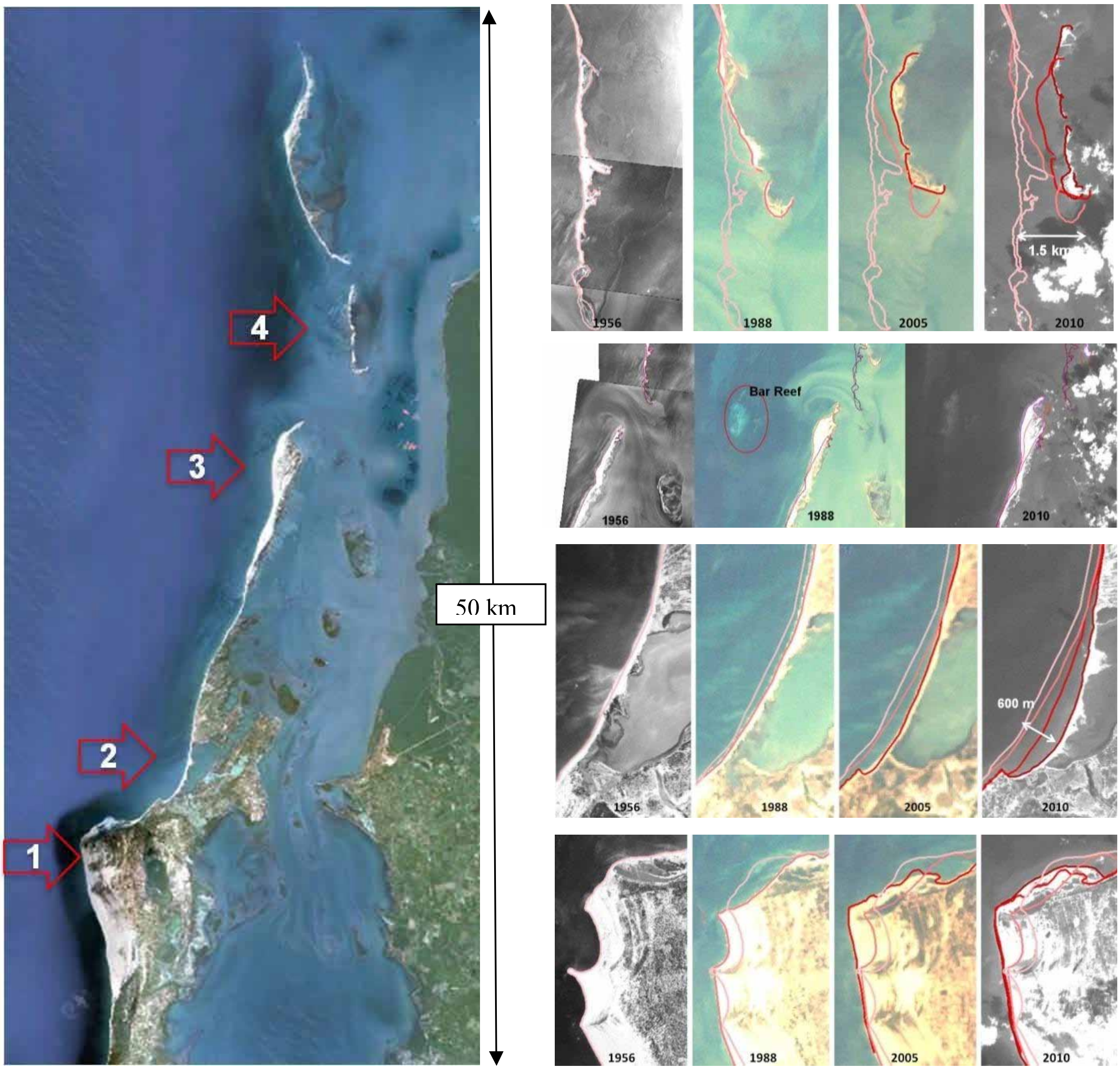

Figure 3-3 Long-term dynamics

3.3. Short-term Dynamics

The short-term analysis was done using the ALOS PALSAR images from 2007 to 2009 **(Figure 3-4)**. The analysis was confined to Kudawa sand pit area, where the shoreline found to be more dynamics on seasonal wave climates. It was detected that there is 300 m retreat within 10 months from 2007 March to 2008 January. Even thought the retreat was detected on satellite images, the processes that drive such kind of retreat cannot be understood using the same images. Hence two outdoor optical sensors were deployed at 21 m height, to observe the area for six months. But it was not possible to examine the processes in the absence of repeated behavior of the shoreline within the period. Further it was noticed from the shorelines in the lagoon side that considerable changes has not been occurred in lagoon shoreline.

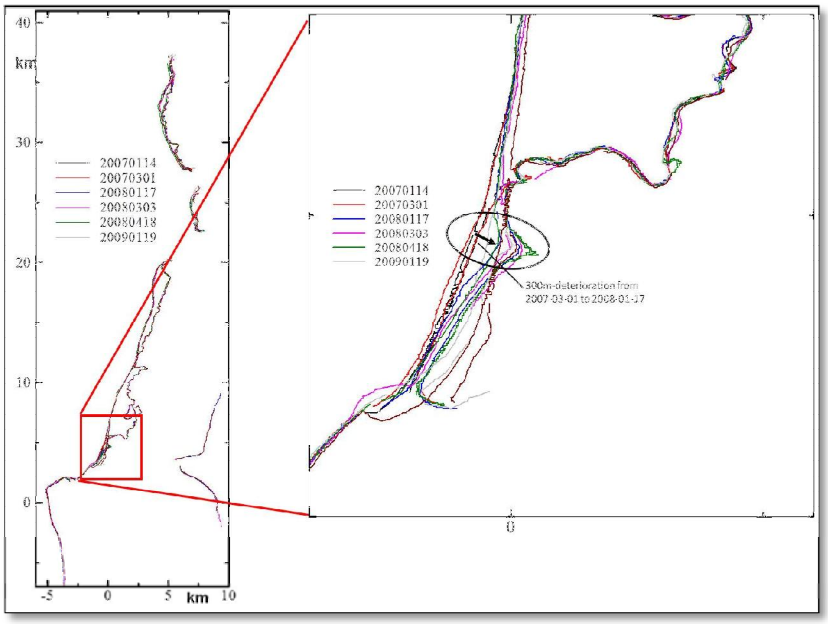

Figure 3-4 Short-term Dyanamics

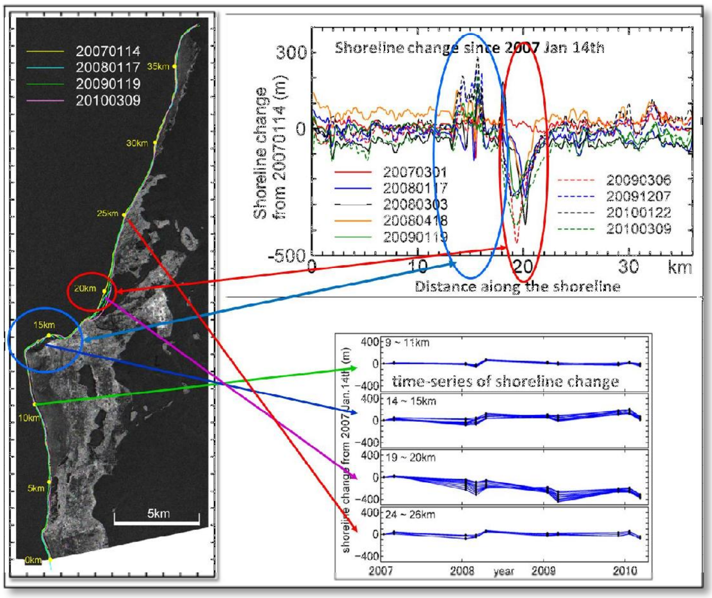

Figure 3-5
Short-term Dyanamics at Kalpitiya Coastal Window

During the analysis it was found that a considerable change had been taken place along the entire Kalpitiya Coastal Window between 2007 and 2010. The major changes have been detected at the locations of 15km (Kandakuliya) and 20 km (Kudawa) measured along the shore. At 15 km, accumulation of sediment can be observed, and at 20 km huge retreat.

As per the results of the analysis on the short-term alongshore dynamics, it can be estimated that the sediment entered from upstream (Southern End), accumulated at 15 km (KandaKuliya) region. Hence hardly and sediment is available for 20 km region (Kudawa), resulting erosion. With the investigations done on the geophysical features, it is found that due to the Groyne field at the south of 20 km (Kudawa), the hydrodynamics pattern might have accelerated the erosion situation. The eroded sand moves further northward and accumulated at the 35 km region (Uchchumunai) due to the shelter of Bar Reef in the near shore area.

3.4. Multiple Sensor Approach

In the long-term dynamic analysis explained in 3.2, a series of images acquired through multiple sensors such as aerial camera, Landsat, Ikonos and ALOS PALSAR were used. In such an analysis done for a period of 55 years, the multiple sensor approach cannot be avoided due to the unavailability of single sensors, activated for longer time span. With the different characteristics of images from multiple sensors, such as spatial resolution, band combinations etc, the analysis would become complex and the results would be more qualitative or indicative. Further even for short-term analysis, single sensor could not interpret the entire scenario. Hence in-situ and ex-situ multiple sensors were used with deferential temporal resolutions, backscattering or energy remittance technologies etc.

3.5. Decision Support

During the course of the study, nature of the analysis and the results were shared with stakeholders and coastal communities, in particular with the tourism authorities and investors. Particularly, the visual demonstration of coastal dynamics, possible erosion and accretion, and a discussion on the impact of coastal resources in the future interested almost all the stakeholders. Satellite based analysis proved as an effective tool in influencing local communities, policy makers and investors. Based on discussion took place in stakeholders meetings, some of the major investments have already been scale down with understanding of the dynamics and the erosion vulnerability. There were problems for the fishing communities in navigation and landing of fishing crafts due to the shoreline dynamics. With the results of the study, it was possible to change some of the decisions to restrict certain development using better adaptation strategies. Accreted land management has become one of the crucial decision making in the area. The local administrators were aware about the dynamics of the area but it was only possible to quantify after this study. Considering the specific issues of the area with the coastal dynamics, the area has been proposed to manage under the “Special Area Management” program of national Coastal Zone Management Plan. In addition, the area is added to the proposed “Man and the Biosphere (MAB)” of “Mannar Basin” for MAB Program of UNESCO, and the results were shared for decision making.

4. CONCLUSIONS & RECOMMENDATIONS

The Kalpitiya Coastal Window is highly sensitive with its dynamical characteristics. The identified natural discontinuities of sediment drift would results on the existence of some islets. Satellite information used in conjunction with various airborne data proved to be a vital instrument in identifying coastal dynamics including accretion and erosion. Both optical and SAR data showed their usefulness in coastal applications, specifically potential of SAR data where the cloud cover remain as a factor when short-term exploration is required. Further, space based technologies provided vital information to verify sediment transport model developed for the study area to justify the validity for future estimations of coastal changes. With further studies, it is the high time to make decisions on disappearing islets with no or less impacts to the equilibrium of the coastal system. Given due considerations to the system complexity, the Kalpitiya coastal region shall be managed cautiously in consultation with the scientific community.

Coastal regions are subjected to the continued natural processes, resulting dynamics of the shoreline. For the decision making on the sustainable coastal developments, the dynamics of the systems have to be explored and understood. Many technologies and tools shall be used for exploring the coastal system. Due to the continued nature of the dynamics, the spatial extent, to be studied, would not be convenient to undertake without far-reaching technologies such as satellite earth observation and airborne imaging. In the current context of earth observation, the varying sensor technologies would be a challenge for long-term quantitative analysis of coastal dynamics. The interoperable sensor technologies, and multi sensor image analysis technologies and tools shall be developed and shared.

5. ACKNOWLEDGMENTS

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