

COASTLINE CHANGE MEASUREMENT AND GENERATING RISK MAP FOR THE COAST USING GEOGRAPHIC INFORMATION SYSTEM

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ABSTRACT:

Information on the pattern, rhythm and long-term trend of shoreline dynamics is vital to managing the coast, especially in mapping risk areas and in establishing the width of construction setback lines. Unfortunately, such data are often missing or where present of doubtful quality. In this paper, we share our experience in mapping coastline change in Singapore, using geographic information system (GIS). Most important before embarking on measuring coastline change is defining the coastline and deciding on a working definition where this line can be established on the ground, on maps or other sources of data. Complications arise where the coastline is extracted from different data sources to detect changes. In Singapore, coastline is defined as 2.515 m chart datum and this line which theoretically separates land from sea is shown on cadastral maps.

The East Coast Park of Singapore is selected to illustrate the different techniques in measuring coastline change using GIS. Techniques include setting up a series of profile lines monitored and analyzed in GIS over a decade to detect changes, and using GIS to generate the 2.515 m chart datum line from a dense network of elevation points collected on the beach. Maps showing various rates of shoreline erosion are then derived and finally a Risk map for the coast generated.

1. INTRODUCTION

Information on coastline change from seasonal to longer term trend constitute an essential and vital input in any coastal management plan, so that areas of potential loss to erosion can be identified and appropriate land use planning adopted. Unfortunately, such information is lacking and, where present, often of doubtful reliability. In Singapore, additional problems are encountered: the coastline is often <40 years old, created after land reclamation and still undergoing changes towards equilibrium. Along many coastal sectors the retreat has been planned and many beaches have been nourished to slow down shoreline retreat and maintain popular beaches. Information on beach management and the amount of sand used for nourishment is usually not available. Hence, interpreting coastline change under such circumstances is difficult.

A proper understanding of coastal processes in general and the local history of land reclamation is required to interpret the changing coastline. A retreating coastline may not be of concern as it may be planned. On the other hand, a stable coastline maintained by nourishment should be of concern. Different sectors of the ECP show diverse behavior, with some stable while others receding or advancing. This spatial pattern of different rates of erosion and accretion provides the basic information for micro management of the coast. Emplacement of canal structures and additional breakwaters has also changed the sedimentation pattern. All these have made interpreting coastline change even more difficult. Despite this, careful analysis of the data would still yield useful information on erosion hazards and risks for development. Shoreline management is not an exact science and may entail a series of responses as unanticipated problems emerge from time to time. When accurate information on shoreline dynamics is lacking, it may be

wiser to adopt a precautionary principle in management. Sometimes, facilities are constructed in a high risk area for temporary use and this causes misunderstanding when not properly explained. Different types of land use strategies require different types on erosion hazards. Data on seasonal coastline change is used to establish the width required to create a buffer zone where the shore can retreat and recover unimpeded. Longer term change will aid in land use planning by establishing the highly dynamic and sensitive areas that should not be developed.

2. MEASURING COASTLINE CHANGES: CONSIDERATIONS

Important questions that need to be addressed in coastline change studies include why coastline change is measured, what is being measured and how the measurement is carried out (Teh et al, 2005). It is important to understand the reasons for measuring coastline change and the accuracy of measurement so that the results derived can be properly applied for planning purposes. Short-term changes have less value for planning compared to long-term changes. On the other hand the latter may not capture the seasonal changes provided by the former which may be critical. If the reasons for measurements are understood, this will help towards a suitable definition of the coastline and the choice of techniques to be employed. Past studies have used different datum for measuring coastline change. The popular datum or feature used includes a legally defined coastline which varies from country to country, MHWS, vegetation line, seaward foot of coastal dunes and coastal scarp. Different values are obtained with the use of different datum or coastal features. Longer term coastline changes usually use the oldest reliable topographic map as a baseline whereas short term changes

employ field techniques to detect small changes in coastline position.

2.1 Short-Medium Term Measurements:

The usual technique is to conduct repeat surveys along fixed profile lines from a temporary bench mark (TBM) down to low water. Spacing of profiles and intervals between successive profiling is influenced by objectives, coastal landscapes and man power. Usually four surveys are conducted each year to capture monsoonal influence and from 1 to 5 profiles are set up for each sediment compartment to capture the spatial variation. Profiles may also be set at fixed intervals along the coast. Monitoring over several years will provide useful data on medium term coastline change.

2.2 Longer-Term Measurements:

The usual method of detecting longer term coastline change is by overlaying a series of topographic maps of the same scale from different years. The displaced coastline is then measured and the rate of change calculated. The coastline on the topographic map is represented by the blue line. This method only allows large scale changes to be detected, as a 0.2 mm width line would represent 10 m and 2 m on the ground on a 1:50,000 map and 1:10,000 map respectively. When vertical aerial photographs became easily available, this new source of information was used to supplement topographic maps. The problems that came with this new approach was trying to convert the aerial photographs, often showing tilt and of different scale from the topographic maps, to the scale of the topographic map. A more serious problem was in deciding what the blue line on the topographic map represents on the aerial photographs.

3. EAST COAST PARK, SINGAPORE

The East Coast Park (ECP) is reclaimed from the sea in several phases by Housing and Development Board of Singapore to create land for the East Coast Parkway, public housing and recreational space (Figure 1). (Wong, 1973) suggested a sequential development of beaches along the ECP to equilibrium, forming five beach types according to their developmental level. At the time of his study, he classified the bays from HL2 (Headland2) to HL4 (Headland 4) as new beaches and developing beaches.

3.1 The Study Area - Headland 2 to Headland 4

A short section of the ECP, from HL 2(Headland 2) to HL 4(Headland 4), is selected as the study area as shown in Figure 1(Ikonous Satellite image, 2000). This is in front of McDonald and represents one of the more popular coasts along the ECP. The coastline is badly eroding and shoreline retreat and loss of facilities have resulted in various responses to hold the coastline. This coastal sector was designed to consist of three inverse J-shaped bays developed between four emplaced headlands. The net littoral transport after land reclamation is westwards as suggested by the pattern of erosion and accretion adjacent to headlands and canal structures. However, there is drift reversal at times. The study area in this paper covers only a short sector of the ECP monitored for coastline change.



Figure 1. The East Coast Park study area

4. SHORT MEDIUM TERM COASTLINE CHANGE

The profiles are grouped under compartment 1, consisting of P5 to P6iic and compartment 2, consisting of P6iib to P6v. The profiles are analyzed for rate of coastline change individually. The profile monitored and analyzed in the study area consists of 10 profiles (Table 1).

Profile	Location	Start-end monitoring	No. month	Description
P5	HL2-3	18/7/03-9/4/09	69	East of headland 2
P6i	HL2-3	19/7/01-9/4/09	93	Across dry headland, scarped
P6ii	HL2-3	24/12/01-9/4/09	88	Badly eroding sector, erosion mitigated, scarped
P6iib	HL2-3	13/8/04-9/4/09	56	West HL3, erosion mitigated, scarped
P6iic	HL2-3	10/9/04-9/4/09	55	West HL3, erosion mitigated, scarped
P6iiib	HL3-4	10/9/04-9/4/09	55	East HL3, nourished, scarped
P6iv	HL3-4	24/12/01-9/4/09	88	East HL3, nourished, scarped
P6ivb	HL3-4	13/8/04-9/4/09	56	East HL3, nourished, scarped
P6ivc	HL3-4	13/8/04-9/4/09	56	West HL4, nourished, bermed
P6v	HL3-4	24/12/01-9/4/09	88	West HL4, nourished, bermed

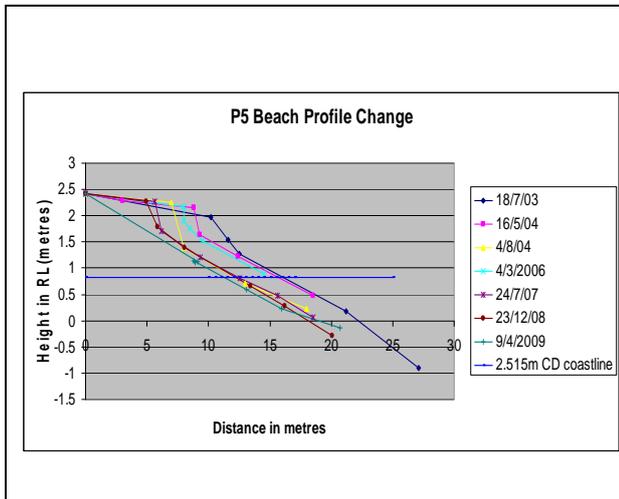
Table 1. Profiles monitored from HL2 to HL4

The field technique uses repeat surveys along fixed lines, with painted ground markers and land marks (Teh, 2000). Each profile begins with a temporary bench mark (TBM) in which the reduced level has been tied to a nearby precise level bench mark (PLBM). Beach profiling is carried out mainly by using a digital automatic level from TBM to Low water mark during low tide (Singapore Tide Tables, 2009). The collected data are processed in profile information system developed in GIS software and the coastline change measured graphically and the rate of change expressed in meter per month and meter per year. This monitored coast is highly dynamic showing changes in profile form and coastline position as a result of beach engineering and monsoonal influence. Between mid 2004 and the end of 2008 the coastland was displaced landwards.

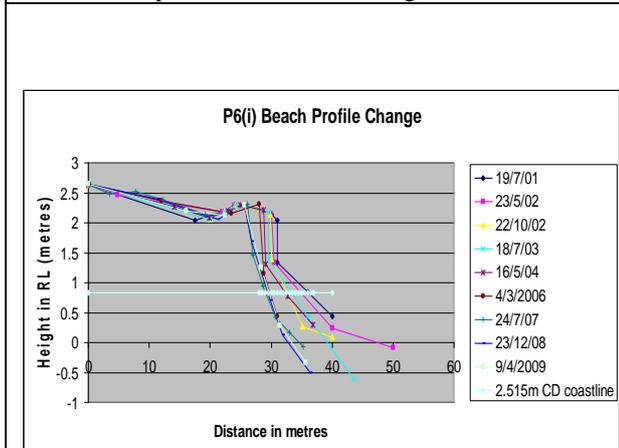
The datum used for defining coastline in this paper is the 2.515 m chart datum or 0.863 m RL for the study area (Singapore Tide Tables, 2009). This datum is shown on cadastral maps to separate land from sea in Singapore. Figure 2 displays the graphs for selected profiles generated by the system. The system also allows the user to choose the different time period and calculate rate of recession of coast for that particular period.

The profile information system manipulates all the input data for a profile and summarizes the results as a report for the individual profile as shown Table 2.

Date profiled	Coastline distance from TBM in metre	Coastline adv/retreat in metre from 24/12/01	Total months from oldest profile	Rate of change in metre per mth/ metre per yr from 24/12/01
24/12/01	12	-	-	-
24/5/02	19.1	+7.1	5	+1.42/+17.04
22/10/02	12.9	+0.9	10	+0.09/+1.08
18/7/03	17.5	+5.5	19	+0.289/+3.474
16/5/04	21.5	+9.5	29	+0.327/+3.931
28/8/07	14.3	+2.3	68	+0.034/+0.406
23/12/08	10.1	-1.9	84	-0.023/-0.271
9/4/09	11.8	-0.2	88	-0.0023/-0.0273



2A. P5 beach profile and coastline change 2003-09



2B. P6i beach profile and coastline change 2001-09

Table 2. P6iv change in coastline position 2001-2009

The system also generates the report for the complete set of profiles as shown in Table 3.

Profile	Start-end monitoring	Months	Coastline change (m)	Rate of change (+/- m/yr)
C1-P5	18/7/03-9/4/09	69	-4.5	-0.783
C1-P6i	19/7/01-9/4/09	93	-6.5	-0.839
C1-P6ii	24/12/01-9/4/09	88	-5.3	-0.723
C1-P6iib	13/8/04-9/4/09	56	6.1	1.307
C1-P6iic	10/9/04-9/4/09	55	4.5	0.982
C2-P6iiib	10/9/04-9/4/09	55	-6.3	-1.375
C2-P6iv	24/12/01-9/4/09	88	-0.2	-0.027
C2-P6ivb	13/8/04-9/4/09	56	0.7	0.15
C2-P6ivc	13/8/04-9/4/09	56	4.6	0.986
C2-P6v	24/12/01-9/4/09	88	-0.8	-0.109

Table 3. Coastline change over monitored period

Figure 2. Selected Profiles of Compartment 1

4.1 Interpreting the Profile Data Report:

The medium term coastline change data, summarized in Table 3, showed that the rate of retreat since 2001/2003 for the coast from HL2 to the Dry HL (P5 and P6i) was greater. For the coast from Dry HL to HL3(P6ii), the medium term change recorded a retreat rate in front of the Dry HL since 2001 comparable to the coast to the west. However, towards the east near HL3 (P6iib and P6iic) the coastline has propagated since 2004 because of nourishment and from supply of alongshore sands. Along the inverse J shaped bay from HL3 to HL4, the coastline change is varied since 2004. Profiles P6iib, P6iv and P6v has shown retreat trend while nourishment in had resulted in profiles P6ivb and P6ivc showing coastline advance. Hence GIS allows the coastal planners and managers to observe the beach profiles more accurately and take important decisions like when the beach need to nourished more appropriately.

5. LONGER -TERM COASTLINE CHANGES

The longer term coastline change of the study area is established by comparing the 1972 2.515 m CD coastline shown on cadastral maps with that of the 2007, 2.515 m CD coastline (0.863 m RL) generated in ArcGIS from a dense network of elevation points collected on the beach using Total Station. The elevation points from low water mark to 5 m were collected along the whole ECP in 2007 was used for this study.

Triangulated Irregular Network (TIN) was created from elevation data collected by field surveys using ArcGIS 3D analyst (Ormsby et al, 2009). Further the TIN (Figure 3a) was converted to Digital Elevation Model (DEM) raster layer using ArcGIS (ESRI Link,2009) at a spatial resolution of 0.25 meter as shown in the Figure 3b.

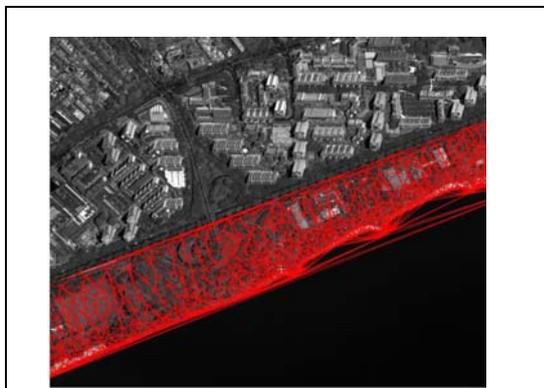


Figure 3a TIN

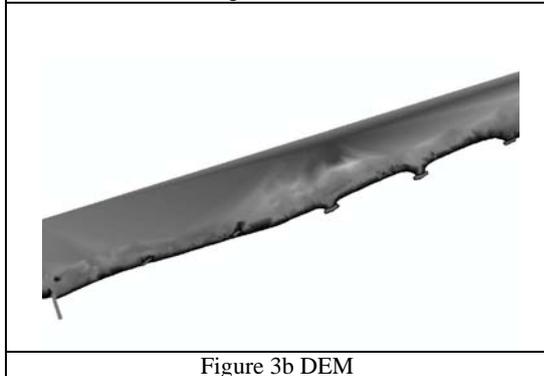


Figure 3b DEM

Figure 3.Generation of DEM

DEM can be validated spatially by comparing it with the spot heights (Herano, 2003). Spot heights provided by the Singapore Government survey agency were used for compassion in our study. The spot heights were imported as thematic layer in ArcGIS and overlaid over the DEM and compared spatially (Santosh et al, 2009).The resultant error value revealed a good correlation between the verification points and the DEM. The vertical accuracy was below 0.1m in the areas where field survey work was carried out. This DEM raster was analyzed for the elevation value 0.863m by executing spatial query using raster calculator tool in ArcGIS spatial analyst which resulted in the generation a coastline with the 0.863 m elevation.

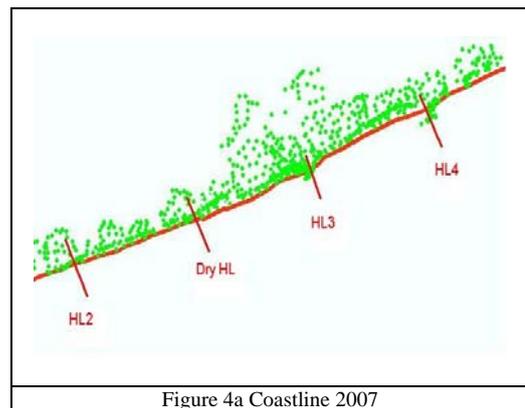


Figure 4a Coastline 2007

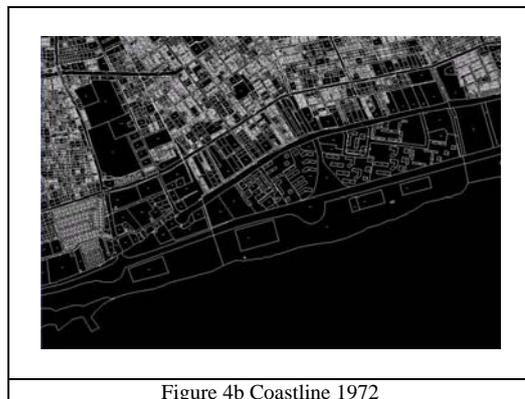


Figure 4b Coastline 1972

Figure 4. Coastline of Study area.

1972, 2.515 m CD (0.863 m RL) coastline shown on cadastral maps (Figure 4b) was obtained from Singapore Land Authority Department, Singapore. World view -1(WV-1) satellite image tasked in July 2008 for the study area was georeferenced in ArcGIS and used as the backdrop layer for the comparison. The 1972 coastline and 2007 coastline were imported in ArcGIS as a thematic layer and were overlaid on the WV-1 satellite image for comparison. The average retreat was calculated spatially by identifying the area of polygon formed between the headlands and dividing it with the corresponding distance between the two headlands. The maximum retreat was calculated spatially by measuring the distance between the lines using tools in Arc Map module of Arc GIS software. Comparison of different year's topographic maps of same scale in GIS software is more accurate and reliable source for coastline change measurement and coastal land use management.

5.1 Results of the Longer-Term Coastline Change:

Comparing the 2.515 m CD coastline of 1972 and 2007 and examining the location of the headlands and dry headland strongly suggests that the whole study area from HL2 to HL4 has retreated since 1972, but the retreat has been varied (Figure 5). The 300 m coast between HL2 and the Dry HL recorded the least retreat, with an average of 6.55 m (-0.187 m/yr) and a maximum of 12.37 m (-0.354 m/yr). The coast from the Dry HL to HL3 shows an increasing landward displacement of the coastline eastwards. The average retreat was 29.82 m (-0.852 m/yr) and the maximum retreat 46.52 m (-1.33 m/yr). The greatest retreat took place between HL3 and HL4, where the 1972 coastline was evenly displaced landwards to the headland-breakwater built on land. Average retreat was 45.35 m (-1.29 m/yr) and the maximum retreat was 49.52 m (-1.41 m/yr).

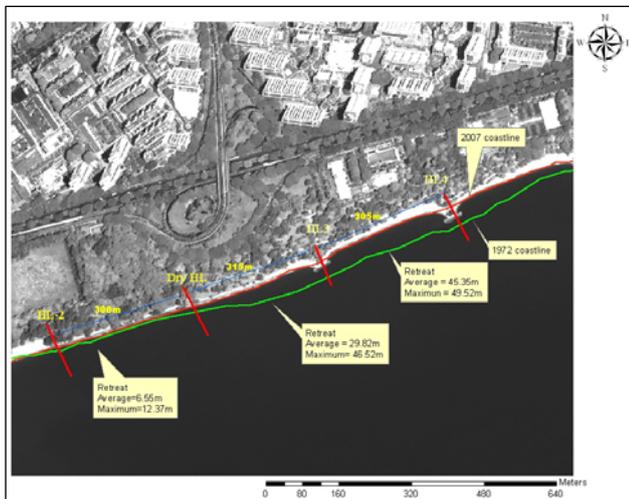


Figure 5. Retreating coastline of ECP 1972-2007 (35 years)

Long term coastline change records a retreating. The loss of beach lamps, tracks, drains and trees to erosion indicate that the erosion was unanticipated. On the whole, the coastline is badly eroding and shoreline retreat and loss of facilities have resulted in various responses to hold the coastline. Intervention using beach nourishment, relocation of tracks and trying to hold the coastline using structures are the usual responses for coasts facing critical erosion.

6. A COASTAL EROSION HAZARD AND RISK MAP OF ECP

There are different ways of classifying erosion. An obvious method is to group them under different rates of erosion (e.g. high, moderate, low) providing such data is available and reliable. In Samoa, as part of a study to identify the various coastal hazard zones and formulate policies for sustainable coastal management, coastal erosion hazard zones for 100 year time frame were mapped, based on erosion rates calculated using GIS (Taulealo and Bismark-Crawley, 2002). Erosion is widespread along the whole ECP, especially within the study area. The beaches will continue to erode and intervention measures will have to be carried out to maintain

the beaches and hold the coastline position. Intervention measures will become increasingly costly and will have to be carried out at shorter intervals. Other potential option to be considered include the enhancement and preservation of natural protection (e.g. replanting of mangroves and sea grass), use of softer options such as artificial nourishment and raising the height of ground of buildings and dewatering (Wong, 2003). A rising sea will lead to accelerated erosion. Managing the ECP will become increasingly more challenging and will need all the help possible. It is with this in mind that an initial attempt is made here to prepare a coastal erosion hazard and risk map for the study area, which can later be extended to cover the whole island. The coastal erosion hazard and risk map generated by using GIS shows various categories of erosion, together with the future coastline position in 15, 30, 50 and 100 years (Figure 6).

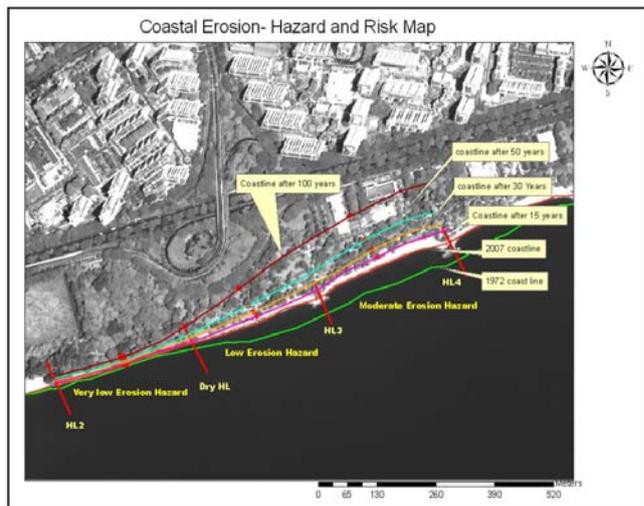


Figure 6. A coastal erosion hazard and risk map

Erosion hazards for the current study have been tentatively grouped under 5 classes based on the rate of retreat. These are <math><0.5\text{ m/yr}</math> (very low), $0.5\text{-}1.0\text{ m/yr}$ (low), $1.0\text{-}1.5\text{ m/yr}$ (moderate), $1.0\text{-}1.5\text{ m/yr}$ (high) and $>1.5\text{ m/yr}$ (very high). Three classes of erosion hazard are identified for the study area based on the long term rate of coastline change. This set of data is favoured over the shorter term change because of recent human intervention. The coast from HL2 to Dry HL is classed as very low, the coast from Dry HL to HL3 as low and the coast from HL2 to HL as moderate. The future projection of coastline was made by assuming the rate of retreat as linear. The projected future coastline position for different years allows coastal planners to assess risk for developments at different distances from the sea. The map serves as a guide and should be reviewed from time to time. Obviously the closer to the beach the greater the future risk. This coastal erosion hazard map acts as a guideline for setting up the setback lines by the coastal land use planners and other coastal land stake holders. The use of coastal construction setback lines is an important tool in coastal management and many countries have used this concept in various forms to regulate development and prevent future losses of property, structures and life caused by shoreline erosion.

7. CONCLUSION

Reliable information on short and long term trends in shoreline dynamics form the basis for identifying coastal sectors of varying sensitivities to development and aid in proper landuse planning of the coastal zone. Unfortunately, such information is lacking and should be addressed immediately. It is important to have information on the rate of natural retreat so that future shoreline positions for different years can be predicted using GIS. The general absence of data on coastline change and on sand volume used for beach nourishment make interpreting coastline change data very difficult. An ideal state would be to have such data on various coastal sectors around Singapore where human intervention had been minimal. The erosion hazard and risk map produced here using GIS represents a first approximation and will be refined as more data becomes available from the field monitoring.

Through this study a maiden attempt was made to demonstrate successfully the use of GIS system to integrate and analyse field data sets to develop erosion hazard and risk map using the short and long term coastline change data. The information provided by an erosion hazard and risk map helps coastal managers to assess degrees of risk when a particular coastal site is developed. High risk areas should be left undeveloped as a buffer zone. Since risk is related to rate of erosion which may change abruptly, an erosion hazard and risk map should be reviewed on a regular basis and changes made in accordance with changing erosion rate and pattern. The resultant map also allows the stake holders and scientist for decision making on adaptation measures e.g. beach nourishment.

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