Ramnath, S.L., Ramsewak, D. and Benetti, S. 2022. The determination of coastal sensitivity indices for Cocos and Columbus bays, Trinidad using GIS multi-criteria analysis. *Caribbean Journal of Earth Science*, **53**, 13-27.

The determination of coastal sensitivity indices for Cocos and Columbus bays, Trinidad using GIS multi-criteria analysis

SUNIL L. RAMNATH[1], DEANESH RAMSEWAK*[1], SARA BENETTI[2]

[1] *Centre for Maritime and Ocean Studies (CMOS), The University of Trinidad and Tobago, Chaguaramas Campus, Trinidad and Tobago*
[2] *School of Geography and Environmental Sciences, Ulster University, Coleraine Campus, Northern Ireland, United Kingdom.*
* *deanesh.ramsewak@utt.edu.tt*

ABSTRACT. A Coastal Sensitivity Index (CSI) map is a critical input for deriving coastal management plans. Development of these maps has typically been challenging since many of the datasets required are non-existent or unavailable. This study focused on determining CSIs for Cocos and Columbus Bays on the island of Trinidad. Historically, both bays have experienced severe erosion, which have led to the construction of high-priced coastal protection structures. Ten (10) erosion-inducing physical variables for each bay were categorized into two groups; one containing five (5) structural variables and the other consisting of five (5) process variables. Using a multi-criteria analysis approach, these variables were incorporated into a geographic information system (GIS) for the determination of the CSIs. All variables were ranked using published ranking criteria based on a scale of 1 - 5 (5 being the most sensitive). Two additional variables, storm surge and coastal protection structures, not traditionally used in sensitivity studies, were also included. Variables were manipulated using the geo-processing and spatial analyst tools in ArcGIS 10.4.1 to calculate the indices and generate the final CSI maps. CSI values were validated against field and desktop studies. Final CSI maps revealed that sensitivities for both study sites were predominantly high and very high. Erosion, sea level rise and increasing storm intensity and frequency are ever escalating threats to the coast. The initial results of this study and these growing threats further justify the need to include CSIs in coastal management plans. Hard engineering coastal protective structures usually require significant financial investment and the establishment of coastal setback distances can be a preferred shoreline management tool.

Keywords: Coastal Sensitivity Index (CSI), GIS, Multi-Criteria Analysis, Trinidad, Coastal Management.

1. INTRODUCTION

Beaches are a critical natural and economic resource for many small island developing states (SIDS). These sections of the coastline, which often serve as recreational areas for humans, exhibit some of the most dynamic changes in nature over timescales of hours to years. Built infrastructure, such as hotels, guest houses, craft shops, tourism booths, among others, in coastal areas are important to islands, which rely on tourism as a significant economic determinant (**Cambers, 1998**). Developers usually locate infrastructure close to the waterfront with no regard for coastal vulnerability. Often, this vulnerability results from the impacts of climate change and sea level rise (**Abuodha and Woodroffe, 2010**). Hard engineering structures help to counteract the impacts of erosion by intercepting sediment cross-shore transport. These structures are however not aesthetically appealing, but, through proper coastal planning and management alternative measures can be implemented to maintain the natural ambiance of the environment. The establishment of effective coastal setback distances that accommodate the constant short, medium and long-term changes which occur during erosion and accretion along the coastline can be an effective solution (**Cambers, 1988**). A coastal setback may be defined as a prescribed distance to a coastal feature, such as the line of permanent vegetation, within which all or certain types of development are prohibited (**Cambers, 1988**). **Sanò et al.** (**2011**) defines a coastal setback as *"…a buffer space where permanent constructions are not allowed, defined by a specific distance from the shoreline's highest water mark"*. Whereas **Cambers** (**1998**) established the reference as the permanent vegetation line, **Sanò et al.** (**2011**) used the high-water mark. In Trinidad and Tobago coastal boundaries are commonly measured using the high-water mark hence in this study the definition by **Sanò et al.** (**2011**) was used as the reference boundary. The impact of sea-level rise on physical and ecological coastal processes is widespread even though eustatic sea level is presently rising by a few millimetres per year (**Intergovernmental Panel on Climate Change [IPCC], 2014**). These impacts include exacerbation of coastal erosion and flooding from climate change and increased frequency and intensity of storms and storm surges, particularly on low-lying expansive bays and estuaries (**Ballinger and Dodds, 2017**). A number of abiotic marine and terrestrial factors affect the resilience of the coastline. These may include the beach slope, beach sediment, grain size, geology and geomorphology. Stopping coastal erosion and shoreline retreat is difficult; however, the reduction of erosion rates and restoration of endangered areas can be accomplished by coastal engineers and planners (**Charlier et al., 1989**). Multiple techniques such as seawalls, groynes, beach nourishment among others, have been trialled with varying degrees of success and occasionally with undesired, if not unexpected consequences (**Klein et al., 2001**). Establishing and implementing building line setbacks is potentially a more effective soft engineering approach. Multi-criteria geographical information systems (MC-GIS) analysis was used in this study to determine CSIs for Cocos and Columbus Bays, Trinidad. Both bays are classified as micro-tidal, low-lying and mainly affected by water levels, hence their vulnerability to sea level rise, coastal erosion and increases in storm frequency and intensity. Previous studies also indicate that both bays have undergone significant erosion in the last 30 years (**Oostdam, 1982**; **Kenny, 2002**; **Singh and Fouladi, 2003**; **Leung Chee et al., 2014**; **Chin Sang, 2015**), and this is likely to worsen in the near future.

CSIs have traditionally been used for the development and implementation of appropriate coastal management strategies (**Gornitz, 1991**; **Gornitz et al,, 1992**; **Thieler and Hammer-Klose 1999**, **2010**; **Pendleton et al., 2005**; **Abuodha and Woodroffe, 2006**, **2010**; **Prasetya, 2007**; **Addo, 2013**, **Faour et al., 2013**; **Murali et al., 2013**; **Pramanik et al., 2015**). The CSI is one of the most commonly used methods for establishing a coasts susceptibility to erosion and inundation. It is an approach that adopts a qualitative technique for assessing the vulnerability of a coastline due to the impacts of climate change (**Bagdanavičiūtė et al., 2015**). This approach is widely accepted (**Bagdanavičiūtė et al., 2015**), as it is a powerful method used to inform coastal managers of the risk along a country's coastline which can also be used to develop effective management strategies (**Addo, 2013**). In many instances, additional erosion-inducing factors such as shoreline exposure, barrier types and beach types, have substituted for unavailable native data sets (**Abuodha and Woodroffe, 2006**, **2010**; **Addo, 2013**; **Theiler and Hammer-Klose, 1999**, **2010**) and sources therein. This approach however, has seldom been used on non-tidal or micro-tidal bays.

2. MATERIALS AND METHODS

2.1. Study area

Cocos Bay (**Figure 1**), also locally referred to as Manzanilla Bay, is a barrier beach system bounded by two prominent, rugged headlands (**Darsan, 2013a**). Over the past decade this bay has experienced significant coastal erosion (**Darsan et al., 2012**) which has caused concern for persons living and working in the area (**Mahabir and Nurse, 2007**). Most of this erosion was recorded within the southern part of the bay. Columbus Bay (**Figure 1**), has experienced high erosion rates dating back to the early 1900's (**Leung Chee et al., 2014**; **Alexis, 2014**; **Kenny, 2002**; **Oostdam, 1982**). It is approximately 4 km long and is located along the northern face of the south-western peninsula of Trinidad. Beach profile and littoral data were collected at both of these bays for the IMA's Coastal Conservation Programme which has been in effect for more than two decades. Long term averages derived from this historical data were used in the multi-criteria analysis for this study. Both bays are relatively long and multiple IMA monitoring stations provided relevant information on coastal dynamics along the bay. There were five monitoring stations at Cocos Bay and eight at Columbus Bay (**Darsan, 2013b**). Even though, there are similarities between their geological and geomorphological settings both bays are exposed to varying beach dynamics and wave energies. Cocos Bay is a relatively straight, north-south oriented, sandy bay with low dunes exposed to plunging and multiple spilling breakers from the Atlantic Ocean while Columbus Bay is a sandy northeast to southwest oriented bay, located within the south-western region of the coastline of Trinidad. Columbus Bay is sheltered by the Gulf of Paria and has a dense coconut estate and low vegetation in the backshore with intermittent outcrops of mangrove. There are also differences in exposure to varying wave dynamics due to their locations. Each bay is exposed to varying wave approach and breaker types and they are both impacted differently by storm surges. Other erosion factors such as wind speed and direction also vary at each bay. Within recent times, both bays were highlighted in the local newspaper and were earmarked for coastal protection and other coastal development (**Fraser, 2014**; **Alexis, 2016**; **Ramdass, 2017**).

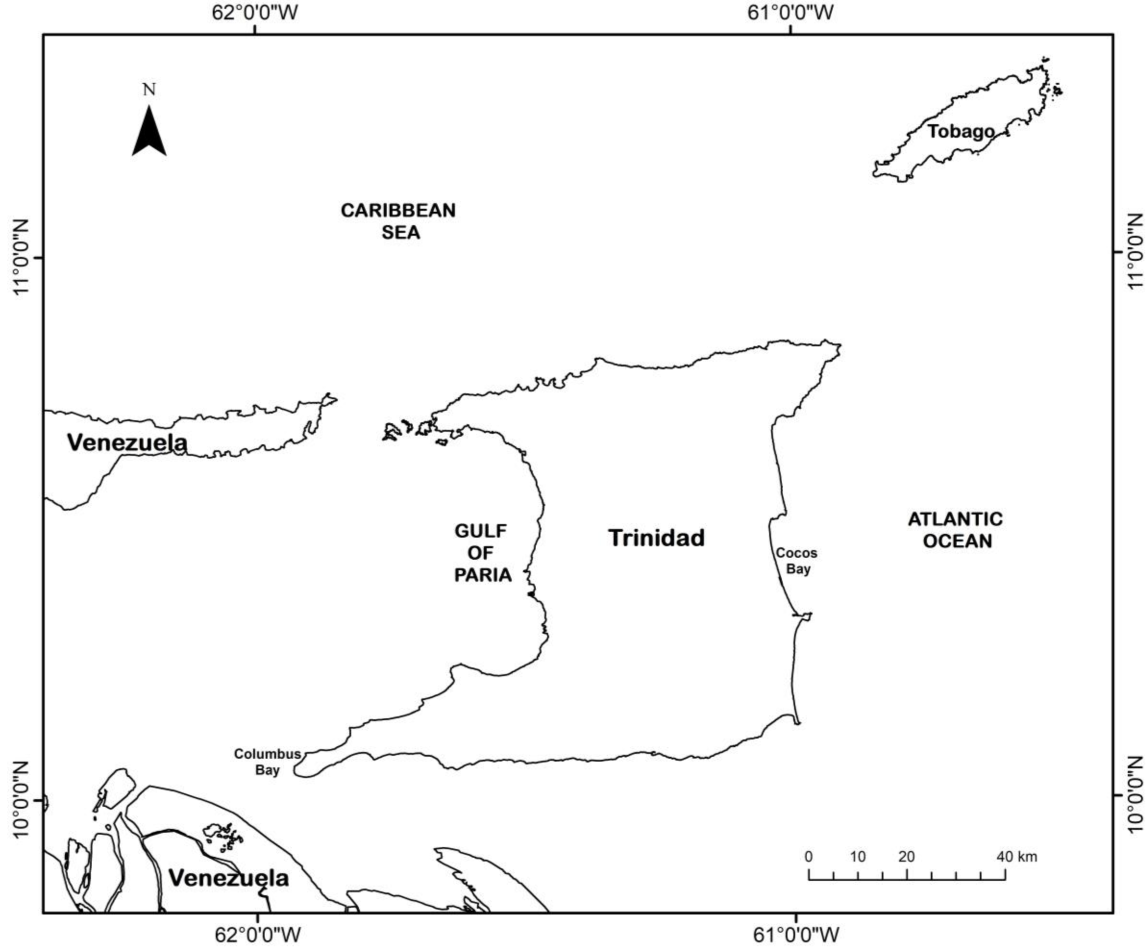


Figure 1. Map showing the locations of Cocos Bay and Columbus Bay

2.2. Delineating the study sites

Prior to deriving the weightings and rankings for the numerous variables, the specific study sites were each delineated from a 2014 coastline shapefile of Trinidad obtained from the IMA. Cocos bay which lies between Manzanilla Point and Point Radix was first clipped out. The coordinates of the IMA benchmark stations were then plotted onto this clipped section and a 50 m buffer applied (**Figure 2**). Since there was a lack of monitoring data for some of the regions in between the IMA monitoring stations, the measured point data at each of the stations, were used to represent the various coastal sections. The bay was then divided into six coastal regions based on vulnerability between the IMA benchmark stations. Columbus Bay between Los Gallos Point and just south of Corral point, was then clipped from the Trinidad coastline to define the second study area. This clipped region was buffered and divided into fifteen sections (**Figure 3**). Both study site regions were then saved in raster format and used as base layers to apply the rankings for the nine variables used in deriving the CSI.

3. Ranking criteria

Each parameter utilized was ranked in order of their contribution to the vulnerability of the coastline. Ranks were derived based on information gathered from previous studies. With regard to the coastal protection measures variable, ranking was based on expert opinion. Advice from local coastal engineering experts suggested that it was difficult to rank coastal protection structures in terms of their performance, however, a ranking scheme could still be used based simply on whether these structures were present or not. If present, they could be ranked based on whether they were hard or soft engineering structures. In the end, the ranking criteria adopted for this research were adopted from Abuodha and **Woodroffe** (**2006**, **2010**). The variables for the CSI were considered and selected based on previous

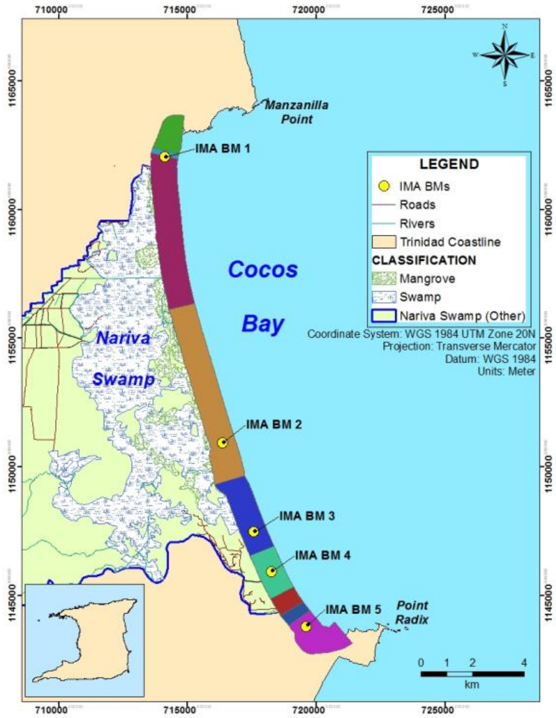


Figure 2. Base map of Cocos Bay showing buffered overlay regions

works by **Abuodha and Woodroffe** (**2006**, **2010**), **Addo** (**2013**), **Faour et al.** (**2013**), **Gornitz** (**1991**), **Gornitz et al.** (**1992**), **Thieler and Hammer-Klose** (**1999**, **2010**), **Pendleton et al.** (**2005**), **Prasetya** (**2007**), **Mahendra et al.** (**2011**), **Murali et al.** (**2013**), **Bagdanavičiūtė et al.** (**2015**) and **Sankari et al.** (**2015**). Two variables not referenced by previous authors but considered crucial to the analysis were storm surge (SS) and the presence of shoreline protection measures (CP). Both were present at each study site and as such were included in this study. Variables were separated into two groups 1) structural variables and 2) process variables. The five (5) structural variables were; geology, geomorphology, coastal/beach slope, shoreline change and presence of coastal protection. The five (5) process variables were; mean significant wave height, sea level rise, mean tidal level, storm surge and dune elevation. **Tables 1** and **2** show the ranking criteria used for each of the variables described below.

3.1. Geology

Geology/lithology represents the varying rock type which is located on or below the shoreline that is exposed to wave action (**Abuodha and Woodroffe, 2010**). **Addo** (**2013**) classified the geology of the Accra coastline in Ghana into five rankings from 1 to 5 where 1 was least vulnerable and 5 was most vulnerable, however, only three of these were used to characterize the geological conditions. These included sandstones and metamorphic outcrops, which were assigned a rank of 2, unconsolidated sediments, clay and gravel beaches were assigned a rank of 4 and lagoonal/fluvial sediments were assigned a rank of 5. **Abuodha and Woodroffe** (**2010**) also developed five rankings but only four were actually used in their study. Older resistant rocks were given a rank of 2, shale units which undergo erosion instability was given a rank of 3, sandstone, siltstone, shale and coal with minor conglomerate and tuffaceous beds were given a rank of 4, while quaternary unconsolidated sediments such as sand was given a rank of 5. For this study, the ranking adopted by **Abuodha and Woodroffe** (**2010**) was used for both Cocos and Columbus Bays. At Cocos Bay, with the exception of the headlands at Manzanilla and Radix Points, the entire bay consisted of recent alluvium (classified

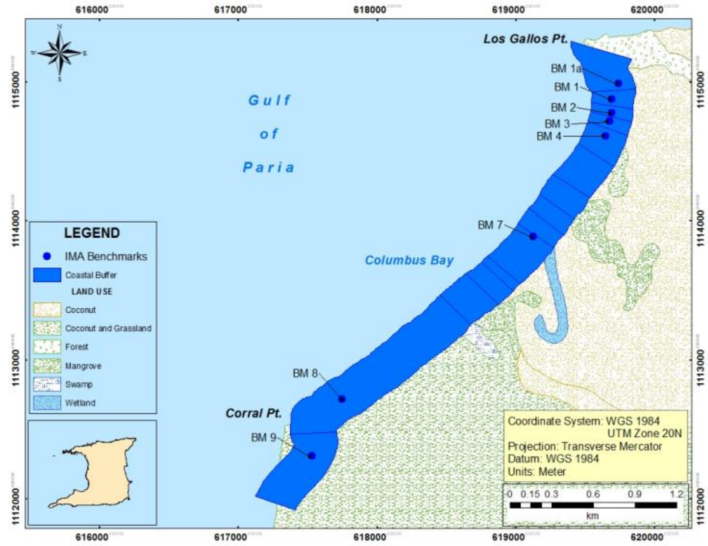
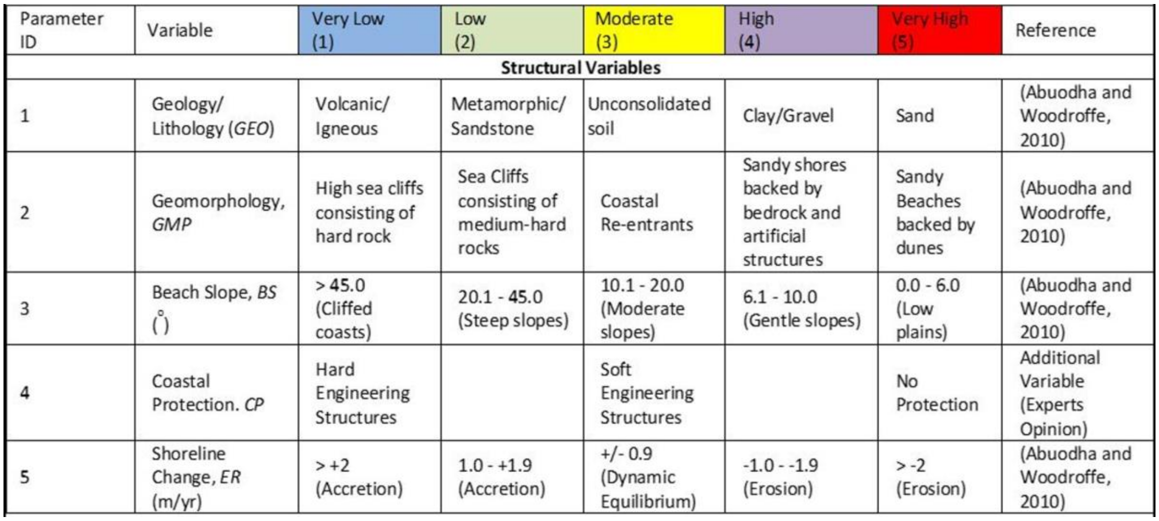


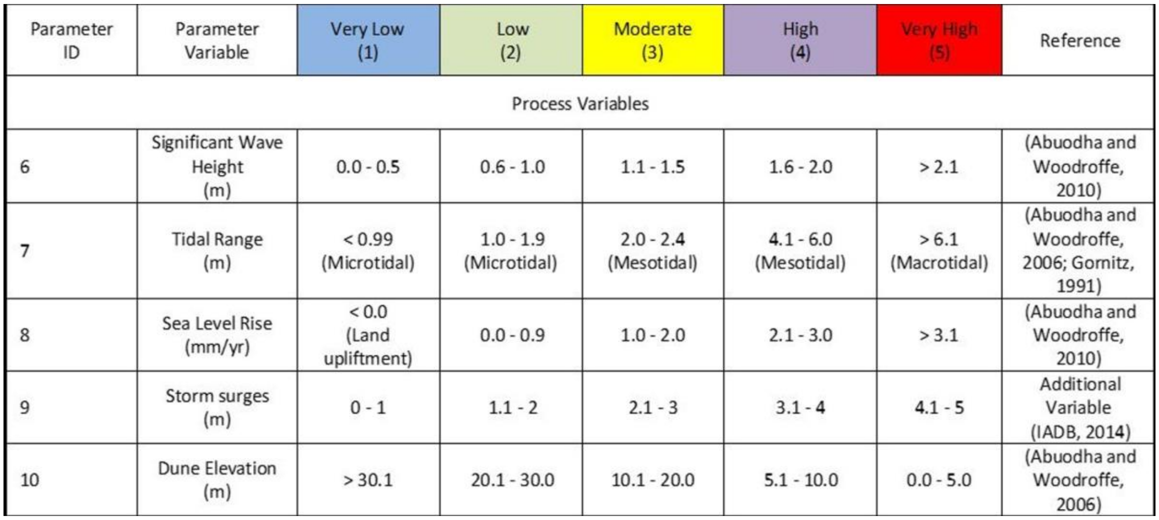
Figure 3. Base map of Columbus Bay showing buffered overlay regions

Table 1 Ranking criteria for structural variables used in the study



Parameter ID	Variable	Very Low (1)	Low (2)	Moderate (3)	High (4)	Very High (5)	Reference
				Structural Variables			
1	Geology/ Lithology (*GEO*)	Volcanic/ Igneous	Metamorphic/ Sandstone	Unconsolidated soil	Clay/Gravel	Sand	(Abuodha and Woodroffe, 2010)
2	Geomorphology, *GMP*	High sea cliffs consisting of hard rock	Sea Cliffs consisting of medium-hard rocks	Coastal Re-entrants	Sandy shores backed by bedrock and artificial structures	Sandy Beaches backed by dunes	(Abuodha and Woodroffe, 2010)
3	Beach Slope, *BS* (°)	> 45.0 (Cliffed coasts)	20.1 - 45.0 (Steep slopes)	10.1 - 20.0 (Moderate slopes)	6.1 - 10.0 (Gentle slopes)	0.0 - 6.0 (Low plains)	(Abuodha and Woodroffe, 2010)
4	Coastal Protection. *CP*	Hard Engineering Structures		Soft Engineering Structures		No Protection	Additional Variable (Experts Opinion)
5	Shoreline Change, *ER* (m/yr)	> +2 (Accretion)	1.0 - +1.9 (Accretion)	+/- 0.9 (Dynamic Equilibrium)	-1.0 - -1.9 (Erosion)	> -2 (Erosion)	(Abuodha and Woodroffe, 2010)

Table 2. Ranking criteria for process variables used in the study



Parameter ID	Parameter Variable	Very Low (1)	Low (2)	Moderate (3)	High (4)	Very High (5)	Reference
				Process Variables			
6	Significant Wave Height (m)	0.0 - 0.5	0.6 - 1.0	1.1 - 1.5	1.6 - 2.0	> 2.1	(Abuodha and Woodroffe, 2010)
7	Tidal Range (m)	< 0.99 (Microtidal)	1.0 - 1.9 (Microtidal)	2.0 - 2.4 (Mesotidal)	4.1 - 6.0 (Mesotidal)	> 6.1 (Macrotidal)	(Abuodha and Woodroffe, 2006; Gornitz, 1991)
8	Sea Level Rise (mm/yr)	< 0.0 (Land upliftment)	0.0 - 0.9	1.0 - 2.0	2.1 - 3.0	> 3.1	(Abuodha and Woodroffe, 2010)
9	Storm surges (m)	0 - 1	1.1 - 2	2.1 - 3	3.1 - 4	4.1 - 5	Additional Variable (IADB, 2014)
10	Dune Elevation (m)	> 30.1	20.1 - 30.0	10.1 - 20.0	5.1 - 10.0	0.0 - 5.0	(Abuodha and Woodroffe, 2006)

the Los Gallos headland, the entire bay consisted of recent alluvium and hence all stations along this bay were assigned a ranking of 5.

3.2. Geomorphology

Murali et al. (**2013**) defines geomorphology as the study of surface landforms, processes and the evolution of the earth which resulted in its present landscape. This occurs due to many factors including; tectonic influences, structural features, the lithology of the rocks which forms the coastline and the erosive/accretionary cycles of the beach. The geomorphological characteristics of a coastline play a vital role in determining how the coastline responds to sea level rise and erosion (**Thieler and Hammar-Klose, 1999**). Geomorphology is differentiated from geology in that whereas the former is a function of the actual landforms in the foreshore and backshore of the beach, the latter is a measure of the relative resistance to the underlying bedrock (**Abuodha and Woodroffe, 2010**). With the exception of the headlands at Manzanilla and Radix Points, the entire bay consisted of recent alluvium, which is classified as quaternary sediments and hence assigned a rank of 5. Columbus Bay is a sandy, low gradient with a low topography erodible, unconsolidated sediment backshore. The north-eastern end of the bay however, is sheltered by incoming waves from the northeast in the Gulf of Paria which refracts inward into the bay around the Los Gallos headland. The headland creates a shadow-zone in its lee, which allows accretion to occur. This region of the bay up to IMA's benchmark (BM) 3 was assigned a rank of 4 due to the protection offered by the Los Gallos headland. The remainder of the bay was assigned a rank of 5 due to its high vulnerability and notable erosion.

3.3. Beach slope

One of the most important factors to be considered in coastal vulnerability is the coastal/beach slope. Some impacts of sea level rise such as increased erosion, flooding and coastal inundation are reduced by coastlines with increasing steep slopes (**Abuodha and Woodroffe, 2010**; **Thieler and Hammer-Klose, 1999**). Steep coasts are therefore less susceptible to the impacts of sea level rise, wave attack, storm surges and erosion compared to low gradient slopes. At both study sites, a low gradient shore face is backed by a low dune that generally has a low to flat gradient inland. Over a 14-month period from 2005–2006 during the winter and summer months, nine profiles conducted by Darsan (2013a) showed the mean beach slope at Cocos Bay to be 4.13°. This value considered readings taken along the entire coastal section, which had a range of 3.30°–5.60°. The northern section of the bay had a mean slope of 5.29°, central region 3.50° and the extreme southern region 3.44°. All profiles were therefore assigned a rank of 5 (very high). At Columbus Bay, selected monthly profile data supplied by the IMA for the period 2014–2016 for benchmarks 1–9, showed the mean beach slope to be 4.5°. All profiles at this bay were assigned a rank of 5 (very high).

3.4. Coastal protection

This research adopted a ranking system based on whether there were hard or soft engineering structures present, or, the absence of any type of structures. Hard engineering structures were given a rank of 1 (low), soft engineering structures a rank of 3 (moderate) and for all instances where neither was present, a rank of 5 (high). Hard engineering coastal protection structures currently exist at Cocos and Columbus Bays. At Cocos Bay seawalls are located at the northern end while riprap revetments are located at the lower central-south region. As stated previously, erosion was occurring at the flanks of each of these protective structures. Despite this, the sections of the coastlines at Cocos Bay where hard engineering structures (such as seawalls) were present, were given a rank of 1, while all other sections where structures were absent were given a rank of 5. At Columbus Bay, three groynes constructed in 2008 were initially very effective but were not properly maintained. Only one of these groynes was present in the northeast section of the bay during field visits. Erosion was observed down drift of this structure in a southerly direction while northward, where the two former groynes were located, a significant amount of accretion occurred. Between this single remaining groyne and the region where accretion was observed, a rank of very low (1) was assigned. For all other regions, where coastal protection structures were absent, a rank of very high (5) was assigned.

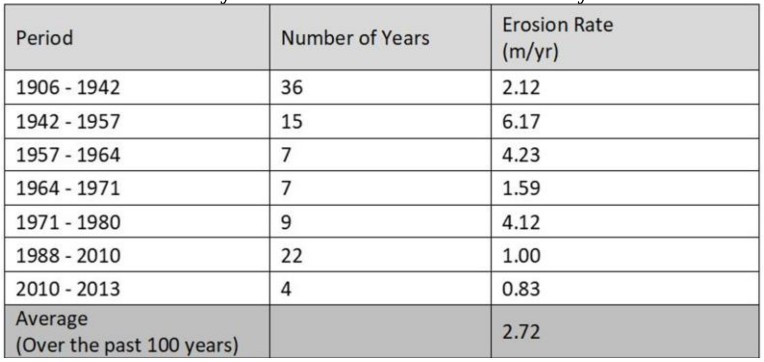
3.5. Shoreline change

Considerable amounts of sand can be displaced on beaches during periods of low wave energy conditions leading to accretion. Conversely, beaches can be significantly eroded during periods of higher wave energy conditions (**Abuodha and Woodroffe, 2010**). **Cambers** (**1998**) noted that Caribbean beaches experienced a winter-summer cycle during which flat swell waves produce a berm during the summer months while high, steep, storm waves produce a convex shaped eroded beach face during the winter months (**Darsan, 2013b**). Progradation occurs during the summer months and recession during the winter months. The summer period in Trinidad extends from May to September while the winter period extends from October to April (**Darsan, 2014**).

Erosion studies conducted by **Singh** (**1997**) indicated that between 1990 and 1996, the southern region of the bay experienced cyclic periods of accretion and erosion between seasons and years. At south Cocos Bay however, between 1990 till present the beach experienced an erosion rate of 1.7 m/yr. A similar study done by **Mahabir and Nurse** (**2007**) showed that north of the Nariva River in the vicinity of IMA BM 2, there was accretion of 0.17 m/yr during the period 1990–1999. For the entire bay however, the average erosion rate was 0.55 m/yr. From 2004–2008, the central to northern regions of the bay were given a rank of 3 to indicate a predominantly dynamic equilibrium state while the southern region was given a rank of 4 to reflect its rate of shoreline change.

At Columbus Bay, the erosion rates supplied by the IMA suggest that while the bay is eroding between Los Gallos and Corral Points, the rate of erosion is seasonal and it is classified as being in dynamic equilibrium. A summary of the erosion during varying periods compiled by **Oostdam** (**1982**) and the IMA is presented in **Table 3**. As can be seen, the time periods for which the erosion rates were calculated by **Oostdam** (**1982**) are not uniform, however, the average erosion rate at Columbus Bay from 1906 to 2013 is 2.72 m/yr. Hence a rank of moderate (3) was assigned to all benchmarks in this region. At IMA BM 9 (**Figure 3**), located south of Corral Point, however, the bay is eroding in excess of 1.0 m/yr and hence is ranked as high (4).

Table 3 Summary of erosion rates for Columbus Bay 1906 – 2010



Period	Number of Years	Erosion Rate (m/yr)
1906 - 1942	36	2.12
1942 - 1957	15	6.17
1957 - 1964	7	4.23
1964 - 1971	7	1.59
1971 - 1980	9	4.12
1988 - 2010	22	1.00
2010 - 2013	4	0.83
Average (Over the past 100 years)		2.72

3.6. Significant wave height

A 14-month monitoring study of Cocos Bay between winter 2005 and summer 2006 by **Darsan** (**2013b**), determined the wave height to be 0.7 m on average. The northern region had an average of 0.6 m, the central region 0.65 m and the southern region 0.80 m. Data from the IMA for the period 2014–2016 for all stations, indicated that the range of the significant wave height for Cocos Bay was 0.61 m and therefore remained in the low vulnerability class 2. Similarly, for all stations at Columbus Bay for the same period, data illustrated that the significant wave height was 0.3 m and therefore remained in the very low vulnerability class 1. Using the buffered coastal sections for Cocos and Columbus Bays, a field was added to the attribute tables of the polygon layer in the GIS, and the rank associated with wave height value inputted. The layer was then rasterized and included in the GIS analysis.

3.7. Tidal range

Higher tidal ranges are associated with stronger currents, increased sediment transport and capacity to cause erosion, hence macro-tidal coastlines, classified as tidal ranges greater than 4 m, are more vulnerable than meso- or micro-tidal coastlines (**Gornitz, 1991**). This logic was also adopted by **Abuodha and Woodroffe** (**2006**). **Thieler and Hammer-Klose** (**1999**) and **Pendleton et al.** (**2004**) however, adopted the view that higher tidal ranges suggested lower vulnerability, based on the premise that storms and storm surges rarely exceeded the highest tidal levels at a macro-tidal coastline. At Cocos Bay, the tidal pattern is influenced by both the Caribbean Sea and the Atlantic Ocean and experiences a 12.5-hour, semi-diurnal tide regime with a maximum spring tide range of 1.2 m (**Darsan, 2012a**). **Kenny** (**2008**) noted that there was a slight variation between the north and south tidal ranges, such that it could vary from 50–60 cm between high and low tides. **Leung Chee et al.** (**2014**) suggested that the changes in tidal ranges for Columbus Bay was minimal. **Table 4** depicts the various tidal heights for both Cocos and Columbus Bays.

Table 4 Tidal heights for Cocos and Columbus Bays

Tide	Cocos Bay	Columbus Bay
Mean high water spring (MHWS)	+1.20	+0.96
Mean high water neap (MHWN)	+1.00	+0.80
Mean low water neap (MLWN)	+0.70	+0.72
Mean low water spring (MLWS)	+0.49	+0.72

For this study, the views of **Gornitz** (**1991**) and **Abuodha and Woodroffe** (**2006**) were used in determining the rank. Although the tidal ranges were ranked in **Table 2** based on five categories, only two ranking criteria were used, Cocos Bay having a tidal range between 1.0 and 1.9 m, while Columbus Bay had a range less than 0.99 m as seen in the mean high water spring data presented in **Table 4**. All Cocos Bay stations at the IMA were therefore assigned a rank of 2 while stations at Columbus Bay were assigned a rank of 1. The attribute table of the buffered coastline polygon was updated to include a column for tidal range and all stations were assigned a rank of 2.

3.8. Sea level rise

One of the most important consequences of climate change is sea level rise (**Murali et al., 2013**). When tidal datum is derived over a 19-year period and the arithmetic mean of hourly water elevations is calculated, the value obtained is called the mean sea level. The Brunn Rule, which was established in 1962 suggests that depending on the slope of the beach, a coastal retreat of 50 to 100 times the expected rise in sea level is required to maintain the equilibrium of the beach. The retreat is given by the equation:

$$R = \frac{h_{SLR}}{S}$$

where: R is the expected retreat, h is the rise in sea level, and S is the slope of the beach.

This equation suggests that coastlines with low gradients will be extremely vulnerable to even small changes in sea level rise. Information gathered from published literature and supported by IMA data supplied, illustrated that the beach slope at both Cocos and Columbus Bays are low, hence both of these coastlines are extremely vulnerable to erosion. A statement published by the Government of the **Republic of Trinidad and Tobago [GORTT]** (**2011**), indicated that Caribbean countries are projected to experience sea level rise between 1.8 mm and 5.9 mm per year till 2100 and that this change will not be uniform throughout the Caribbean region. **Chin Sang** (**2015**) proposed estimates of sea level rise for Trinidad to be 1.8 mm/yr. Only one ranking is applicable to both bays in this study, i.e. a rank of 3 or moderate. The attribute tables of the two buffered polygon layers for Cocos and Columbus Bays were amended to include a field for sea level rise and a rank of 3 was inputted for all Cocos and Columbus Bays stations. Polygon layers were then converted to raster format using ArcGIS and included in the analysis.

3.9. Storm surge

Faour et al. (**2013**) suggested that while sea level rise is considered a serious risk, the changes in extreme sea levels are possibly of greater importance, since the risks to coastal regions are significantly higher. The Caribbean has a history of natural disasters, particularly due to hurricanes and tropical storms which are identified as being the most significant natural hazard risks (**IADB, 2014**). The **IADB** (**2014**) used numerical modelling methods based on historical storm data for the island of Trinidad, to determine that the average storm surge value was 3.0 m, this was classified as moderate (3). In ArcGIS, the buffer attribute table was updated to include the CVI rank for storm surge for both Cocos and Columbus Bays. Buffer polygons created for the various sections were then converted to raster format in preparation for the GIS analysis.

3.10. Dune elevation

Another measure of coastal vulnerability is dune elevation. **Abuodha and Woodroffe** (**2006**) suggested that the greatest height of the backshore dune could be applied in this context. Dunes of higher elevations are less likely to be inundated than those of lower elevations and are essentially the first line of defence to the action of waves. The height of the backshore dunes occurs at less than 3.0 m above mean sea level (MSL) along the entire 20 km stretch at Cocos Bay and less than 3.0 m along the 4 km stretch at Columbus Bay. Erosion studies from 1991 to 2001 in these low-lying areas indicate that rates of 1–2 m/yr on average at these coastlines may be as a result of increased sea level or chronic erosion caused by local patterns of currents and waves. Due to these reasons both Cocos and Columbus Bays, which are classified as sandy beaches backed by low dunes (**Darsan et al., 2012**), were assigned a rank of 5. The attribute tables of the base maps with the buffers were edited to include a field for the rank of the dune elevation variable.

4. INTEGRATION OF PARAMETERS AND RANKINGS

A GIS multi-criteria analysis based on these variables was then conducted in ArcGIS 10.4.1 to determine the final CSIs. Once the rankings were determined and assigned, each variable map was converted into raster format and reclassified. The final reclassified raster maps with the assigned ranks were then used to generate the coastal vulnerability maps for Cocos and Columbus Bays. A formula, adapted from studies done by **Gornitz** (**1991**), **Gornitz et al.** (**1992**), **Thieler and Hammer-Klose** (**1999**, **2010**), **Abuodha and Woodroffe** (**2006**, **2010**), **Pendleton et al.** (**2005**), **Prasetya** (**2007**), **Mahendra et al.** (**2011**), **Addo** (**2013**), **Faour et al.** (**2013**), **Murali et al.** (**2013**), **Bagdanavičiūtė et al.** (**2015**) and **Sankari et al.** (**2015**) was incorporated into ArcGIS to derive a composite layer for generating the CSI. The composite CSI of the buffer sections for each variable was determined by finding the square root of the product of the ranked variables divided by the number of variables. This is represented by the following mathematical formula:

$$\text{C.S.I.} = \sqrt{\frac{(R_{GEO} \times R_{GMP} \times R_{BS} \times R_{CP} \times R_{ER} \times R_{SWH} \times R_{TR} \times R_{SLR} \times R_{SS} \times R_{DE})}{N}}$$

where:

R = rank of individual variables

N = number of variables (= 10)

GEO = Geology

GMP = Geomorphology

BS = Beach Slope

CP = Coastal Protection

ER = Erosion Rate

SWH = Significant Wave Height

TR = Tidal Range

SLR = Sea Level Rise

SS = Storm Surge

DE = Dune Elevation

Table 5. Coastal sensitivity rankings for Cocos and Columbus Bays

BAY	Coastal Sensitivity Index Rankings (CSI)				
	Very Low	Low	Moderate	High	Very High
Cocos Bay	85 – 117	117 - 149	149 - 181	181 - 213	213 - 245
Columbus Bay	95 - 131	131 - 166	166 - 202	202 - 238	238 - 274

After calculating the CSIs for each buffered section, ten (10) value ranges were obtained, five (5) for each bay (**Table 5**). Using the ArcGIS platform, the difference between the highest and lowest values was calculated and this was then divided into five equal sensitivity classes of very low, low, moderate, high and very high. This processing was also executed in ArcGIS and the classes produced were representative of the CSIs for the specific regions of each bay. The CSI maps for both bays showed that there were areas at both sites with varying degrees of vulnerability to coastal erosion (very low, low, moderate, high and very high).

5. DATA VALIDATION

Field visits were conducted at both bays in order to validate the CSI maps. Metadata and quantitative measurements were collected to determine if the resultant sensitivities were accurate. At Columbus Bay, the entire bay was inspected from the northeast end to south of Corral Point using a total of 18 inspection points. At Cocos Bay however, only 10 inspection points located at or near to the existing IMA benchmarks were used. The sites visited to validate the CSI maps for both Cocos and Columbus Bays are shown in **Figures 4 and 5**. Data collected at each site included: site coordinates in UTM WGS 1984 format, coordinates of the extents of coastal protection structures, wave height and direction, cliff heights, beach slope, wind speed and direction, observed erosion, backshore features and sediment characteristics. Wave heights were measured using a ruled, extendable survey staff by walking into the water and recording the wave heights behind the breaker zone. The wave height was taken to be the difference between the still water level and the height of the passing wave. A total of 10 wave heights was recorded and the average calculated. Wave direction was recorded using a Brunton Geo Compass to the nearest degree. Cliff height was measured using a standard construction extendable measuring tape. Beach slope was recorded at the approximate mid-point between the high and low water using the Brunton Geo compass measured to the nearest degree. Wind speed and direction were recorded using a Brunton ADC Anemometer and Brunton Geo Compass respectively. A simplified flow chart illustrating the key methodological steps from data collection to final CSI map validation is depicted in **Figure 6**.

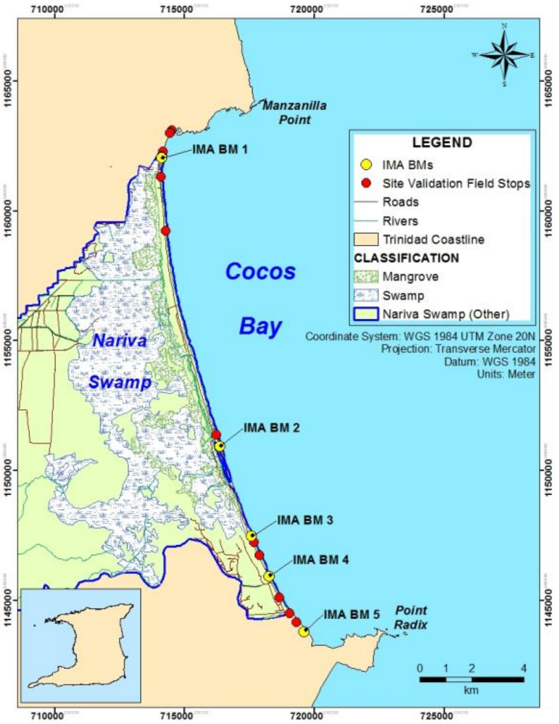


Figure 4. Map of Cocos Bay showing field validation sites and the locations of IMA Benchmarks

6. RESULTS

The final CSI map of Cocos Bay (**Figure 7**) illustrates that only four (4) out of five (5) possible categories of ranks on the bay were obtained i.e. very low, moderate, high and very high. The majority of the bay had a high-ranking sensitivity from the northern end to the upper southern region. A small section in the northern region was ranked very low. This region coincided with a 252 m seawall located at the Manzanilla Bay Facilities. Sections ranked moderate were located in the

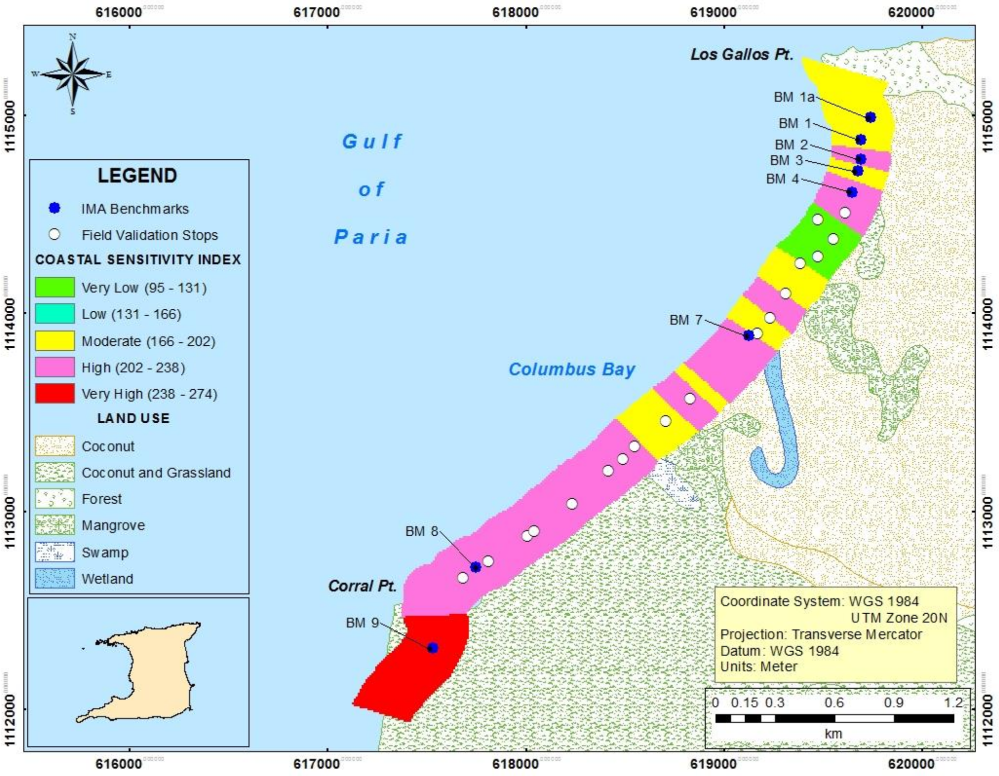


Figure 5. Map of Columbus Bay showing field validation sites and the locations of IMA Benchmarks

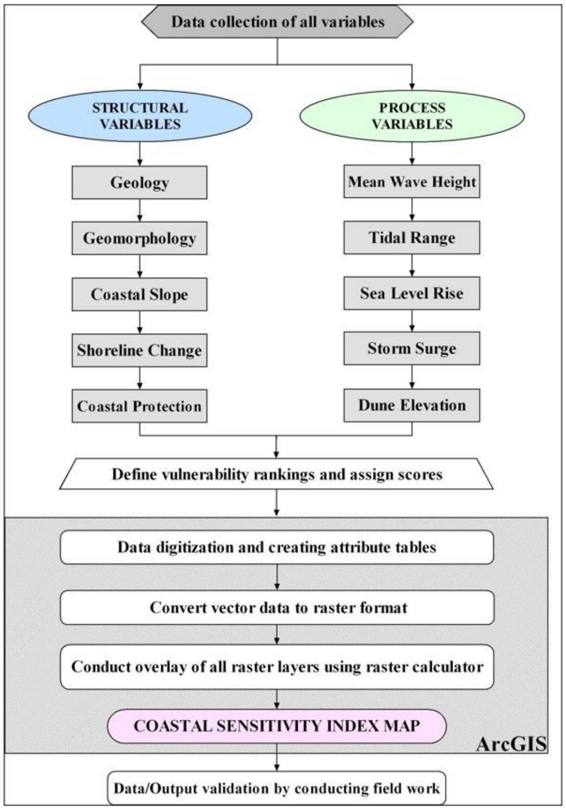


Figure 6. Methodological flow chart of steps for deriving Coastal Sensitivity Index

southern region of the bay. These sections were representative of the locations of the riprap revetments which existed along this region of the bay. The gap which existed between these two structures was ranked as very high, possibly due to the erosion which occurs at the flanks of the hard engineering structures due to longshore current scour. The southern end of the bay is ranked as very high due to the extensive erosion occurring at this location.

The final CSI map for Columbus Bay (**Figure 8**), illustrates that only four out of five possible categories of ranks were obtained, very low, moderate, high and very high. The northern region of the bay was ranked as moderate possibly due to the geomorphological sheltering impact at this region. High rank classifications were attained for the area between the northern region and the groyne, potentially due to the low coastal slope, the geological unconsolidated sediments which make up the backshore as well as its location outside of the sheltering effects of the Los Gallos Headland. The very Low ranked region along the bay is located approximately 283 m northwards of the existing groyne where the beach stabilization effects of the groyne were clearly observed. Southwards of the groyne, the majority of the bay was identified as high-ranking sensitivity up to Corral Point but there

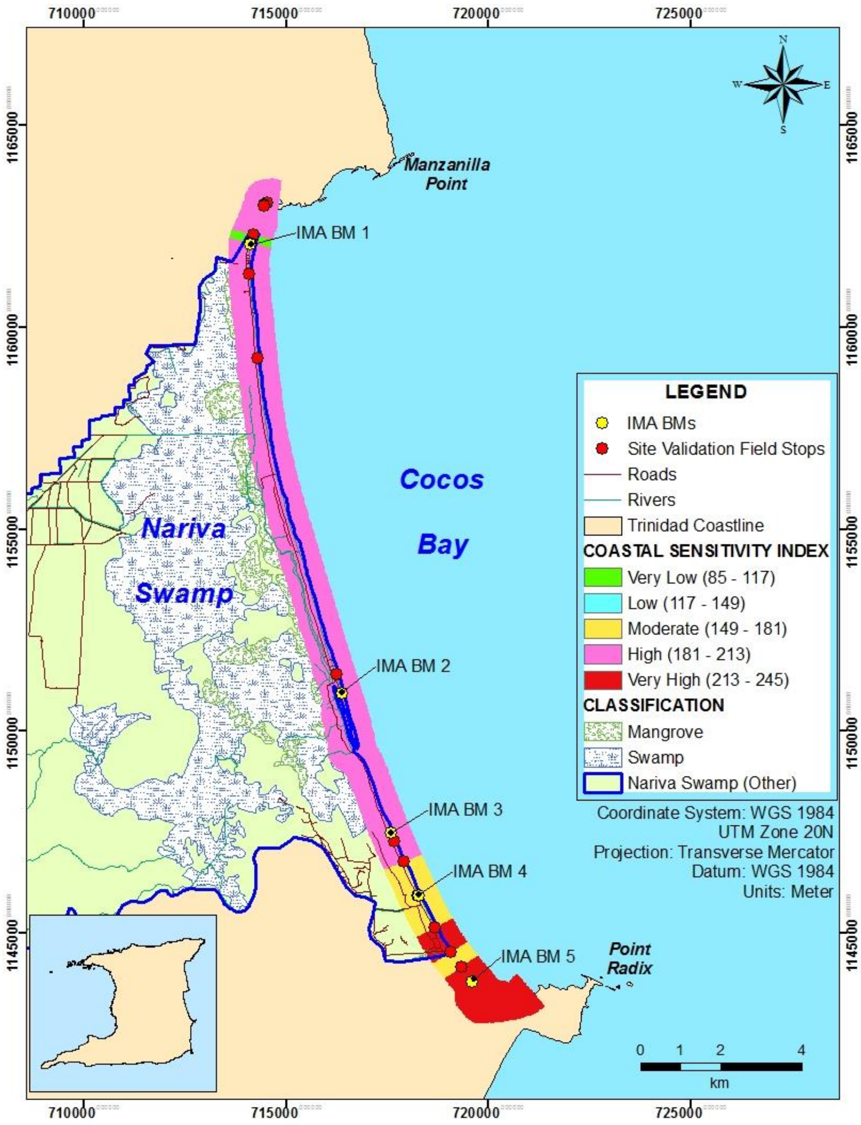


Figure 7. Final Coastal Sensitivity Map for Cocos Bay

are discontinuous sections within the central region where it was dissected by regions of moderate ranking. All moderate ranking regions were located where mangrove outcrops exist along the shoreline. Beyond Corral Point, the bay was ranked as very high due to the extreme erosion occurring at this region. Erosion impacts at this region of the bay have been well documented and highlighted by **Oostdam** (**1982**), **Kenny** (**2002**), **Alexis** (**2014**) and **Leung Chee et al.** (**2014**).

The lengths of each of the ranked areas in both bays were measured and the percentages of the total lengths of each bay were calculated and presented in **Table 5**. The length of Cocos Bay considered in the study was 22.9 km while for Columbus Bay it was approximately 4.4 km. The calculations recorded in **Table 6** reveal that if the high and very high Sensitivity Indices alone were considered at Cocos Bay, these will account for 85% of the bay (= 19.4 km) with 70% being attributed to high sensitivity (= 16.0 km) and 15% to very high sensitivity (= 3.5 km). At Columbus Bay, 67% of the bay or 3.0 km is attributed to high and very high sensitivities, with 53% being high (= 2.4 km) and 14% being very high (= 0.6 km). The very high classification occurs in the region south of Corral Point. This region was also observed to be severely affected by erosion with damaged roadway, fallen coconut trees, exposed water lines, and coastal regression. The field validation trips revealed that the southward boundary of this region was a transition zone where erosion ceased and accretion began at Punta del Arenal.

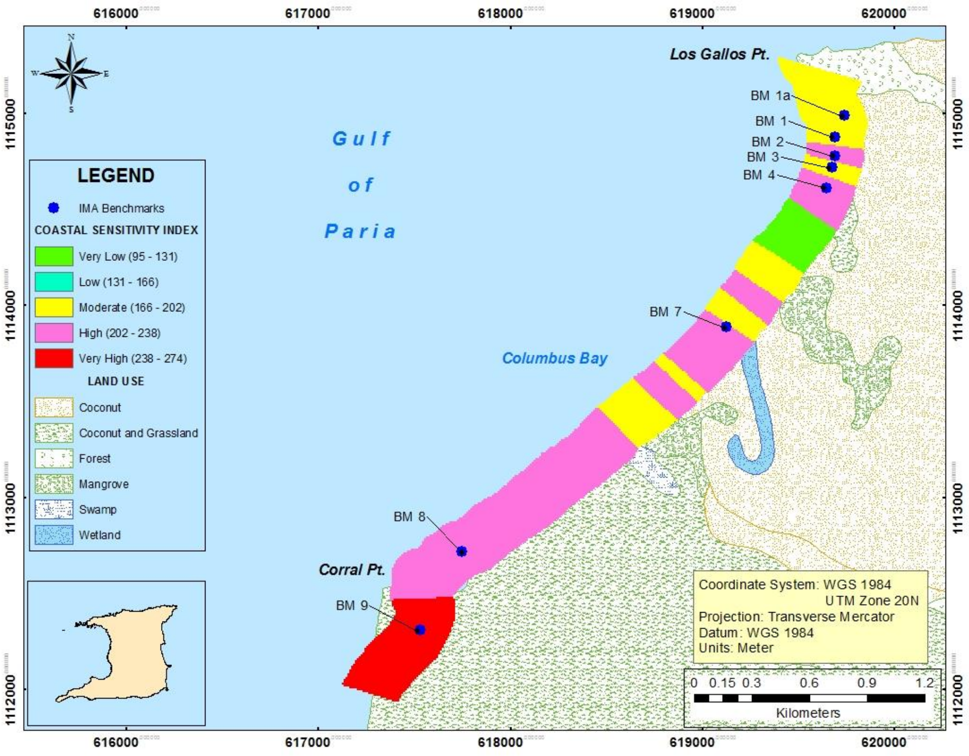


Figure 8. Final Coastal Sensitivity Map for Columbus Bay

Table 6 Lengths and percentages of Cocos and Columbus Bays relating to the Coastal Sensitivity Index rankings

CSI CLASS	Length (m)	% of Total Coastal Length	Length (m)	% of Total Coastal Length
	COCOS BAY		COLUMBUS BAY	
Very Low	476	2	288	6
Low	0	0	0	0
Moderate	2,880	13	1,169	26
High	15,984	70	2,373	53
Very High	3,459	15	609	14
Total	22,800	100	4,439	100

At Cocos Bay, there was the presence of built environment consisting of private residential properties, state beach and fishing facilities, a state-owned road approximately 20 km in length, an extensive coconut plantation and other agricultural lands which are privately owned (**Mahabir and Nurse, 2007**). At Columbus Bay however, built area only occurred at the northern region of the bay where the beach facility existed, at the backshore region near the existing groyne where a single-family dwelling unit existed, and at the southern end of the bay where a coconut processing industry existed further backshore.

7. DISCUSSION AND CONCLUSION

CSI studies should precede and/or be included in any Integrated Coastal Zone Management (ICZM) plan. It would be useful to include socio-economic datasets such as population, in the analysis, however, **Mclaughlin and Cooper** (**2010**) notes that this data can change considerably with time, suggesting that the output of the study will be specific to a time-constrained period. The approach presented in this study can also be applied to other beaches and bays in Trinidad and Tobago as well as in the wider Caribbean region. Standard methodologies used by various researchers were used to determine the vulnerability and sensitivity indexes using the unit weight for all variables. Although the data is more accurately represented when weighted (**Cendrero and Fischer, 1997**), the weighting process is difficult due to the diverse number of value judgments which exist behind combined weights. Nevertheless, it is believed that for a more complex coastline where there is significant deviation from the set of variables used in this study, a weighting factor will strongly influence the CSI results. From the results it was evident that coastal erosion at Cocos and Columbus Bays is occurring at rates which threaten coastal infrastructure including roads, buildings, commercial properties and land. One approach for dealing with this threat is to allow nature to take its course, since remediation using hard engineering solutions such as seawalls, groynes, breakwaters, revetments and beach nourishment is currently very costly (**Singh and Fouladi, 2003**). It may be prudent therefore, to establish and enforce coastal setback distances for any proposed development in these particular bays. **Mycoo** (**2006**) and **Udika** (**2009**) note that a maximum setback distance of 30 m from the high-water mark was implemented in Barbados's ICZM plan. This has been used successfully to manage coastal erosion, environmental issues and development in the island's coastal region since the 1980's (**Scruggs and Bassett, 2013**; **Mycoo, 2006**). Although this distance is still considered to be low by some, given the potential for inundation of coastal regions due to hurricanes and tropical storms, it can be a useful precedent for other Caribbean SIDS. Supporting legislation and regulations should be integrated within the relevant institutional framework, however, to guide coastal planning and development (**Udika, 2009**). The CSIs determined for Cocos and Columbus Bays in this study support the need for a coastal management plan in these areas and by extension, the entire coastline of Trinidad and Tobago. The recognition and need for coastal setback distances is currently identified in the ICZM Draft Policy Framework for Trinidad and Tobago (Integrated Coastal Zone Management Steering Committee, 2014). Further studies using additional data will be required to enhance the analysis and to assess the vulnerabilities of the entire coastline. In this manner accurate setback distances can be derived and implemented to support sustainable coastal development.

Acknowledgements. The authors would like to express their gratitude to the Institute of Marine Affairs (IMA) for providing essential data to support this study and Ms. Naimah Mohammed for assistance with proofreading and formatting. We would also like to thank the reviewers for taking the time and effort necessary to review our manuscript. We sincerely appreciated all comments and suggestions, which helped us to improve the quality of our manuscript.

Funding. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Authors Contributions. Sunil Ramnath: Conceptualization, Methodology, Formal analysis, Validation, Writing Original Draft, Visualization. Deanesh Ramsewak: Methodology, Writing, Review & Editing, Visualization, Supervision. Sara Benetti: Methodology, Writing, Review & Editing, Visualization, Supervision.

Data availability statement. The datasets generated during this study that support the findings are available from the corresponding author [DR], upon reasonable request.

REFERENCES

Abuodha, P. and Woodroffe, C. 2006. Assessing vulnerability of coasts to climate change: A review of approaches and their application to the Australian coast. Research Online. [online] Available at: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.461.2048&rep=rep1&type=pdf [Accessed 15 May 2017].

Abuodha, P. and Woodroffe, C. 2010. Assessing vulnerability to sea-level rise using a coastal sensitivity index: a case study from southeast Australia. *Journal of Coastal Conservation*, **14**(3), 189-205. http://spicosa-inline.databases.eucc-d.de/files/documents/00000981_C14.189-205.pdf

Addo, K. 2013. Assessing Coastal Vulnerability Index to Climate Change: the Case of Accra – Ghana. *Journal of Coastal Research*, **165**, 1892-1897.

Alexis, C. 2014. Coastal erosion - A challenge for small island developing states. *Trinidad Express Newspaper*. http://www.trinidadexpress.com/featured-news/Coastal-erosion-273867871.html

Alexis, C. 2016. Coastal erosion a problem at Cocos and Guayaguayare Bays. *Trinidad Express Newspaper*. http://www.trinidadexpress.com/20161110/features/coastal-erosion-a-problem-at-cocos-and-guayaguayare-bays

Ballinger, R. and Dodds, W. 2017. Shoreline management plans in England and Wales: A scientific and transparent process. *Marine Policy*, **111**, 102689. https://orca.cardiff.ac.uk/99733/1/Shoreline%20management%20plans%20in%20England%20and%20Wales%20A%20scientific%20and%20transparent%20process.pdf

Bagdanavičiūtė, I., Kelpšaitė, L. and Soomere, T. 2015. Multi-criteria evaluation approach to coastal vulnerability index development in micro-tidal low-lying areas. *Ocean & Coastal Management*, **104**, 124-135.

Cambers, G. 1998. Planning for Coastline Change. Coastal Development Setback Guidelines in Antigua and Barbuda. [online] pp. 1-64. http://www.unesco.org/csi/act/cosalc/cosalc1.pdf 2015].

Cendrero, A. and Fischer, D. 1997. A procedure for assessing the environmental quality of coastal areas for planning and management. *Journal of Coastal Research*, **13**(3), 732 - 744.

Charlier, R., De Meyer, C. and Decroo, D. 1989. Beach protection and restoration part I: hard structures and Beach erosion. *International Journal of Environmental Studies*, **33**(1-2), 29-44.

Chin Sang, J. 2015. The Status of Climate Change Data: A Case Study for Trinidad and Tobago. [online] United Nations Framework Convention on Climate Change. http://www.niherst.gov.tt/files/Fellowship_Report(Final)-JoanneChinSang.pdf

Darsan, J. 2013a. Beach Morphological Dynamics at Cocos Bay (Manzanilla), Trinidad. *Atlantic Geology*, **49**, 151.

Darsan, J. 2013b. Beach state classification: the dissipative domain of Cocos Bay, (Manzanilla), Trinidad. *Caribbean Journal of Earth Science*, **46**, 1-11. http://caribjes.com/CJESpdf/CJES46-01-DarsanBeach.pdf

Darsan, J., Ramnath, S., and Alexis, C. 2012. Status of beaches and bays in Trinidad 2004 - 2008. Institute of Marine Affairs. Hilltop Lane, Chaguaramas. https://www.ima.gov.tt/wp-content/uploads/2018/04/Coastal-Con-March-2012-Status-Beaches-Bay-Trinidad-2004-08-Final-Dec2016.pdf

Faour, G., Fayad, A. and Mhawej, M. 2013. GIS-based approach to the assessment of Coastal Vulnerability to sea level rise: Case study on the eastern Mediterranean. *Journal of Surveying and Mapping Engineering*, **1**(3), 41-48. http://www.academicpub.org/DownLoadPaper.aspx?paperid=15070

Fraser, M. 2014. $225m to prevent coastline erosion. *Trinidad Express Newspaper*. http://www.trinidadexpress.com/news/225m-to-prevent-coastline-erosion-242153751.html

Gornitz, V. 1991. Global coastal hazards from future sea level rise. *Global and Planetary Change*, **3**(4), 379-398.

Gornitz, V., White, T. and Daniels, R. 1992. A Coastal Hazards database for the U.S. East Coast. [online] Knoxville, Tennessee: Environmental Sciences Division. https://www.osti.gov/scitech/servlets/purl/7061112

Government of the Republic of Trinidad and Tobago (GORTT). 2011. National Climate Change Policy. https://www.preventionweb.net/files/60670_trinidadandtobagoclimatechangepolic.pdf

Integrated Coastal Zone Steering Committee 2014. Integrated Coastal Zone Management Draft Policy Framework. Ministry of Environment and Water Resources. http://www.ima.gov.tt/home/images/docs/Ingrated_Coastal_Zone_Mment_Policy_Framework_Minister_April_2014.pdf

Inter-American Development Bank [IADB]. 2014. Understanding the Economics of Climate Adaptation in Trinidad and Tobago - See more at: https://publications.iadb.org/handle/11319/6512#sthash.TTpdHfQK.dpuf

Intergovernmental Panel on Climate Change [IPCC].2014. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva, Switzerland: Intergovernmental Panel on Climate Change. http://ipcc.ch/pdf/assessment-report/ar5/syr/SYR_AR5_FINAL_full_wcover.pdf

Kenny, J. 2002. The Changing Coastline of the Cedros Peninsula, Trinidad. *Living World, Journal of The Trinidad and Tobago Field Naturalists' Club*, 01-07. http://ttfnc.org/livingworld/index.php/lwj/article/viewFile/4/2

Klein, R.J., Nicholls, R.J., Ragoonaden, S., Capobianco, M., Aston, J., and Buckley, E.N. 2001. Technological options for adaptations to climate change in coastal zones. *Coastal Research*, **17**(3), 531 - 543.

Leung Chee, C., Singh, A., Persad, R. and Darsan, J. 2014. The Influence of Tidal Currents on Coastal Erosion in a Tropical Micro-Tidal Environment - the Case of Columbus Bay, Trinidad. *Global Journal of Science Frontier Research: H Environment & Earth Sciences*, **14**(5) Version 1, 15-31. https://journalofscience.org/index.php/GJSFR/article/download/1442/1304/

Mahabir, D. and Nurse, L. 2007. An assessment of the vulnerability of the Cocal area, Manzanilla, Trinidad, to coastal erosion and projected sea level rise and some implications for land use. *CERMES Technical Report* No **4**. Cave Hill, Barbados: Centre for Resource Management and Environmental Studies (CERMES). http://iwlearn.net/resolveuid/b4b9627dbc1d8c0fb6fbe4825fcfa949

Mahendra, R., Mohanty, P., Bisoyi, H., Kumar, T. and Nayak, S. 2011. Assessment and management of coastal multi-hazard vulnerability along the Cuddalore–Villupuram, east coast of India using geospatial techniques. *Ocean & Coastal Management*, **54**(4), 302-311.

Mclaughlin, S. and Cooper, J. 2010. A multi-scale coastal vulnerability index: A tool for coastal managers? *Environmental Hazards*, **9**(3), 233-248.

Murali, R., Ankita, M., Amrita, S. and Vethamony, P. 2013. Coastal vulnerability assessment of Puducherry coast, India, using the analytical hierarchical process. *Natural Hazards and Earth System Science*, **13**(12), 3291-3311. http://www.nat-hazards-earth-syst-sci.net/13/3291/2013/nhess-13-3291-2013.pdf

Mycoo, M. 2006. Sustainable Tourism Using Regulations, Market Mechanisms and Green Certification: A Case Study of Barbados. *Journal of Sustainable Tourism*, **14**(5), 489-511. https://www.researchgate.net/publication/249023794_Sustainable_Tourism_Using_Regulations_Market_Mechanisms_and_Green_Certification_A_Case_Study_of_Barbados

Oostdam, B. 1982. Columbus Bay – Coastal Erosion and Accretion at Corral Point, S.W. Trinidad. Chaguaramas, Trinidad: Institute of Marine Affairs. http://www.boostdam.net/Columbus_Bay/Columbus_BayTripod/ColBay.html

Pendleton, E., Thieler, E. and Williams, S. 2005. Coastal Vulnerability Assessment of Point Reyes National Seashore to Sea-Level Rise. Reston, Virginia: U.S. Geological Survey https://pubs.usgs.gov/of/2005/1059/images/pdf/report.pdf

Pramanik, M., Biswas, S., Mondal, B. and Pal, R. 2015. Coastal vulnerability assessment of the predicted sea level rise in the coastal zone of Krishna–Godavari delta region, Andhra Pradesh, east coast of India. *Environment, Development and Sustainability*, **18**(6), 1635-1655.

Prasetya, G. 2007. Coastal protection in the aftermath of the Indian Ocean tsunami: What role for forests and trees? Chapter 4: *Proceedings of the Regional Technical Workshop, Khao Lak, Thailand, 28–31 August 2006*: Food and Agriculture Organization of the United Nations - Regional Office for Asia and the Pacific, 103-130. https://www.fao.org/3/ag127e/ag127e07.pdf

Ramdass, A. 2017. Severe erosion on East Coast. *Trinidad Express Newspaper*. http://www.trinidadexpress.com/20170606/news/severe-erosion-on-east-coast

Sankari, T., Chandramouli, A., Gokul, K., Surya, S. and Saravanavel, J. 2015. Coastal Vulnerability Mapping Using Geospatial Technologies in Cuddalore-Pichavaram Coastal Tract, Tamil Nadu, India. *Aquatic Procedia*, **4**, 412-418.

Sanò, M., Jiménez, J., Medina, R., Stanica, A., Sanchez-Arcilla, A. and Trumbic, I. 2011. The role of coastal setbacks in the context of coastal erosion and climate change. *Ocean & Coastal Management*, **54**(12), 943-950. http://intranet.geoecomar.ro/rchm/wp-content/uploads/downloads/2014/11/Sano_Stanica_et_al_OCM_2011.pdf

Scruggs, G. and Bassett, T. 2013. Coastal Zone Management the Barbados Model. Lincoln Institute of Land Policy - Land Lines. https://www.lincolninst.edu/sites/default/files/pubfiles/2322_1662_Coastal_Zone_Management_1013LL.pdf

Singh, B. and Fouladi, A. 2003. Coastal erosion in Trinidad in the Southern Caribbean: probable causes and solutions. *Transactions on The Built Environment*, 70. https://www.witpress.com/elibrary/wit-transactions-on-the-built-environment/70/2410

Thieler, E. and Hammer-Klose, E. 1999. National Assessment of Coastal Vulnerability to Sea Level Rise: Primary Results for the U.S. Atlantic Coasts. Woods Hole, Massachusetts: U.S. Geological Survey. https://pubs.usgs.gov/dds/dds68/reports/eastrep.pdf

Thieler, E. and Hammer-Klose, E. 2010. National Assessment of Coastal Vulnerability to Sea Level Rise: Primary Results for the U.S. Atlantic Coasts. Woods Hole, Massachusetts: U.S. Geological Survey. https://pubs.usgs.gov/dds/dds68/reports/westrep.pdf

Udika, R. 2009. Climate Change and vulnerability: Responding to climate change impacts on the coastal urban corridor, Barbados. In: 45th ISOCARP Congress - Low Carbon Cities. International Society of City and Regional Planners (ISOCARP). http://www.isocarp.net/Data/case_studies/1510.pdf

Editorial Responsiblity: Dr S. James-Williamson. Type setting: Prof. S. F. Mitchell

Accepted 6th December 2021