AN ENGINEERING BASED ANALYSIS OF THE COAST OF CAMPECHE AS THE PATH TO SUSTAINABLE MANAGEMENT DECISIONS

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Chronic coastal erosion problems have been reported in Campeche State; however, beaches and ecosystems have not yet been degraded to the point of being at high risk. A proposal for coastal segmentation is presented here, in order to rank the coastal sectors according to the urgency required for intervention; given that this approach applies a large – scale perspective; the analysis is suited to any other coastal zone. The proposed methodology hierarchically identifies littoral segments in three steps: 1) dividing the study area into littoral cells, 2) assessing coastal vulnerability and 3) identifying the immediacy of intervention needed for each coastal sector.

Keywords: littoral cell; vulnerability; hierarchical littoral segments

INTRODUCTION

Coastal occupation has dramatically increased in recent decades, mainly due to the demands of tourism and leisure activities (Anfuso et al. 2011), producing more pressure on littoral systems. Chronic erosion problems have been reported as a consequence in many areas. It is therefore necessary to develop a more precise understanding of coastal dynamics in order to achieve better protection, restoration and management alternatives. There are still many parts of the more than 11,000 km long Mexican coastline where sustainable development is still possible and could bring benefits to the country.

The state of Campeche, on the Yucatan Peninsula (Fig. 1), has 4.2% of the national Gross Domestic Product (INEGI 2014). The coast of Campeche is 520 km long, of mainly by sandy and rocky beaches. Even though there are no massive touristic and urban developments, erosion rates of up to 7 m/year, with maximums of up to 15 m/year, have been reported (Ortíz – Pérez 1992).

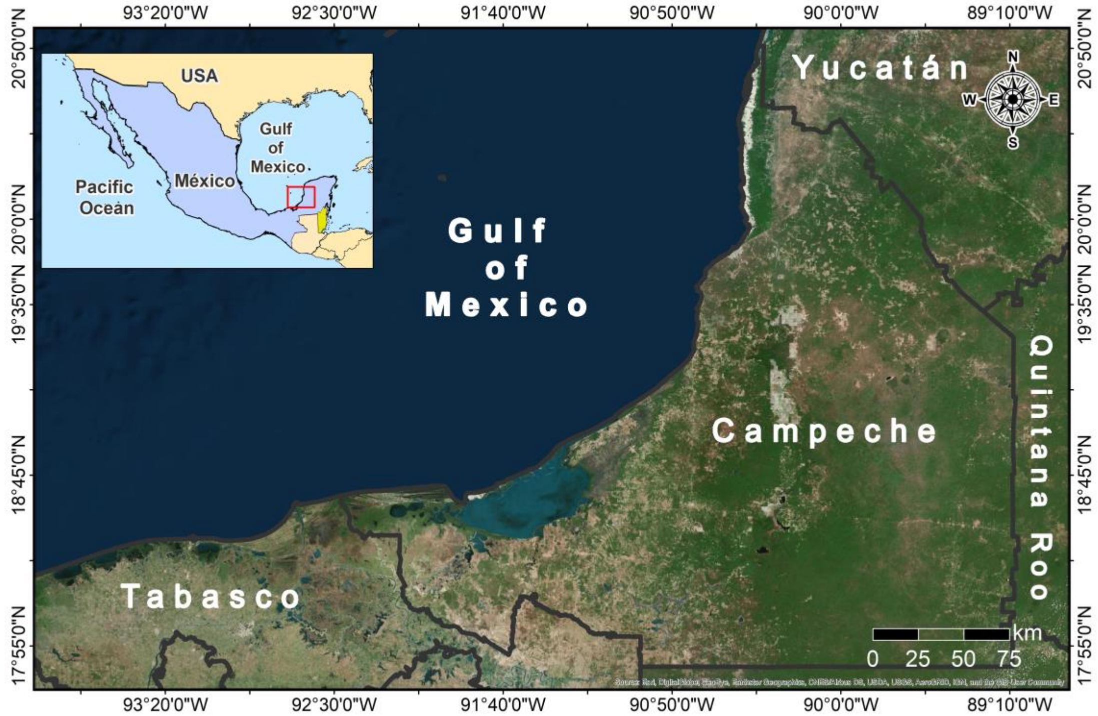

Figure 1. Location of the study area.

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Given its beautiful landscape and historical heritage as well as its proximity to the Riviera Maya in Quintana Roo, the coast of Campeche is attractive location for the tourism industry, as evidenced by the recent construction of the Aak Bal and Campeche Country Club resorts, as well as the enlargement of Seybaplaya and Ciudad del Carmen ports (Alpuche 2014) (Fig. 2).

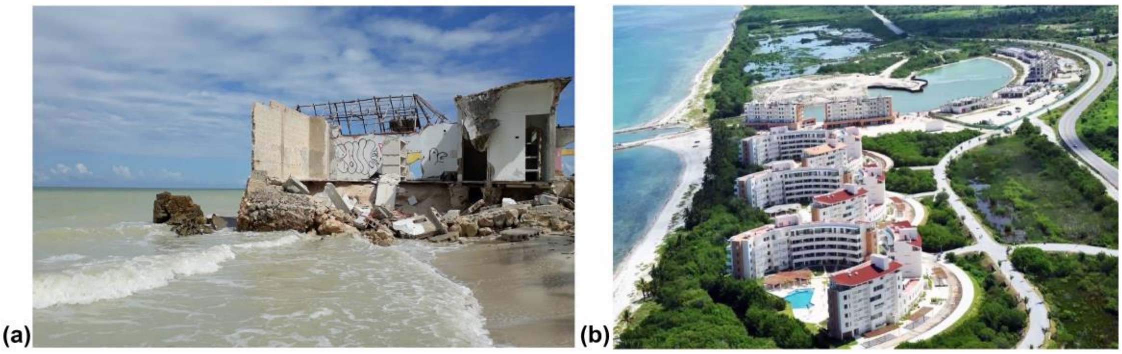

Figure 2. (a) Erosion problem; (b) Aak Bal resort.

In contrast to the evolution of the resorts in Quintana Roo, where the beaches have degraded to a point where the ecosystems, economic activities and even the infrastructure are at high risk (Silva 2007; Diez et al. 2009), most of the Campeche coast can still be conserved. Thus, understanding the coastal processes and adequate coastal planning could allow the state to develop tourism and urbanizations in a way that is harmonious with the environment.

METODOLOGY

The main goal of this work is to provide knowledge on the coastal dynamics of Campeche to serve decision making. The methodology proposed is as follows:

1. Characterization of littoral cells (from an engineering point of view).
2. Evaluation of the coastal and social vulnerability.
3. Determination of the areas of priority, using an action immediacy index.
4. Raking of littoral segments.

Littoral cell characterization

Littoral cells are defined as the basic units into which the coastline can be divided. The determination of the cells is basic to the understanding of coastal transport, the reconstruction of its formation and the prediction of the evolution of the coastline in the medium and long term (Anfuso 2004). The boundaries of the cells separate the parts of the coast that are interdependent in terms of physical processes (Bray et al., 1995).

Littoral cells are constituted by input and output elements. The first refers to the contributions of sediments received by the cell and can come from different sources such as rivers, erosion of dunes, cliff and from other cells by coastal transport. In the output components submarine canyons, accumulation in dunes, river mouths, lagoons, and other sediment traps are included. The input and output components can be natural or anthropic (Carter 1988; Juárez León & Torres 2008).

To identify the littoral cells, different criteria have been proposed, the most relevant being:

1. Determination of sedimentary transport related to hydrodynamic processes, flows caused by gradients of energy dissipation, etc. This method has been used by Sulis and Annis (2014) at Sa Mesa Longa beach, Italy, as well as by Bray et al. (1995) in southern England.
2. Description of morphological, sedimentological and volumetric criteria. For example, the studies carried out by Samsuddin and Suchindan (1987) in the coast of Kerala, India and Shih and by Shih and Komar (1994) in the Coast of Oregon, United States.
3. Analysis of aerial photographs of satellite images. Employed in the coastal area of Kuwait by Al Bakri (1996), on the coast of Kerala, India by Kunte (1994) and on the northeast coast of the Nile delta by El – Asmar (2002).

In this study for the characterization of the littoral cells, it is necessary to generate a database with information on coastal currents, geomorphology, sediment size, evolution of the coastline and type of coast. For each topic, a map is generated, and the changes are identified as limits (Fig. 3).

With the satellite images, changes in geomorphology, coastal structures of relevant importance, sources and sinks are identified, these features are identified in maps.

An identification code is used based on the type of sediment and transport patterns. The maps are superimposed and 3 limits are identified:

1. Main: if 3 or more characteristics match.
2. Secondary: if 2 characteristics match.
3. Transition: only one characteristic is presented. If the limit corresponds to a river or geomorphological feature, it is considered a secondary limit.

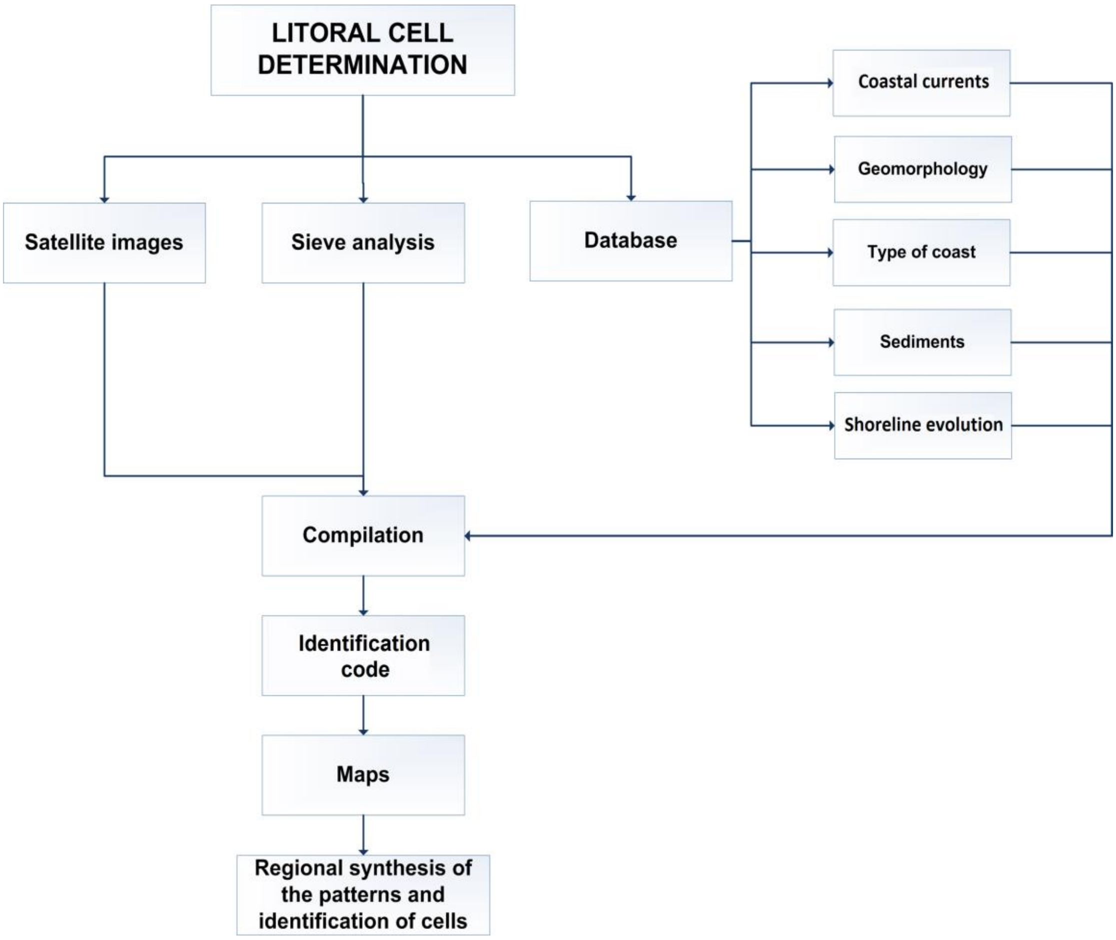

Figure 3. Characterization scheme of littoral cells.

Coastal vulnerability index

The vulnerability is defined as the level at which the human population and ecosystems are subject to damage or hazards due to social and biophysical factors (Ávila 2007). The vulnerability assessment of the coastal region must consider physical and socioeconomic variables, to generate information for decision making for sustainable development and reduce the risk of disasters.

The index proposed here considers 5 groups of variables (physical and socioeconomic), each with its respective classification (see Fig. 4).

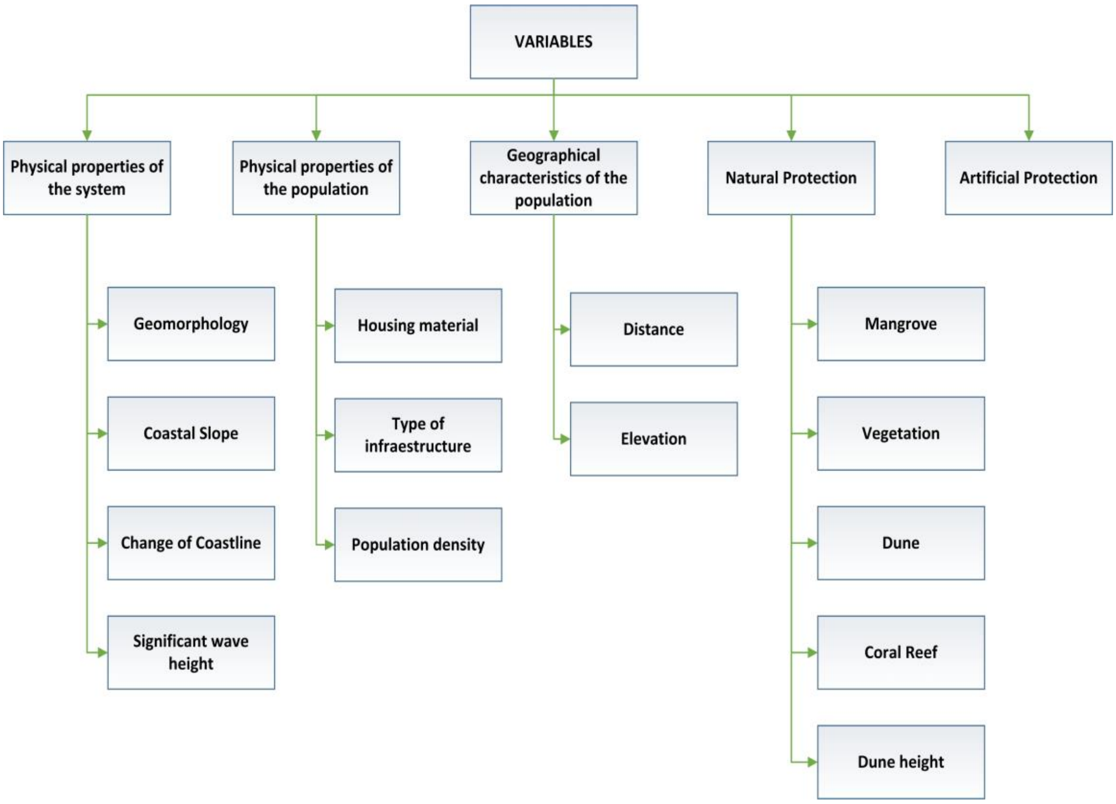

Figure 4. Variables scheme used for the Coastal Vulnerability Index (CVI) assessment.

Each variable is assigned a specific value and weight (Table 1). Diez et al. (2007) observed that the CVI defined as the sum of differentially weighted variables was more sensible to the environmental diversity. The present calculations indicate that the sum of the variables with the rank numbers of each multiplied by a specified weightage value, as detailed below, better represents the conditions along the coast.

Table 1. Synthesis of variables, weight, classification and specific values for the CVI.

Weight	Variables	Classification	Specific values	Weight	Variables	Classification	Specific values
15	Elevation (Praddep et al., 2014)	Greater than 10 m	0	8	Dune height	Greater than 5 m	0
		Greater than 4 m and less than or equal to 10 m	0.2			Greater than 2 m and less than or equal to 5 m	0.5
		Greater than 1 m and less than or equal to 4 m	0.5			Less than or equal to 2 m	0.9
		Less than or equal to 1 m	0.9	7	Dune	Dune with vegetation	0.2
14	Distance to coast	Greater than 4 km	0			With dune	0.5
		Greater than 1 km and less than or equal to 4 km	0.5			Without dune	1
		Greater than 500 m and less than or equal to 1 km	0.7	6	Geomorphology (type of coast) (Nageswara et al., 2008)	Cliff or rocky beach	0.2
		Less than or equal to 500 m	0.9			Sandy or gravel beach	0.7

13	Coastal slope (Ashraful Islam et al., 2016)	> 1.0	0			Mud coast	0.9
		0.50 – 1.0	0.2	5	Change of coastline (Nageswara et al., 2008)	> 2.0	0
		0.10 – 0.50	0.5			1.0 to 2.0	0.2
		0.10 – 0.05	0.7			-1.0 to 1.0	0.5
		< 0.05	0.9			-2.0 to -1.0	0.7
12	Significant wave height (Nuñez et al., 2016)	< 0.55	0			< -2.0	0.9
		0.55 – 0.85	0.2	4	Artificial protection	With artificial protection	0.5
		0.85 – 1.05	0.5			Without artificial protection	1
		1.05 – 1.25	0.7	3	Mangrove	With mangrove	0.2
		> 1.25	0.9			Without mangrove	0.9
11	Population density (Mani et al., 2013)	Scattered	0.2	2	Vegetation (without considering mangrove)	With vegetation	0.2
		Concentrated	0.9			Without vegetation	0.9
10	Type of infrastructure	Urban	0.1	1	Coral reef	With reef	0.2
		Rural	1			Without reef	0.9
9	Housing material	Concrete	0.2				
		Wood and others	0.9				

The Coastal Vulnerability Index (CVI) is calculated as the weighted sum of the weight of each variable affected by its specific index and can be expressed by equation 1:

$$CVI = \sum_{i=1}^{n} W_i * \mathrm{SV}_i \qquad (1)$$

Intervention index

This index identifies the importance of an area, according to its physical characteristics and related to erosion and population. It is important to note that the importance or urgency of the intervention in an area does not imply that it will be first for intervention.

Eight variables were considered, each of which was classified and each classification was assigned a value.

Table 2. Synthesis of variables, weight, classification and specific values for the II.

Variables	Classification	Specific values	Variables	Classification	Specific values
Vulnerability	Very low	1	Bathymetry	> 5.0 m	1
	Low	2		5.0 – 4.0 m	2
	Moderate	3		4.0 – 3.0 m	3
	High	4		3.0 – 2.0 m	4
	Very high	5		< 2.0 m	5
Land use	Urban área	1	Distance to source	< 1 km	1
	Agricultural area	2		1 – 2.5 km	2
	Area without vegetation	3		2.5 – 5 km	3
	Pasture	4		5 – 7.5 km	4
	Jungle	5		>7.5 km	5
	Mangrove	6	Distance to sink	>7.5 km	1
Soil characteristics	Kars plain	1		5 – 7.5 km	2
	Fluvial plain	2		2.5 – 5 km	3
	Lacustrine plain	3		1 – 2.5 km	4
	Palustre plain	4		< 1 km	5
	Coastal beach ridges	5	Population density	1.03 – 6.03	1
Average terrain slope	>1.0	1		6.03 – 11.03	2
	0.50 – 1.0	2		11.03 – 16.03	3
	0.10 – 0.50	3		16.03 – 21.03	4
	0.05 – 0.10	4		> 21.03	5
	< 0.05	5			

The index is obtained from the arithmetic sum of specific value of each variable and can be expressed by equation 2:

$$II = \sum_{i=1}^{n} SV_i \tag{2}$$

Hierarchical littoral segments

The limits obtained in the characterization of the littoral cells, the vulnerability index and the intervention index were superimposed on a map, obtaining the coastal segments. These segments are classified as having high, medium, or low priority, based on the economic activities, population and natural environments present.

RESULTS

Hierarchical littoral segments

Four main boundaries were identified, resulting in 3 littoral cells. Two main sinks were identified: Sabancuy Estuary Inlet and Puerto Real Inlet (orange arrows). The blue arrows represent the sources of sediments from rivers discharges. (Fig. 5).

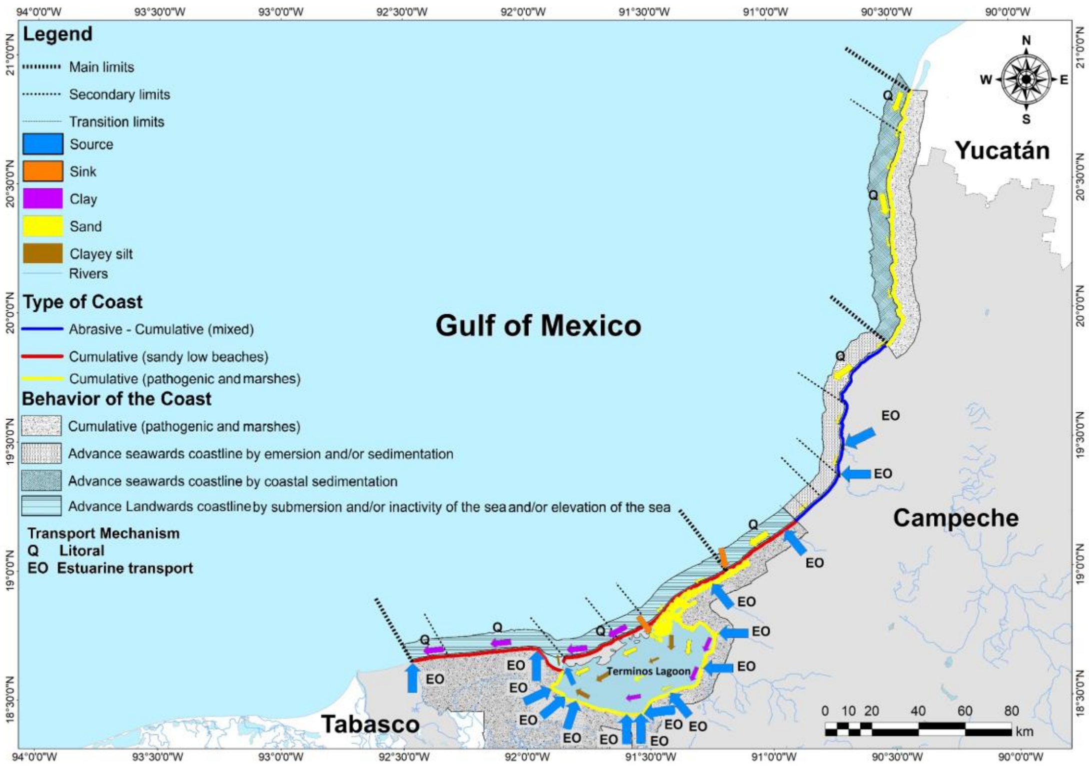

Figure 5. Littoral cells of Campeche State.

Coastal vulnerability index

In order to obtain the information for the analysis of each variable, it was necessary to consult databases of waves, satellite images; as well as field measurements. Examples of the wave and shoreline evolution analysis are shown in Fig. 6.

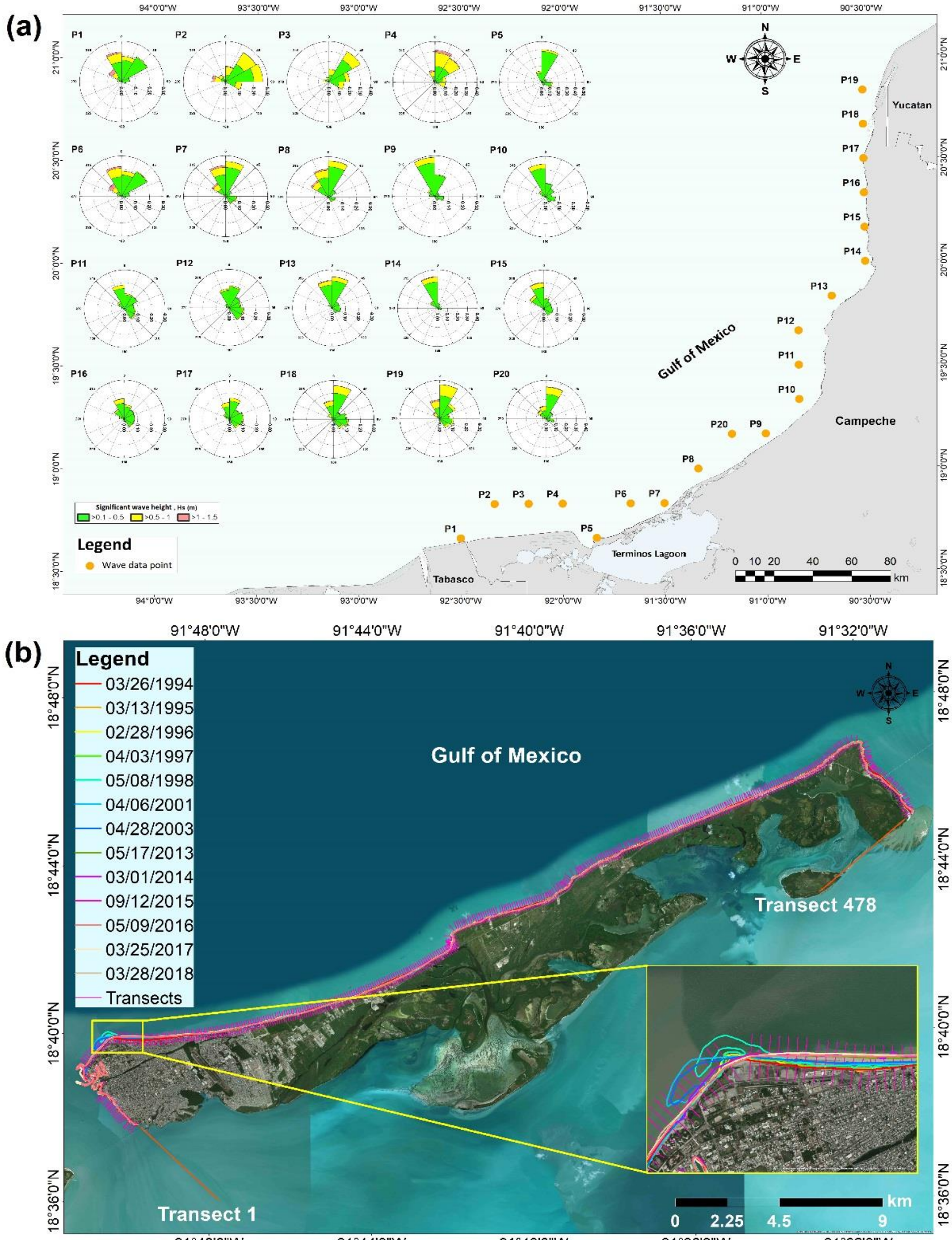

Figure 6. (a) Significant wave height (2005 – 2017) for 20 points near the coast, data is taken from the WWIII database; (b) Shoreline evolution (1994 – 2018) for Isla del Carmen.

A representative minimum value of 10.45 and a maximum of 110.45 was obtained, these values were grouped into five vulnerability categories, seen in Table 3:

Table 3. Groups generated with the results of the Coastal Vulnerability Index (CVI).

Value	Categories
10.45 – 30.45	Very low
30.46 – 50.45	Low
50.46 – 70.45	Moderate
70.46 – 90.45	High
90.46 – 110.45	Very high

The map shown in Fig. 7 represents a synthesis of the vulnerability of the coast of Campeche. The southern area of the state has high vulnerability, the central zone is characterized by moderate vulnerability and two northern zones show low vulnerability.

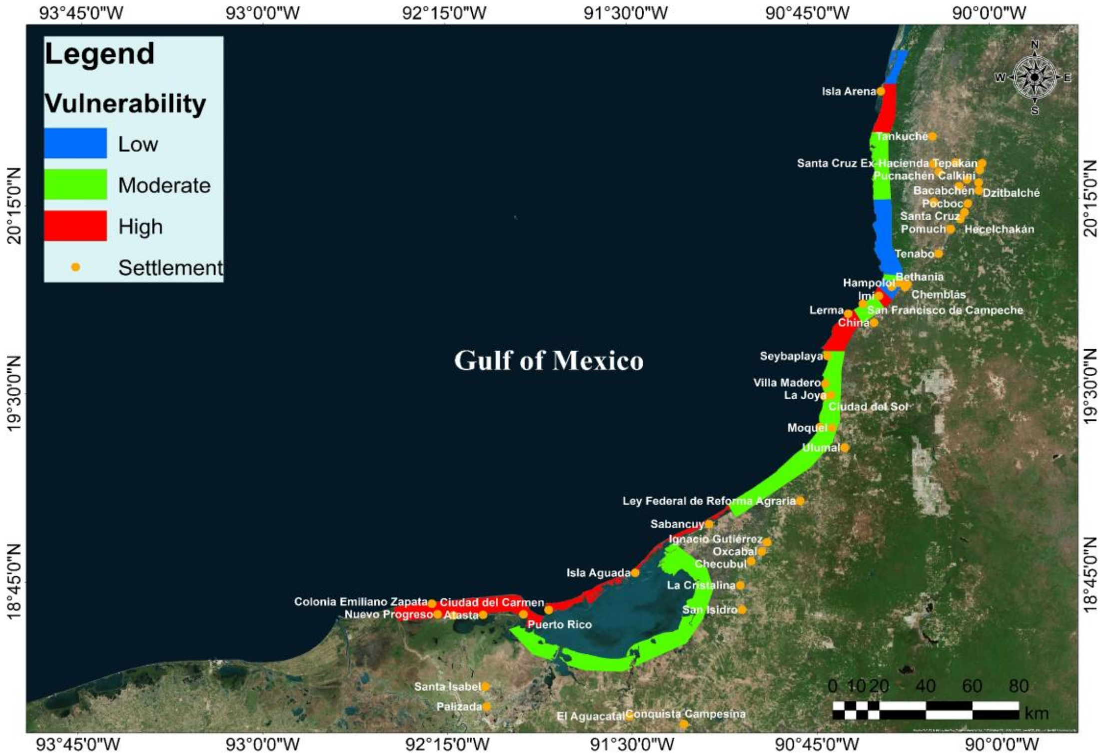

Figure 7. Coastal vulnerability of state of Campeche.

Intervention index

A representative minimum value of 8 and a maximum of 41 was obtained. Four categories were set:

Table 4. Groups obtained from the results of the intervention index.

Value	Categories
8 – 16.25	Low importance
16.25 – 24.5	Moderate importance
24.5 – 32.75	High importance
32.75 - 41	Very high importance

Fig. 8 represents a summary of the action ranking for the coast of Campeche. Two intervention categories were obtained. It is clear that the greatest urgency is found at the southern part of the state.

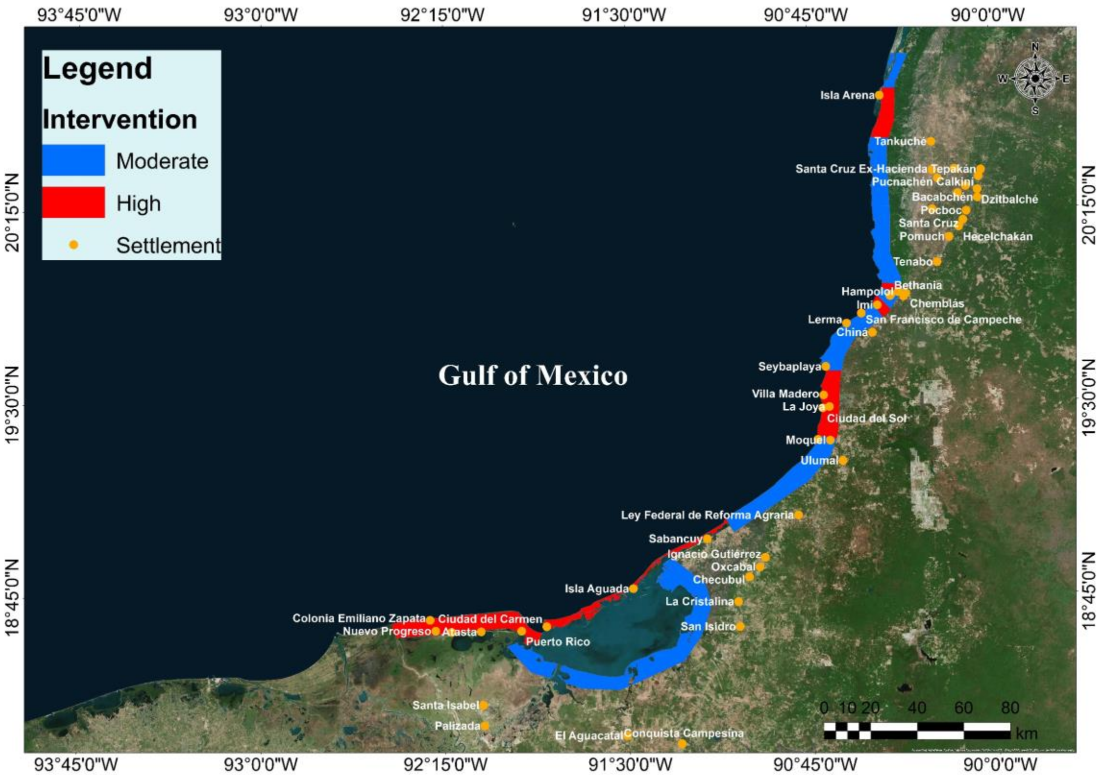

Figure 8. Map of the intervention index for the coast of Campeche.

Hierarchical littoral segments

The hierarchical coastal segments obtained are shown in Fig. 9; where red represents high priority, yellow average and green low priority.

Figure 9. Hierarchical littoral segments of the Campeche coast.

CONCLUSIONS

Coastal management for decision making has been widely studied over the recent years, although no common methodology applicable to all coastal areas of the world has yet been established. The indexes implemented in this work allow the characterization of coastal zones in such a way that financial resources are efficiently used.

The vulnerability assessment proposed here evaluates physical and socioeconomic variables; hierarchical littoral segments are proposed as a tool that evaluates physical, environmental and socioeconomic variables from a large scale perspective, starting from the evaluation of littoral cells, vulnerability and intervention.

The results are a first approximation and application of the methodology proposed, since work must be done on an adjustment and normalization.

Three littoral cells were identified along the Campeche coast: North (Peten Zone), Central (rocky and sand beach) and South (lagoon system and sand beach).

Shoreline changes along the Campeche coast for 1994 – 2018 were assessed. The southern part of the state presents higher rates of erosion, as well as the highest vulnerability so the intervention priority is high.

Littoral segments were identified that allow stakeholders to decide which area to start working on. It is very important to highlight the quality of this study depends on the data and tools available for the assessment.

REFERENCES

Alpuche Gual, L. (2014). Clasificación de playas campechanas para su manejo integral y desarrollo sostenible. Universidad Autónoma de Campeche, 156 pp.

Anfuso, G. (2004). Caracterización de celdas litorales en un tramo costero aparentemente homogéneo del litoral de Cádiz (SO de España). *Rev. C. & G.*, 18, 25 - 36.

Anfuso, G., Pranzini, E., Vitale, G., (2011): An integrated approach to coastal erosion problems in northern Tuscany (Italy): Littoral morphological evolution and cell distribution, *Geomorphology*, Elsevier, vol. 219, 204 – 214.

Ashraful Islam, M., Mitra, D., Dewan, A., & Humayun Akhter, S. (2016). Coastal multi-hazard vulnerability assessment along the Ganges deltaic coast of Bangladesh - A geospatial approach. *Ocean & Coastal Management*, 1 - 15.

Ávila García, P. (2007). Las cuencas hidrológicas de México y su vulnerabilidad socio ambiental por el agua. Sustentabilidad y Desarrollo ambiental. *Agenda para el Desarrollo*, 14, 133 - 161.

Bray, M., Carter, D., & Hooke, J. (1995). Littoral cell definition and budgets for Central Southern England. *Journal Coastal Research*, 11 (2), 381 - 400.

Carter, R. (1988). Coastal Environment - an Introduction to the Physical, Ecological and Cultural Systems of Coastlines. *Academic Press*.

Diez, PG., Perillo, GME., Piccolo, MC. (2007) Vulnerability to sea – level rise on the coast of Buenos Aires province. *Journal Coastal Research*, 23:119 – 126 doi: 10.2112/04-0202.1

Diez. J., Esteban, M., and Paz, R., Cancún – Nizuc coastal barrier. *Journal of Coastal Research*, Vol. 25, No. 1, January, 2009, pp. 57 – 68.

El - Asmar, H. (2002). Short Term Coastal Changes Along Damietta - Port Said Coast Northeast of the Nile Delta, Egypt. *Journal Coastal Research*, 18, 433 - 441.

INEGI. Sistema de Cuentas Nacionales de México 2008. Actividad económica total, 2014.

Juárez León, A., & Torres, J. (2008, septiembre). Identificación en Planta de Formas Costeras de Depósito, mediante el Uso de Percepción Remota Aeroespacial. *Noticias AMIP*, Año 4, Num. 15, 10 – 16.

Kunte, P. (1994). Potential Usage of Remote Sensing Data in Studying the Behaviour of Shore Drift Along Kerala Coast, India. *Estuarine, Coastal and Shelf Science*, 38, 613 - 624.

Mani Murali, R., Ankita, M., Amrita, S., and Vethamony, P. (2013). Coastal vulnerability assessment of Puducherry coast, India, using the analytical hierarchical process. *Natural Hazards Earth System Sciences*, 13, 3291 – 3311.

Nageswara, R., Subraelu, P., Venkateswara Rao, T., Hema Malini, B., Ratheesh, R., Bhattacharya, S., Ajai. (2009). Sea-level rise and coastal vulnerability: an assessment of Andhra Pradesh coast, India through remote sensing and GIS. (S. Science, Ed.) *Journal Coastal Conservation*, 12, 195 - 207. doi:10.1007/s11852-009-0042-2.

Núñez G., J.C., R. Ramos R., E. Barba M., A. Espinoza T., L. M. Gama C. (2016), Índice de vulnerabilidad costera del litoral tabasqueño, México. *Investigaciones Geográficas*, núm. 91, Instituto de Geografía, UNAM, México, pp. 70 – 85, dx.doi.org/10.14350/rig.50172.

Ortíz - Pérez, M. (1992). Retroceso reciente de la línea de costa del frente deltaico del Río San Pedro; Campeche, Tabasco. *Boletín del Instituto de Geografía*, 25, 7- 25.

Pradeep C., Vigneshwaran S., Thirumlaivasan D., (2014). Coastal Vulnerability Assessment for Northern Tamil Nadu Coast using open source numerical software – DELFT 3D. *International Journal of Earth Sciences and Engineering.* Vol. 07, No. 05, pp. 1135 – 1145.

Samsuddin, M., & Suchindan, G. (1987). Beach Erosion and Accretion in Relation to Seasonal Longshore Current Variation in the Northern Kerala Coast, India. *Journal of Coastal Research*, 3, 55 - 62.

Silva, R. Informe final: caracterización morfodinámica y evaluación de alternativas para la recuperación de las playas de la zona norte de Quintana Roo. México, D.F.: *Proyecto Fondo Mixto Conacyt-Gobierno de Quintana Roo*, QROO-2003-C02-12707,2007.

Shyuer-Ming Shih, & Komar, P. (1994). Sediments, Beach Morphology and Sea Cliff Erosion within an Oregon Coast Littoral Cell. *Journal of Coastal Research*, 10(1), 144-157. Retrieved from http://www.jstor.org/stable/4298199

Sulis, A., & Annis, A. (2014). Morphological response of a sandy shoreline to natural obstacle at Sa Mesa Longa Beach, Italy. *Coastal Engineering*, 84, 10 - 22.