Journal of Coastal Research	SI	71	114–121	Coconut Creek, Florida	2014

Beach Erosion in San Benito Chiapas, Mexico: Assessment and Possible Solution

Miguel A. Delgadillo-Calzadilla[†*], Edgar Mendoza[†], Rodolfo Silva[†], José A. González-Vázquez[†], and Dulce Infante-Mata[‡]

[†]Instituto de Ingeniería, Universidad Nacional Autónoma de México
Mexico City, México

[‡]El Colegio de la Frontera Sur
Tapachula, Chiapas, México

www.cerf-jcr.org

www.JCRonline.org

ABSTRACT

Delgadillo-Calzadilla, M.A.; Mendoza, E.; Silva, R.; González-Vázquez, J.A., and Infante-Mata, D., 2014. Beach erosion in San Benito Chiapas, Mexico: Assessment and possible solution. *In:* Silva, R., and Strusińska-Correia, A. (eds.), *Coastal Erosion and Management along Developing Coasts: Selected Cases.* Journal of Coastal Research, Special Issue, No. 71, pp. 114–121. Coconut Creek (Florida), ISSN 0749-0208.

The study area is on the Gulf of Tehuantepec, where a harbour was built at San Benito, near Tapachula, Chiapas, in 1972. Two breakwaters, of 630 m and 800 m, respectively, were constructed to provide protection to the harbour channel. Erosion problems were detected near the harbour even before it was opened to trade. The original design had many flaws as no wave climate analysis had been done and littoral drift had not been taken into account. In 1975, 17 groins were built with the aim of reducing the erosion on the adjacent beach. These were unsuccessful and, in 1980, a rock armour apron was built at the most seriously eroded section in a further attempt to minimize the problem and to protect the population. However, the erosion continues at a rate of around 25 m per year in some sections. Commercial and navigation activities at the harbour are important for the population of San Benito and its surroundings, so coastal management policies must facilitate harmonic coexistence between human activities and the coastal system. This study analyses the problem and offers alternative solutions for minimizing the beach erosion using hard and/or soft solutions.

ADDITIONAL INDEX WORDS: *Erosion, straight beach, soft and hard solutions, groins*.

INTRODUCTION

In developing countries many coastal facilities, including tourist, industrial, port and urban developments, have been designed and constructed without an enough planning or without any investigation of the physical and climatic agents at work in the area. An important number of these projects were doomed to fail through ignorance rather than deliberate fault. In some cases, the same lack of information not only affects the original design but also the solutions employed to rectify the undesired effects caused by it. Whenever a coastal engineer is asked to propose solutions to this kind of problem, analysis has to be done along two branches. Firstly, the existing coastal dynamics prior to the construction need to be understood as fully as possible, even though they may have been altered so much that it can be very difficult to find even hints of the original balances. Secondly, the effect of the infrastructure proposed has to be assessed before any solution is adopted.

The above scenario describes the present condition at San Benito, Chiapas, Mexico, where a long straight beach was severely eroded as a result of the construction of a port and two breakwaters. These breakwaters interrupt the longshore sediment transport and the obvious consequence of this was the accumulation of sediment on the updrift side of the breakwater and severe erosion on the downdrift beaches. Inexplicably, the measures employed to halt the erosion were the construction of 17 groins along the beach. This resulted in a saw-tooth-shaped coastline but the erosion was transferred to neighbouring coastal segments. Subsequently an 18th groin was built, in an apparent obsession with this kind of structure, giving the same result as before. At this point we should recall the basic rules for the functional design of groins as stated by Basco, *et al*., (2001): "if cross-shore sediment transport is dominant consider nearshore breakwaters first, groins cannot create or destroy sediment, to avoid erosion of adjacent beaches always include a beach nourishment, a minimum dry beach width must be defined to evaluate success, a ratio of 2-3 between the longshore spacing and the length from the seaward tip of the groin to the design shoreline is a good start to determine the beach nourishment needed, rely on modern shoreline and cross-shore evolution numerical models, bypassing, structure permeability and balance between net and gross longshore sediment transport are the key factors in the design, consider tapered ends to minimize impacts on adjacent beaches, establish a monitoring program, be prepared to modify or remove the groins if the beach impacts are not acceptable". A review of the history of San Benito port and its consequent results leads one to think that most of these rules were not considered.

The objective of this work is to understand the present conditions near San Benito in order to propose a solution which will stabilize the eroded beach without transferring the erosion to adjacent beaches. A brief characterization of the site is presented, and from the understanding of the hydraulic behaviour combined, with the evaluation of the coastline retreat in recent years, a series of engineering solutions are suggested and numerically tested.

STUDY AREA

San Benito Beach is located in the state of Chiapas, on the Mexican Pacific Coast, within the geographic coordinates

DOI: 10.2112/SI71-014.1 received 12 February 2014; accepted in revision 5 September 2014.
*Corresponding author: MDelgadilloC@ii.unam.mx

N14°32’24”, N17°59’08”, W90°20’32” and W 94°07’13” (see Figure 1), it was a 20 km long, straight beach with a gentle slope. The sediment sources are the discharges of Cahoacan and Coatan rivers. The study area is part of the Gulf of Tehuantepec which lies close to the Mesoamerican trench between the Cocos, Caribbean and North American tectonic plates. The convergence of these three tectonic plates affects coastal dynamics causing local subduction that is compensated by a rise in sea level and other processes (see Silva *et al*., 2014) and therefore the area can be considered stable geologically speaking, as was shown by Martínez *et al*., (2014).

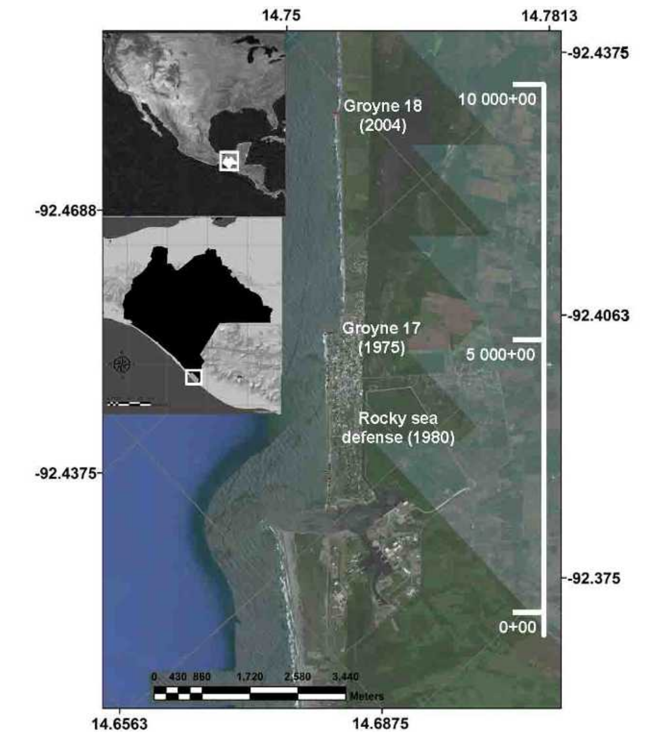

Figure 1. Location of San Benito Beach.

The erosion problems began in 1973 when the construction of the port, then known as Puerto Chiapas, began. This harbour is important for the economy of Southern Mexico as agricultural products are exported from there to the USA, Central and South America and also because from 2006, it has hosted a slowly developing tourism industry. The first stage in the port construction was the building of two breakwaters to form the navigation channel. Historical reports say that even when the construction of the harbour was unfinished and there were still no port activities, San Benito Beach had already begun eroding. In an effort to minimize this erosion, 17 groins were constructed along the adjacent 5 km beach west of the port, in 1975 (see Figure 1). Since the problem only worsened, the construction of an onshore rocky defence (Figure 2) was undertaken in 1980 along the worst affected 3 km. However the unprotected beach next to groin 17 continued eroding, and in 2004 groin 18 (Figure 2) was constructed in an effort to trap the sediment. Despite all these interventions the coastline continues to retreat, placing the population at risk.

It is known that the erosion of a beach is controlled by three main factors: sediment supply, wave forces and sea level variations; given that none of those factors has changed dramatically at San Benito, the erosion must the result of the poorly planned infrastructure. At this point we will analyse the local maritime climate to determine the prevalent and storm conditions which affect the beach system.

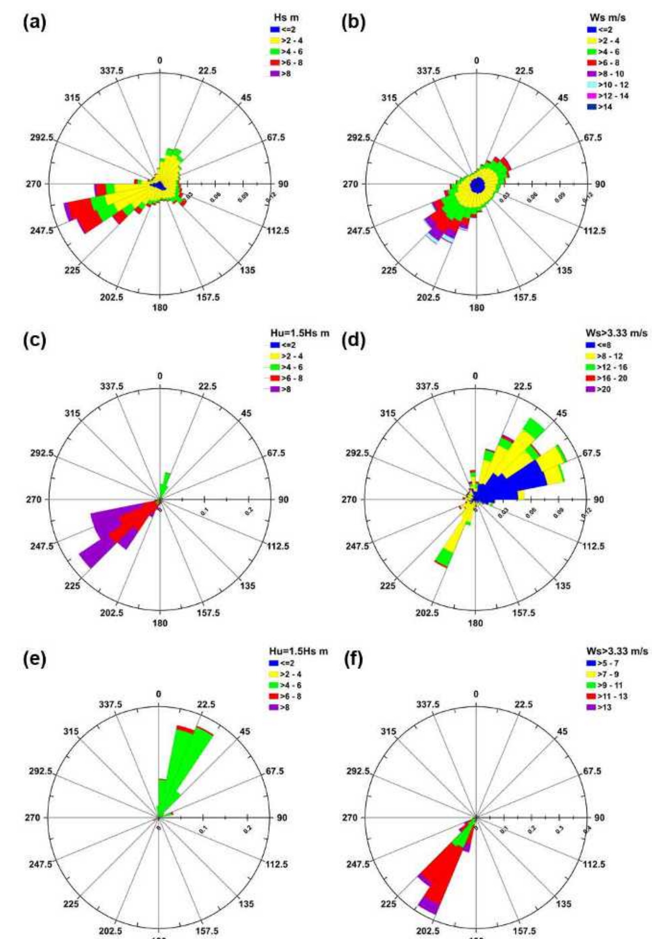

Figure 2. Direction and intensity of waves (left) and winds (right) for 1949 to 2010 at San Benito Beach. (a and b) all data available, (c and d) tropical storms and (e and f) cold fronts.

Waves

The coast of Chiapas is exposed to seasonal dependent waves, *i.e.* the wind direction and intensity governs the wave conditions. In summer, hurricanes and tropical storms produce high energy waves coming from the SW. On the other hand, in winter, winds come from the NE, mainly induced by cold fronts. This behaviour can be seen in Figure 2 where the data from the wind and wave re-analysis of 1949 to 2010 has been plotted; panels a and b show all the data available for waves and winds, respectively; panels c and d show only tropical storms and panel e and f show only the winter storms. A difference of approximately 180° between the direction of winds and waves in summer and in winter is seen. An average of 16 tropical storms and hurricanes hit the coast of Chiapas each year, with wave heights of up to 8 m; while there are 20 cold fronts per year on average, with wave heights of up to 6 m. The mean regime (time periods without storms) has low energetic waves, with a historical mean significant wave height of 2 m. The wave and wind hindcast was perfomed using the WAM-HURAC hybrid model (Ruiz *et al*., 2009) for the period of 1949 to 2010. For the wave analysis, a tropical storm is considered to be an event with a significant wave height greater than 1.5 times the historical significant wave height, for at least 6 hours; while for a winter storm the duration must be of at least 3 hours.

Contribution of the Rivers

The beach of San Benito receives sediment from the discharge of the Coatan and Cahoacan rivers, both of which come from small basins which rise to an elevation of 3600 m over sea level in only 50km. Unfortunately, the Coatan river is not monitored, but its slope, lithology and drainage area are similar to those of the Cahoacan river, for which there are 60 years of time series records of its discharge. The fluvial sediments discharged to the ocean from the Cahoacan River were estimated with the BQART model (Syvitski and Milliman, 2007) giving 7.19 Mt/y, which confirms that the erosion is not the result of a sediment deficit.

Numerical Estimation of Waves and Wave Induced Currents

The hydrodynamics of the area were modelled with WAPO and COCO numerical tools (Silva *et al*., 2005 and Silva *et al*., 2010). The wave input data was of a wave height of 5 m and a period of 8.68 s, which is considered to be representative of a tropical storm. This data is summarized in Table 1

Figure 3a shows the computed wave-induced currents, which are significant only around the East breakwater of the port and close to groin 17. The dominant direction is, as expected, NW. Figure 3b shows the wave height map, it can be seen that the interaction between the beach, the groins and the angle of incidence of the waves produces an energy concentration in the area between groins 17 and 18.

BEACH EROSION ASSESSMENT

Because of their intensity and recurrence, hurricanes are the most relevant meteorological threat to San Benito Beach, the occurrence of which has worsened the erosion problems but, as has been said, the origin of the damage is not natural but anthropogenic.

The main reason for the erosion at San Benito was the construction of the port breakwaters and the subsequent unfortunate solution attempts; which were inadequately designed, without considering the longshore sediment transport (LST). Therefore, the erosion assessment presented here includes a historical analysis of the activity on the coast from 1972 to 2012. Similar to wave direction and intensity, the LST shows a strong seasonal dependency, being SW directed in the winter and NW directed during summer. As stated before, the sources of sedimentary material are the Cahoacan and Coatan rivers, while the main sinks are the continental platform (sediment travelling beyond the closure depth) and the dredging works which remove sand from the navigation channel of the port and deposit it outside the beach system.

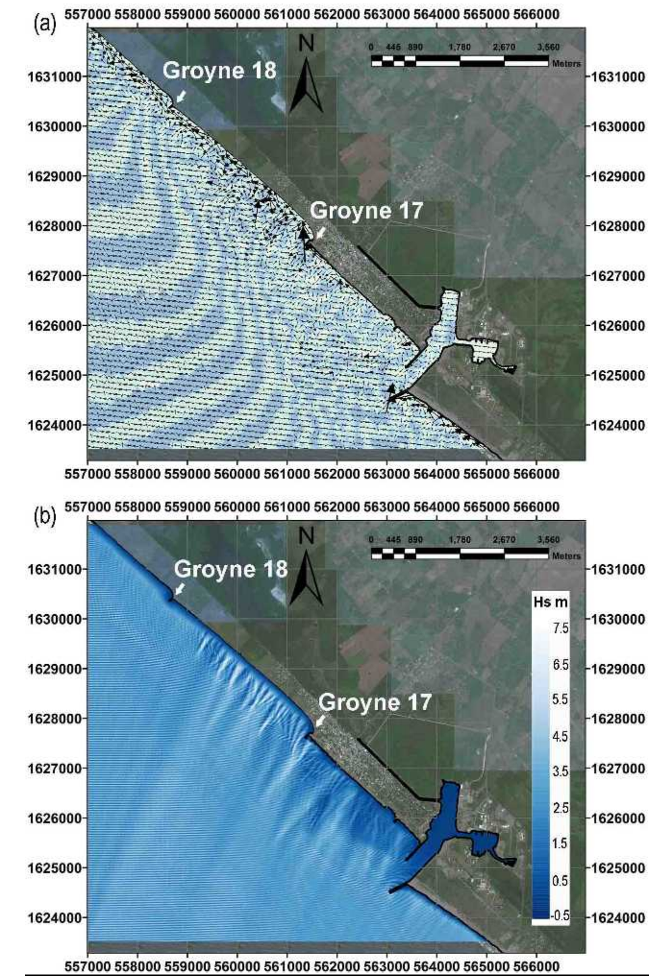

Figure 3. Hydrodynamic model results: (a) wave-driven currents and (b) wave height.

Figure 4 shows a series of Landsat images from 1972 to 1993 in which the evolution of the coastline can be seen. For each of those years the mean direction and rate of the LST was estimated using the mean yearly wave conditions and the Kamphuis formulae (Kamphuis, 1991). Figure 4a corresponds to 1972, prior to the port construction. It is interesting to note that, for that particular year, the mean sediment transport direction was SW (almost cross-shore) probably because a large number of cold fronts occurred that year, as can be seen in the wave rose. No hurricane conditions were reported in that year. Figure 4b shows the mean LST estimated for 1974; by then the harbour was operating. The LST was NW directed, consequently the coastal structures started trapping sand. Figure 4c shows accretion on the beach southeast of the port as a result of sand trapping and shoreline retreat downdrift. This year the LST rate was very low, so a temporary sand deficit may have worsened the erosion.

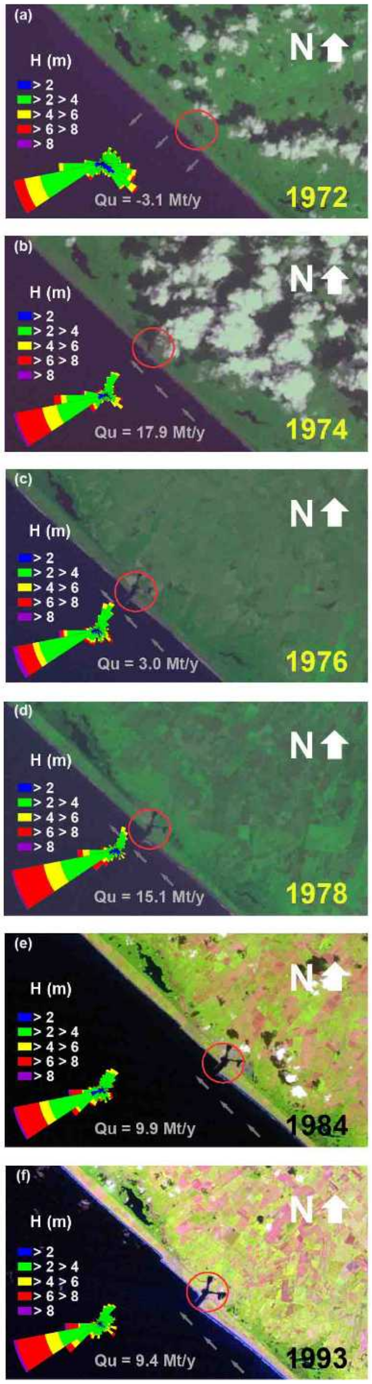

Figure 4. Estimation of the historical rate and direction of the longshore sediment transport in San Benito Beach (images taken from http://landsatlook.usgs.gov/).

Figure 4d shows the study area in 1978. The wave rose shows an important percentage of high energetic waves and the trapping-erosion effects of the breakwaters continue. By 1980 the groin field was built, which means that in 1984, Figure 4e, the effects of these structures were evident. Given that the LST shows the same pattern as in previous years, the erosion problem was transferred downdrift (next to groin 17).

As southwest from the port the beach continued to be displaced seaward, the breakwater of the port was extended a further 115 m, to avoid silting in the navigation channel. This can be seen in Figure 4f. From this review it is seen that one of the main mistakes made in the protection work is that none of them contemplated natural or artificial sand bypassing, so there is no possibility of beach stabilization.

In order to assess and understand the behaviour of the beach better (2009 to 2012), the study area was divided into three sections, using the structures built there to divide them. Section 1 is the farthest from the port; it begins where groin 18 is placed and it ends 1 km westwards. Section 2 is the beach front located between groins 17 and 18 and Section 3 goes from the western breakwater of Puerto Chiapas to groin 17, this is the area where the rocky longitudinal defence has been built. The location of each section is seen in Figure 5. Each section was analysed separately.

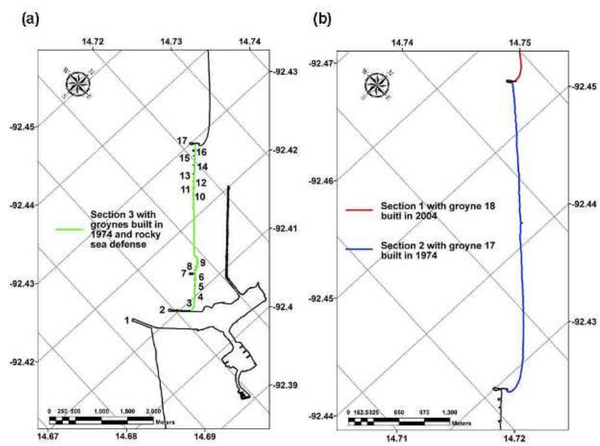

Figure 5. Division of the study area into sections.

Section 1

This section shows the greatest coastline retreat from 2009 to 2012, mainly because a sediment shortage has been artificially provoked by the presence of coastal structures which interrupt the sediment transport. Figure 6 shows the coastline evolution from 2009 to 2012, by this year groin 18 had been in place for 5 years. It can be seen that from 2009 to 2010 shoreline retreat was small, but from 2011 to 2012 a large amount of dry beach was lost, presumably due to the effects of hurricane Dora (18-24 July 2011).

Figure 7 shows a comparison of the coastlines over three years, the erosion trend is evidenced and shows how the effect of the groin is rapidly increasing. The yearly mean, minimum and maximum coastline displacements are shown in Table 1.

Section 2

On average, Section 2 is that most damaged by erosion, specifically the part immediately west from groin 17 where a small part of the town of San Benito is being affected by the erosion and some formerly inhabited areas have been reported to be lost. This section has no sediment supply and therefore a huge sediment budget loss.

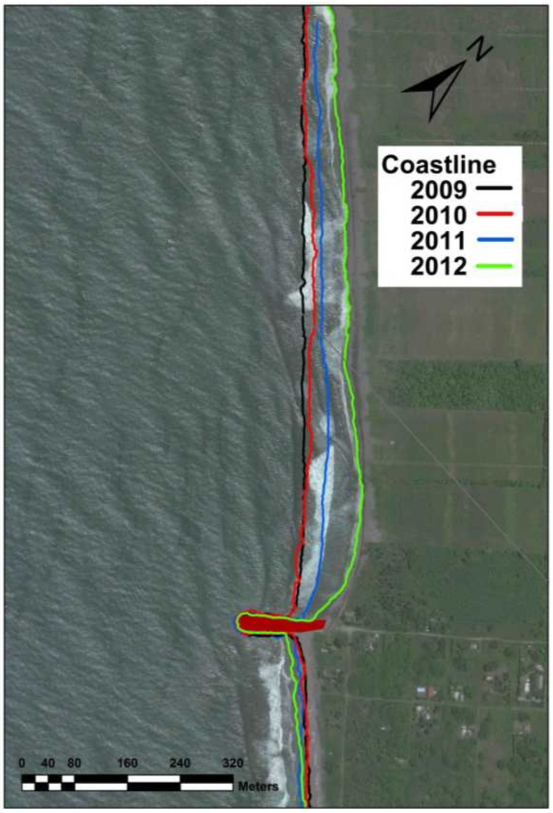

Figure 6. Coastline evolution from 2009 to 2012 in Section 1.

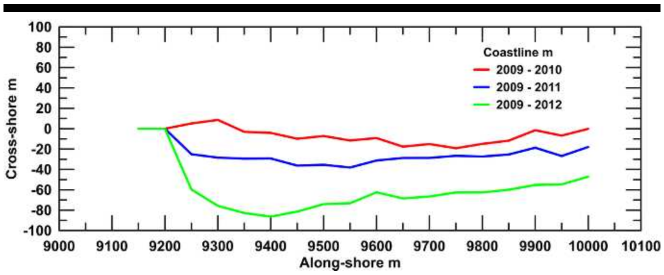

Figure 7. Historical coastline comparison in Section 1.

Table 1. *Coastline displacement values in Section 1.*

Year	*Mean (m)*	*Maximum (m)*	*Minimum (m)*
2009-2010	-6.55	-19.18	+0.10
2010-2011	-25.16	-39.09	-17.94
2011-2012	-59.58	-86.79	-47.07

Figure 8 shows the coastline retreat, where it can be seen that for 2009 to 2010 there was accumulation of sand on coastline, however for 2011 the coastline retreated to behind the 2009 position and for 2012 the erosion is even worse.

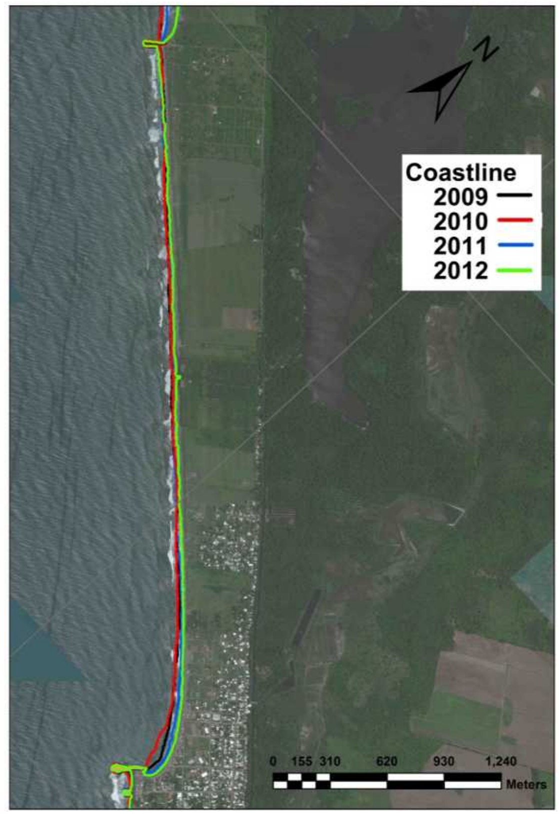

Figure 8. Coastline evolution from 2009 to 2012 in Section 2.

The comparison of historical coastlines shown in Figure 9 shows high instability in some areas of section 2, as episodes of accretion are succeeded by episodes of erosion in the same area. From 2011 to 2012 this variability changes to a trend of chronic erosion to the point that in some areas the coastline has retreated up to 60 m relative the 2009 position.

Table 2 shows the mean, maximum and minimum displacements of the shoreline in Section 2, the instability is evidenced again as positive (accretion) and negative (retreat) values were found. Another characteristic found in this section is that the area next to groin 17 is being eroded but the area close to groin 18 is trapping some sand so a little accretion can be found; unfortunately the groins are too far from one another to produce beach stability.

Table 2. Coastline displacement values in Section 2.

Year	Mean (m)	Maximum (m)	Minimum (m)
2009-2010	+4.54	+51.73	-12.04
2010-2011	-5.62	+14.14	-31.01
2011-2012	-32.98	+16.46	-65.86

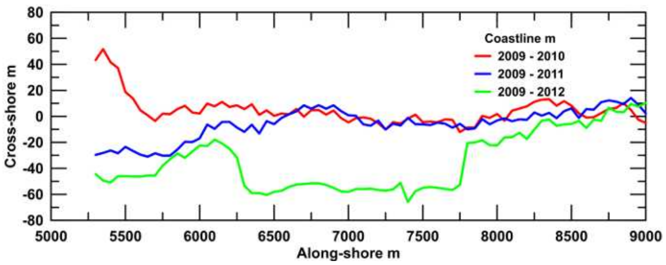

Figure 9. Historical coastline comparison in Section 2.

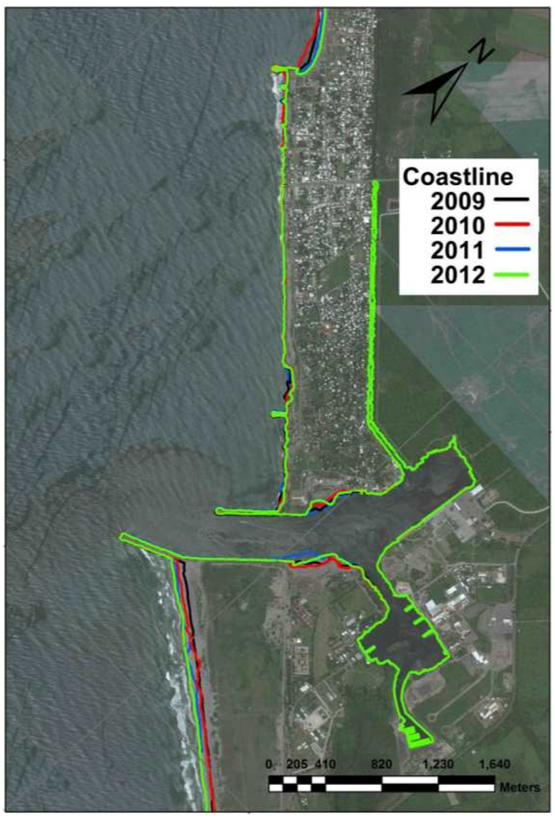

Figure 10. Coastline evolution from 2009 to 2012 in Section 3.

Section 3

This beach section is adjacent to the harbour and is protected by a rocky sea defence built in 1980, to stop the erosion. This longitudinal protection was seen to be justified as the erosion was threatening the urban area. The performance of the rocky protection makes the 15 previously built groins redundant and indeed erosion has stopped, but the environmental and visual costs have been very high. The coastline did not retreat significantly from 2009 to 2012, as can be seen in Figure 10.

Figure 11 shows the comparison of coastlines over the same period for Section 3. The effectiveness of the rocky defence in minimizing the erosion is evidenced, while the eastern breakwater of the port continues to trap sediment. Table 3 shows the variability of the coastline displacement in the period 2009-2012, with the most noticeable feature being the beach accretion east of the port.

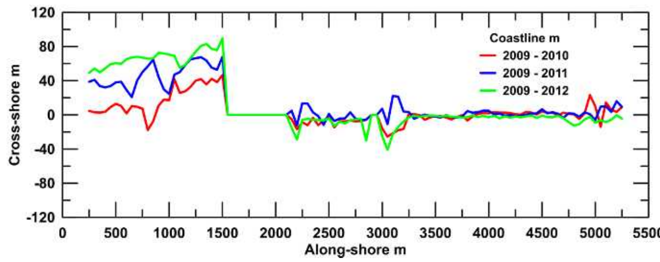

Figure 11. Historical coastline comparison in Section 3.

Table 3. *Coastline displacement values in Section 3.*

Year	Mean (m)	Maximum (m)	Minimum (m)
2009-2010	+7.67	+46.52	-25.50
2010-2011	+47.94	+67.79	-12.16
2011-2012	+60.23	+89.52	-40.93

A PROPOSAL FOR BEACH STABILIZATION

From the historical analysis presented it is hard to accept that the proposal for beach stabilization in San Benito was the construction of more structures. It could seem that the removal of all these structures may be sufficient to get the beach back to its previous state, but the port breakwaters, which are the original cause of all the degradation of the system, cannot be removed as the port activities are so important. This means that, in terms of Coastal Management, the port area can be classified as a politically managed area and there are no technical or scientific arguments against that. However, as the problem has been transferred downdrift and as San Benito town has been placed at high risk, some action needs to be taken, preferably involving a combination of soft and hard engineering works. The following sections describe these options.

Section 1

The beach in this section is long and straight, so a hard solution is not considered suitable. A soft solution combining proper Coastal Management and monitoring would be sufficient to stabilize this section. The only condition that must be ensured is that sediment from the Sections 2 and 3 can get to Section 1, thus re-establishing its sediment supply. It is expected that adding sand artificially to the entire system would enhance natural sand bypassing from groin 18. After that, if the monitoring shows that a more robust solution is needed, a group of small nearshore breakwaters could be constructed.

Section 2

This section presents more variability due to the effect of groins 17 and 18. The proposal here is to remove groin 17 as its performance has shown to cause more damage than benefits. This groin would be substituted by structures detailed below, as part of Section 3. A second proposal is to artificially nourish the beach, to let the beach shaped itself and to allow the sand to settle naturally. If the volume of sand is large enough, the sand might bypass groin 18. A possible sediment source for this nourishment is the beach to the east of the harbour (artificial bypass). It would also be desirable to restore the coastal dune in this area in order to protect the population from the destruction that the erosion is causing and re-establish partially the ecological services.

Section 3

The solution proposed for this section is the construction of two structures and a beach nourishment programme. The first breakwater would substitute groin 17 with an L-shaped structure, one arm perpendicular to the coast, 200 m long; the other, parallel to coastline, and also 200 m long. This configuration would move the diffraction point, letting the sand of the beach nourishment be distributed so that a crenulated beach is formed over time. This is a widely used manner of stabilizing beaches (see for example Silvester and Ho, 1972). The second structure would be a detached breakwater, parallel to the coastline, which would control the wave energy without interrupting the LST. In turn, given that the rocky defence has reduced erosion, all the other groins should be removed.

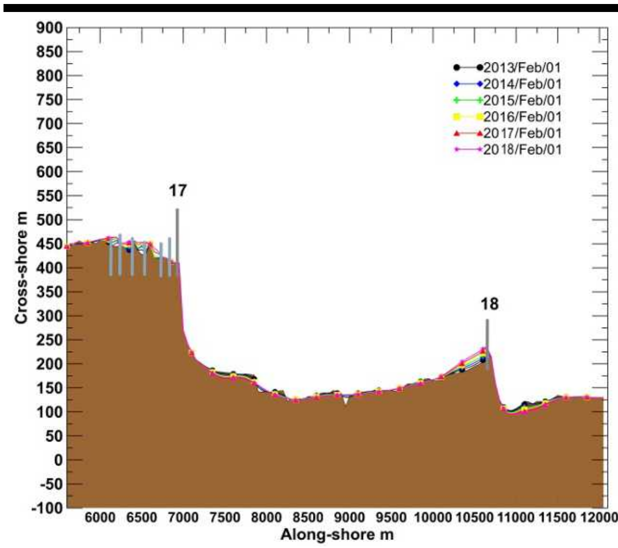

Figure 12. Five years modeling with the actual condition of the beach.

The GENESIS model (Hanson and Kraus, 1989) was used to numerically evaluate the proposal. Figure 12 shows the results of a 5 year modelling of the whole study area under present conditions, showing that the erosion trend will continue in Sections 1 and 2 with the exception of the sand trapped by the groins. The area protected by the rocky defence shows a little accretion. It is worth pointing out that the wave conditions modelled include some mild tropical storms and cold fronts but no extreme events.

Figure 13 shows the modelled results of the proposal over ten years. Beach stabilization is achieved in Section 3 overall, with some accretion. Section 2 has also been stabilized. Groin 18 generates accretion as it interrupts the LST but the erosion downdrift is limited. Proper monitoring may show whether groin 18 can be safely removed or if it is still needed to keep the beach stable.

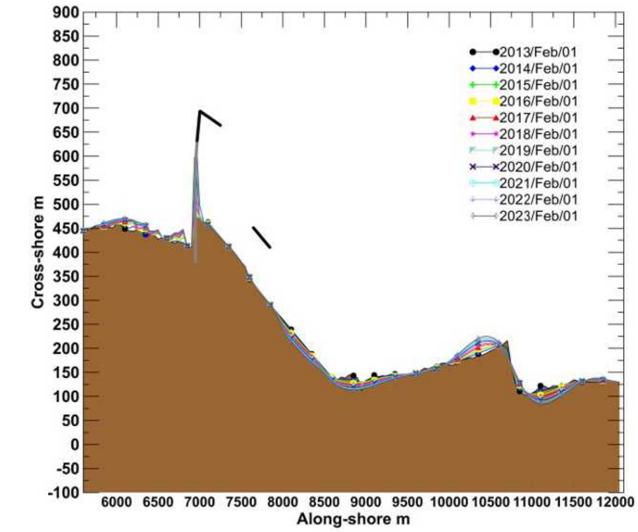

Figure 13. Ten years modeling with the proposed solution.

Although the numerical model predicts stabilization, and as no extreme events were considered, the beach state can be considered as metastable; this means that the beach may need re-nourishment after severe storms.

The shoreline east of the port will continue moving seawards as no intervention is planned there, so it is strongly recommended to periodically take sand from this site and deposit it west of the structure substituting groin 17 in order to allow its distribution along the beach.

DISCUSSION AND CONCLUSIONS

The erosion problems at San Benito have damaged the beach over nearly forty years, but as the activities of the port are so vital to the socio-economic wellbeing of the area, any solution must favour the coexistence of human activities and the coastal system.

The diagnostics of the San Benito beach system show that two sections are unstable and historical records verify that the shoreline has being losing sediment even in the absence of extreme storms. According to Gonzalez and Medina (2001), a limiting shape, known as static equilibrium is reached when a coastline retreats, but here the changes made by building the breakwaters have altered the dynamic equilibrium, interrupting LST and producing an artificial sediment deficit.

Although San Benito beach is not a natural crenulated bay, it can be turned into one as some rigid features already exist and therefore the beach can be stabilized.

Beach and dune nourishment are widely used techniques but they cannot solve a coastal erosion problem by themselves. Carter (1988) defined the term ‘quiet revolution’ to refer to the situations in which hard engineering works transfer the problem to adjacent beaches and stated that the best way to deal with these scenarios is to design a maintenance plan for beach nourishment. This is what the authors suggest for San Benito Beach. The system needs a strict Coastal Zone Management plan. McKenna *et al*., (2000) highlighted the way that humans have altered beaches and explained the advantages of collaborative and community-based approaches, which focus on involving all the actors with interests in a particular coastal area in decision-making processes, as the path to ensure the best practices of exploitation and conservation of beach systems. The success of the solution proposed here depends on good coastal management and on the participation of as many users as possible to keep the beach in a sound state.

ACKNOWLEDGMENTS

This publication is one of the results of the Latin American Regional Network global collaborative project "EXCEED - Excellence Center for Development Cooperation – Sustainable Water Management in Developing Countries" consisting of 35 universities and research centres from 18 countries on 4 continents. The authors would like to acknowledge the support of the German Academic Exchange Service DAAD, the Centro de Tecnologia e Geociências da Universidade Federal de Pernambuco, the Fundação de Amparo a Ciência e Tecnologia do Estado de Pernambuco-FACEPE and the Instituto de Ingeniería of the Universidad Nacional Autónoma de México for their participation in this EXCEED Project.

LITERATURE CITED

Basco, D.R., 2001. Shore protection projects. *In*: *Coastal Engineering Manual, Part V Coastal Project Planning and Design, Chapter V-3, Engineer Manual 1110-2-1100*, U.S. Army Corps of Engineers, Washington, DC.

Carter, R.W.G., 1988. *Coastal Environments – An introduction to the Physical, Ecological and Cultural Systems of Coastlines*. Academic Press, London, 617 pp.

González, M., and Medina, R., 2001. On the application of static equilibrium bay formulations to natural and man-made beaches. *Coastal Engineering* 43, 209-225.

Hanson, H. and Kraus, N.C., 1989. GENESIS: *Generalized Model for Simulating Shoreline Change*. Vicksburg, Mississippi: U.S. Army Engineer Waterways Experiment Station, 247 pp.

Kamphuis, J.W., 1991. Alongshore sediment transport rate distribution. In. N.C. Kraus, K.J. Ginge and D.L. Kriebel (eds.). *Coastal Sediments '91, American Society of Civil Engineers*, (New York, USA), pp. 170-183.

Martínez, M.; Mendoza-Gonzalez, G.; Silva, R., and Mendoza, E., 2014. Land use changes and sea level rise may induce a "coastal squeeze" on the coasts of Veracruz, Mexico. *Global Environmental Change* (in print).

McKenna, J.; MacLeod, M.; Power, J., and Cooper, A., 2000. *Rural beach management a good practice guide*. Donegal County Council, Lifford, Co. Donegal Ireland, Donegal, 109 pp.

Ruiz, G.; Silva, R.; Posada, G.; Pérez, D.M., and Bautista, E.G., 2009. Modelo híbrido para la caracterización de oleaje. *Ingeniería Hidráulica en México*, XXIV(3), 5-22.

Silva, R.; Baquerizo, A.; Losada, M., and Mendoza, E., 2010. Hydrodynamics of a headland-bay beach-nearshore current circulation. *Coastal Engineering*, 57, 160-175.

Silva, R.; Borthwick, A., and Taylor, R., 2005. Numerical implementation of the harmonic modified mild-slope equation. *Coastal Engineering*, 52, 391-407.

Silva, R.; Martínez, M.A.; Hesp, P.; Catalan, P.; Osorio, A. F.; Martell, R.; Fossati, M.; Miot da Silva, G.; Mariño-Tapia, I.; Pereira, P.; Cienfuegos, R.; Klein, A.; Govaere, G., 2014. Present and future challenges of coastal erosion in Latin America. *In:* Silva, R., and Strusińska-Correia, A. (eds.), *Coastal Erosion and Management along Developing Coasts: Selected Cases,* Journal of Coastal Research, Special Issue, No. 71, p. 1–16. Coconut Creek (Florida).

Silvester, R. and Ho, S., 1972. Use of crenulate shaped bays to stabilize coasts. *Proceedings of the 13th International Conference on Coastal Engineering 1972* (Vancouver, Canda), p. 1347-1365.

Syvitski,J.P.M. and Milliman,J.D., 2007. Geology, geography, and humans battle for dominance over the delivery of fluvial sediment to the coastal ocean. *Geology*, 115, 1-19.