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Nature-Based Solutions & Engineered Infrastructure for Risk Reduction in Coastal Areas

A Case Study in Corinto, Nicaragua

Written By:

Ahmed Al Ramady	*11131791*
Amir Kaddoura	*11131720*
Louisa Jahn	*11134427*
Monica Pandey	*11131574*
Paula Perez	*11134436*
Raghid Shehayeb	*11132579*

Supervised By: *Dr. Udo Nehren, and Jasna Wiedemeier*

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Table of Contents

1 Abstract 5
2 Introduction 5
3 Characteristics of the study area 7
3.1 Geographical location 7
3.2 Demographic and socio-economic characteristics 7
3.3 Climate of Corinto 9
3.4 Climate variability 12
3.5 Natural disasters and its impact 13
3.6 Soil in Corinto 15
3.7 Ecosystems of Corinto 16
3.8 Policies and programs 17
3.8.1 Policy specific to the coastal zones 17
3.8.2 Other environmental policies 18
3.8.3 Programs for environmental conservation 18
4 Background: Coastal erosion and existing protection measures 19
4.1 Infrastructure for coastal protection 19
4.1.1 Breakwater and dykes 19
4.1.2 Geotubes 21
4.2 Mangroves for coastal protection 24
4.2.1 Function of mangroves in coastal protection 24
4.3 Reducing erosion & binding soil 25
4.3.1 Mangrove cover in Corinto 26
4.3.2 “Protege tu Mangle” 27
5 Rationale of the study 28
6 Objectives 29
7 Methodology 29
8 Results 30
8.1 The Coastal protection approaches in Corinto 30
8.1.1 Infrastructure and coastal protection 30
8.1.2 Mangroves and coastal protection 30
8.2 Implementing ICZM in Corinto based on Netherlands best practice 30
9 Discussion and recommendations 34

9.1 Success indicators for Geotubes....34
9.2 Success indicators for mangroves....35
9.3 Implementation of coastal zoning....36
10 Conclusion....39
11 Limitations....39
12 References....40

List of Tables

Table 1-Mangroves in Corinto areas 26
Table 2-Monitoring schedule for mangrove restoration projects 36

List of Figures

Figure 1-Location map of Corinto 7
Figure 2-Poverty level in Corinto 8
Figure 3a-Average annual precipitation 9
Figure 3b- Average monthly precipitation in Corinto from 2005-2017 10
Figure 3c-Average annual precipitation 10
Figure 4a-Average Monthly Temperature in Corinto and Al Realejo 1960-1990 10
Figure 4b- Average Annual Temperature in Corinto and Al Realejo 1965-1978 10
Figure 5-Natural disasters in Corinto timeline 13
Figure 6-Tide-gauge record of the 1992 Nicaragua tsunami from the port of Corinto, within an embankment 14
Figure 7-Excess Rain fall during Hurricane Mitch, where light color bars represent the precipitation in October 2008, dark bars represent historical average in october 14
Figure 8-Soil Distribution in Corinto and Al Realejo 15
Figure 9-Construction of the Groyne (Breakwater) at Corinto (1993) 20
Figure 10-Reinforcement of the Sand Dam (Dyke) begins in Corinto (Nov. 2010) 20
Figure 11-Cross-sectional view of the pyramid designed geotubes. 21
Figure 12-Cross-sectional view of the submerged offshore geotube and the onshore geotube. 22
Figure 13a-Geotubes technical sheet 23
Figure 13b- Geotubes arrival in Corinto 23
Figure 13c- Geotubes location and technical data 23
Figure 14-Map showing the impact of coastal erosion on the original village of Egmond aan Zee, North Holland over the past centuries (de Ruig, 1998). 31
Figure 15-Sand Dunes Zone in Egmond aan Zee, Netherlands 32
Figure 16-failure of Geotubes at Candolim beach in India. 34
Figure 17-Image of the southwest end of the Pirates Beach geotube project and the northeast end of Galveston Island State Park along the gulf of mexico , arrows represent the beach's width) 35

Figure 18-Methodology to approach an ICZM process. Modified after 37

1 Abstract

Coastal areas are under a constant pressure due to the impacts of climate change and consequences of drastic land use transformation. In Corinto, Nicaragua two different measures have been adopted in order to cope with these challenges. On the one hand there is an engineered-based solution, namely the implementation of Geotubes to diminish coastal erosion, losses of housing; the second is restoration of the natural mangrove ecosystem which protects the coast also from erosion, as well as flooding and provides other ecosystem services. The study assesses the success and improvement strategies of these two measures as well as the possibility to integrate them. The lack of enough data to be analyzed and of institutional capacities in Corinto were the reasons to develop a recommended monitoring scheme for the success analysis of the erosion-prevention methods. The Netherlands were used as an example of good practices due to their widely known culture of Integrated Coastal Zone Management.

Key words: Coastal protection, Coastal engineering, Shore protection, Ecosystem disturbance, Ecological engineering, Geotubes, Mangroves, ICZM, coastal zone management.

2 Introduction

Coastal areas belong to the world's most rich and productive ecosystems, providing various services from food to resources for trading. The Republic of Nicaragua, here onwards Nicaragua, is the largest country in Central America with the Caribbean Sea in the east and the Pacific Ocean in the west. It has three major zones; Pacific lowland, Central highlands and Caribbean lowlands. Corinto, the study area, is a small peninsula in the Northwest Pacific coastline of the country as shown in Figure 1. (Encyclopedia Britannica, 2012). The coastal area in Corinto comprises various ecosystems providing different services. For instance, sandy beaches are used for recreational purposes and mangrove ecosystems are used for timber and fuelwood. The port located on the coast of Corinto is the largest and most important one for local as well as the country's economy (ENSOME, 2018).

However, the coastal areas in Corinto and around the world, are under severe threat for degradation. With the services they provide, it is inevitable that the pressure upon them increases proportionally with the population growth (Goudarzi, 2006). Migration and settlement of humans on coastal areas is highly sought-after, yet development takes place in an unsustainable way, leading to overuse and exploitation of natural resources that protect coasts and so is the case in Corinto (Martinez Arteaga, 2016). Additionally, there is the climate change factor that is pressuring the worlds coasts; an acceleration in the rise of the sea level mainly due to the human-induced global warming is putting the coastal zones of the world in a vulnerable position (Mengel *et al.*, 2016). All these natural as well as anthropogenic factors are also significantly causing coastal erosion and several problems affecting people and ecosystem (Sistermans and Nieuwenhuis, 2004).

Uncontrolled activities leading to accelerated erosion and degradation of coasts indicate that the traditional "sectoral" approach regarding the management of coastal zones is not contributing to its preservation. There is need for a cross-sectoral approach that considers sustainable management of coastal regions (Cooper, O'Connor and McIvor, 2016). In order to address unsustainable practices and achieve sustainable development, the concept of Integrated Coastal Zone Management (ICZM) approach was originated at the Summit on Environment and Global Development in Rio de Janeiro, 1992 (Cuong and Cu, 2014).

"ICZM is a process of governance and consists of legal and institutional framework necessary to ensure that development and management plans for coastal zones are integrated with environmental (including social) goals and are made with the participation of those affected" (Post and Lundin, 1996). It is a continuous process of balancing ecosystem and coast-economy, therefore, includes all stakeholders across different sectors seeking for most appropriate action (European Commission, 2016). A crucial component of an ICZM approach is the proper coastal zoning established at the beginning of the process. Coastal (environmental) zoning is a technical tool useful for the planning and supporting of environmental management, zoning helps to identify efficient management measures and the most appropriate type of activities for the specific coastal zones (Rojas Giraldo *et al.*, 2010).

During the UN Conference in Rio 1992 "Agenda 21" the Nicaraguan government acceded to commit to the "Integrated Management and Sustainable Development of Coastal areas and the Marine Environment under their national jurisdiction". In practice this means:

- Supporting an integrated policy and decision-making process, involving all related sectors
- Recognizing current and potential uses of coastal areas and their interactions
- Implementing preventive and precautionary approaches in project life cycle
- Making relevant data publicly accessible for individuals and stakeholders to ensure their participation and involvement in decision-making.

3 Characteristics of the study area

3.1 Geographical location

Corinto extends over an area of 70.67 square km and is located in 12°29´ North and 87°10´ West. It lies 2.44 meters above sea level (INIDE, 2006). Geologically, Nicaragua lies in a subduction zone between oceanic and continental tectonic plates, denoting high seismic and volcanic activities, which also include Corinto and its surrounding. Thus, coastal geomorphological character of Corinto represents alluvial deposits covering old volcanic rocks. Corinto island is united to the mainland through two different bridges and belong to the province of Chinandega. The municipality of Corinto is in the Department of Chinandega. The location map is shown in Figure 1. Its coastal geomorphology is represented by El Realejo east, mangrove area in west and small hill of 10 meters high south (ENSOME, 2018).

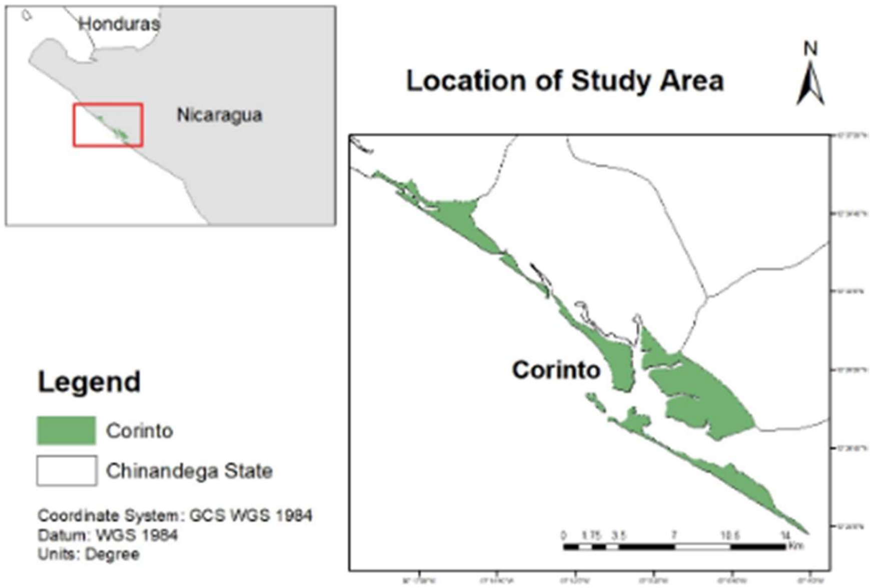

Figure 1-Location map of Corinto (DIVA-GIS, 2019)

3.2 Demographic and socio-economic characteristics

The current population is 18,392 with composition of 52.26% women and the remaining 47.74% are men (INIDE, 2018). Census data shows that 25% of the population are aged between 12 to 25 years, while infant population forms 30% of the total population (INIDE, 2005).

There are two main economic activities important for Corinto: trade and fishery (Wiedermeier, 2019). However, it is a poor region in Nicaragua and most of its inhabitants live in poverty, varying from extreme (in pink) to low poverty (yellow) as shown in Figure 2. Only 5,227 people represent economically active population, and unemployment is a current crucial problem. However, data on unemployment rate are unknown (INIDE, 2006). Correspondingly, social problems like prostitution, high consumption of alcohol and narcotics by young people are also prominent and most are related to port area. However exact percentage data of the population with this problem is unavailable (Martinez Arteaga, 2016).

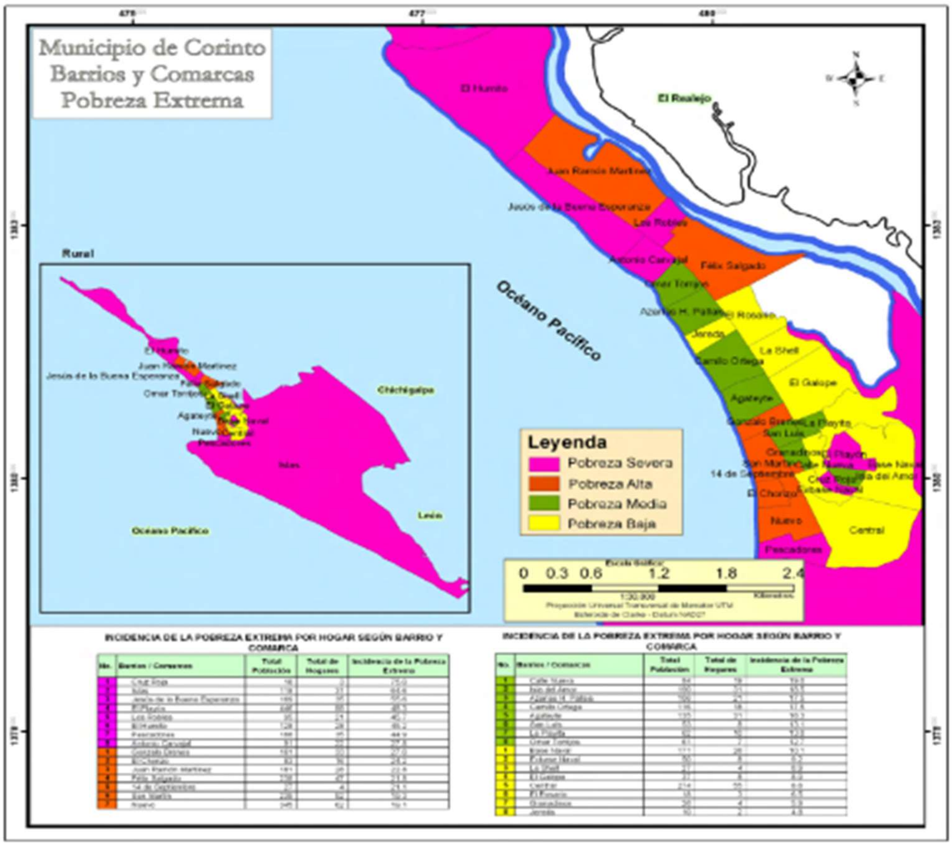

Figure 2-Poverty level in Corinto (INIDE, 2008)

Corinto's port has been highly important for the Nicaraguan economy since its establishment in 1858. The previous port was located around El Realejo, the neighboring municipality, which was highly sanded up due to the activities of the former port "Puerto de la Posesión". Since Corinto has a better geographic location and accessibility, the port was constructed here (ENSOME, 2018). The port created job opportunities and construction of infrastructure like warehouses kicked off to support port activities. This is also one of the reasons for the presence of the varied mosaic of Corinto's population. Till date it is the most important port of Nicaragua, two thirds of all the country's maritime imports and exports are being carried out from it. However, now there are almost no free zone no land to build more warehouses and thus is limiting creation of job opportunities in the area (Martinez Arteaga, 2019).

3.3 Climate of Corinto

According to the Köppen Climate Classification System, Corinto & El Realejo can be considered within the Aw climate zone which is Tropical wet & dry or Savanna climate (ENSOME, 2018). An average annual precipitation in Corinto is between 1200 to 2200 mm/year Figure 3a. Along the Pacific Coast region of Nicaragua, the wet season generally lasts from May to November, and the dry season generally lasts from December to April and so is the case in Corinto Figure 3b. However, at extreme precipitation, values between 300 and 500 mm can occur in a 24-hour period, especially, in the areas of León, Chinandega and Corinto.

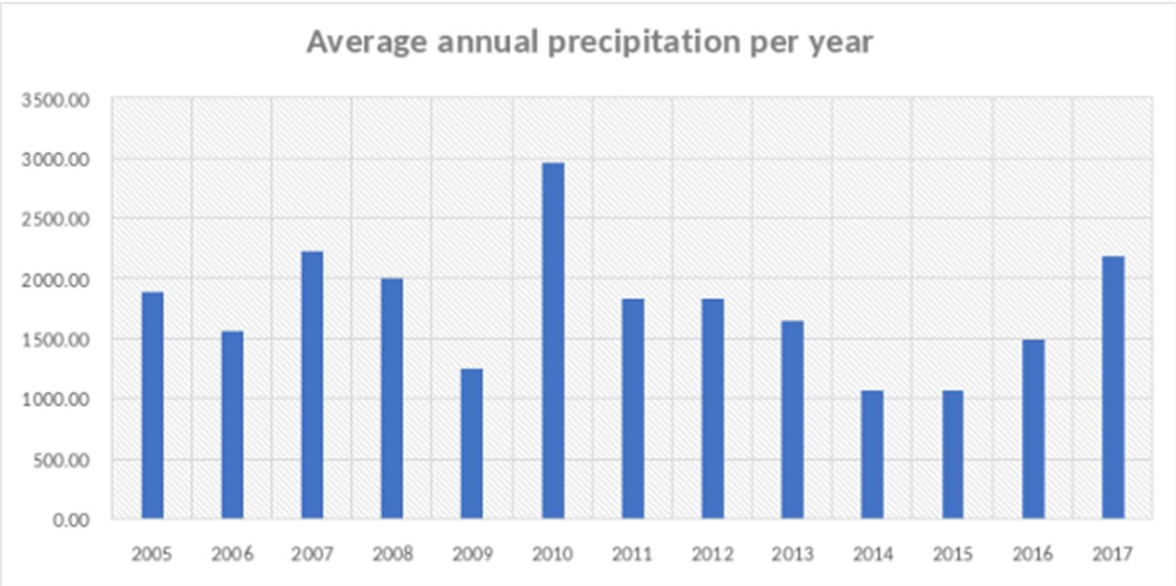

Figure 3a-Average annual precipitation (INIDE, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017)

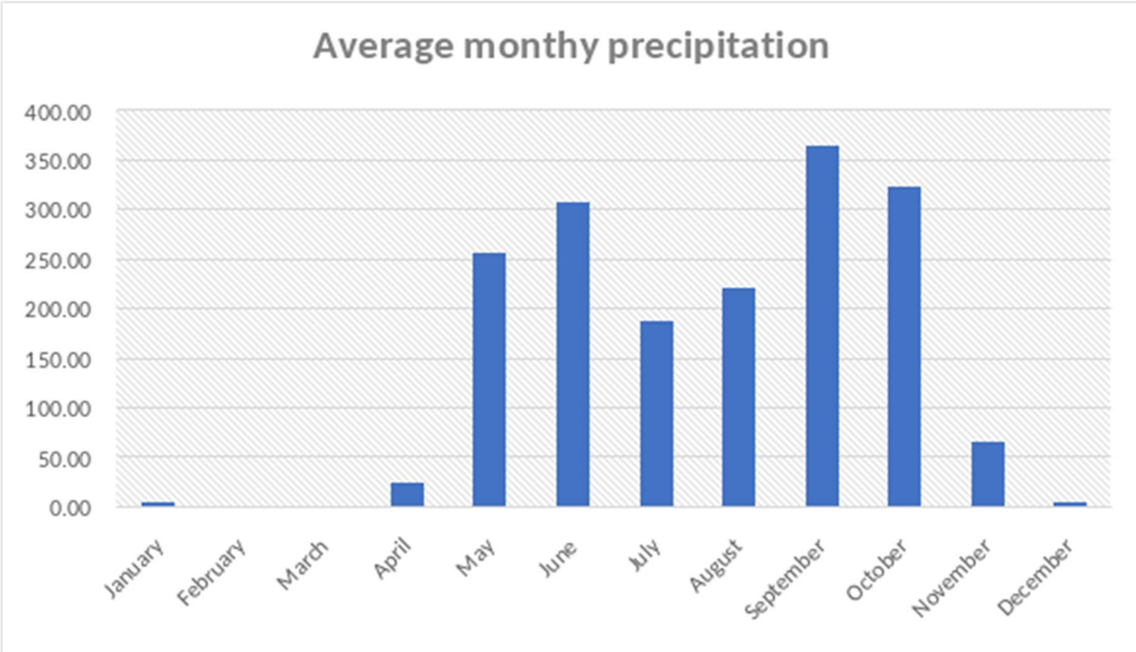

Figure 3b -Average monthly precipitation in Corinto from 2005-2017 Source: (INIDE, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017)

Temperature differential is minimal from season to season with an average annual of 27 °C as shown in Figure 4a and Figure 4 b shows average annual temperature by location, where coastal areas have slightly higher temperature than inland area.

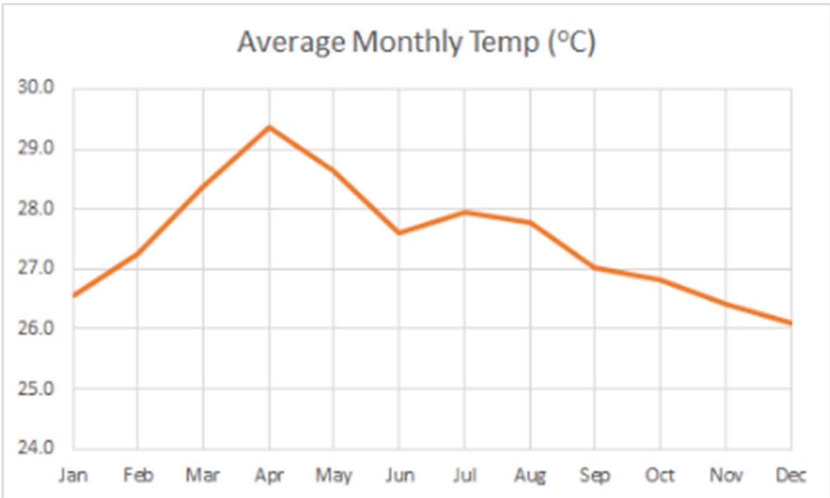

Figure 4a-Average Monthly Temperature in Corinto and Al Realejo 1960-1990 (WorldClim, 2005)

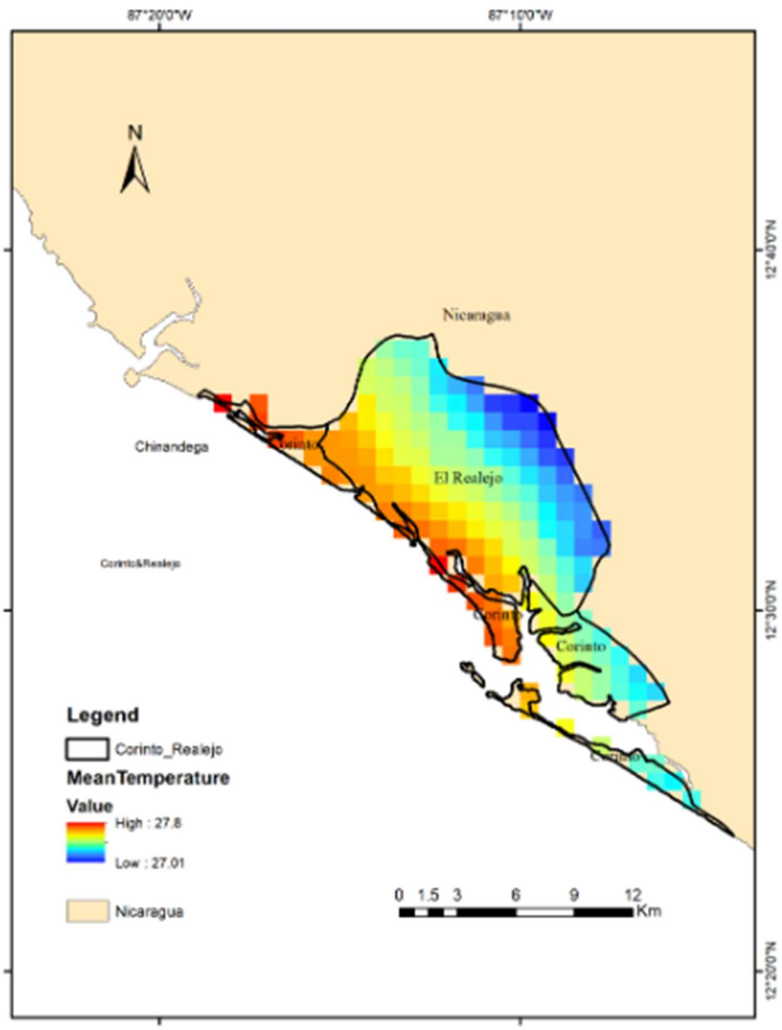

Figure 4 b-Average Annual Temperature in Corinto and Al Realejo 1965-1978 (Hijmans et al., 2005)

In Nicaraguan coasts, wind generally flows eastwards throughout the year, but in the coastal area of Corinto, wind flow has a special direction of south and southwest over the period from May to November. However, records from Corinto station between 2008 to 2017 showed different trend in direction i.e. from North to northwest from January to March and then south and southwest from April to December with different speed ranging from 3.7 m/s to a maximum of 7 m/s (ENSOME, 2018).

3.4 Climate variability

Increase in atmospheric greenhouse gas concentrations has brought changes in the normal climatic conditions around the world and coasts are among the vulnerable zones to suffer from the impact (Sistermans and Nieuwenhuis, 2004). There are significant indicators for climate change and its impact on Nicaragua, when compared to the average historic climate in the country which has caused a number of disaster events. These events are mostly driven by the Intertropical Convergence Zone (ICZ), El Niño Southern Oscillation (ENSO) and La Niña. El Niño, which is also known as warm deviations, often occurs every four to seven years and lasts from 12 to 18 months (UNDP, 2013). Both El Niño and La Niña occurs between June and August making a variation in air circulation, precipitation and temperatures along the tropical Pacific and can lead to climate hazards such as droughts, heavy rainfall, floods and landslides (UNDP, 2013).

The last time the country was affected severely by El Niño was during the winter of 1997-1998, by La Niña in the winter of 2010-2011. La Niña years tend to increase average rainfall and thereby heighten the chances of severe floods. It is noteworthy that heavy rainfall and floods can occur very far from the center of a tropical storm (UNDP, 2013).

Along the Pacific Coast region of Nicaragua, the wet season generally lasts from May to November, and the dry season generally lasts from December to April. Apart from the regular dry periods, from November to April and from mid-July to mid-August (canícula or midsummer drought), the Pacific and central regions are often subject to irregular dry periods as a result of a decrease of precipitation by 35 % especially at the pacific and central regions. The period of drought can last some days or weeks and are always related to El Niño years, the most severe years were 1972, 1976 to 1977, 1991, 1992, 1993 and 1997 (UNDP, 2013).

Additionally, climate change has caused sea-level rise and aggravated storminess, both resulting in coastal erosion and flooding (Masselink & Gehrels, 2014). In Corinto, during the last 5 years, frequency of hurricanes or storms in the Pacific Ocean has increased, affecting Corinto more intensely. Twenty years ago, coasts were affected by tides that were more than 9.0 feet high, mainly in the months of October but now the occurrence period has been extended by 3-4 months with the same or even more tidal height (Martinez Arteaga, 2019).

The average temperatures across Nicaragua have increased by about 0.9° C since 1960, which is slightly higher than global average warming. Rainfall has decreased by about 5 to 6 % per decade, but heavy rainfall (high intensity rainfall) events have increased. The frequency of hot days and hot nights increased by 16.4% and 11.7%, respectively, between 1960 and 2003. The number of cold days and nights has decreased. For the Pacific coastline, they project a 0.13 m to 0.51 m increase by 2090 relative to 1980–1999 sea levels (UNDP, 2013).

3.5 Natural disasters and its impact

Nicaragua was ranked as the third most affected country regarding extreme climate threats leading to injuries, death and economical damages (UNDP, 2013). Figure 5 shows the timeline of the natural disaster that affected Corinto since 1976.

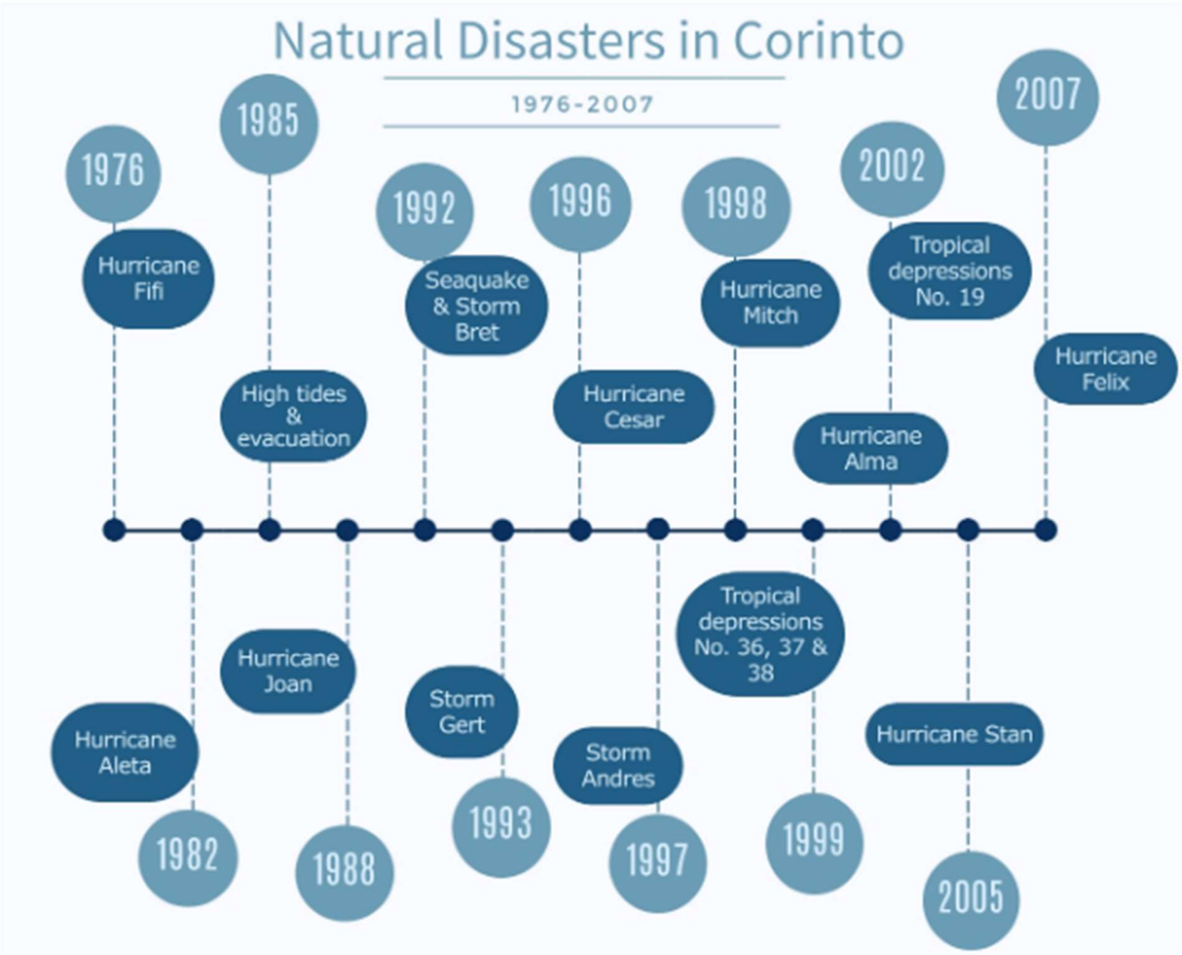

Figure 5-Natural disasters in Corinto timeline (Martinez Arteaga, 2019)

These natural disasters are also the causes of erosion in coastal area in Nicaragua (Higman and Bourgeois, 2008). As the lower parts of the beaches are flooded with every tide, tons of sediment are taken to the coastal strip annually by wind and water (Masselink and Gehrels, 2014).

In 1992, an earthquake of 7.7 magnitude hit Nicaragua which led to a tsunami of 4 to 6 m, causing enormous damage of life and property along about 200 km of the Nicaraguan coast. In Corinto harbor, single large wave with half meter on tide gauge was recorded with 2–4 m at the same latitude on the open coast. The tsunami over-topped and eroded an artificial sand barrier in northern town (community of

Barrio Nuevo) and deposited 100 m or more landward barrier to the shoreline as shown in Figure 6. (Higman and Bourgeois, 2008)

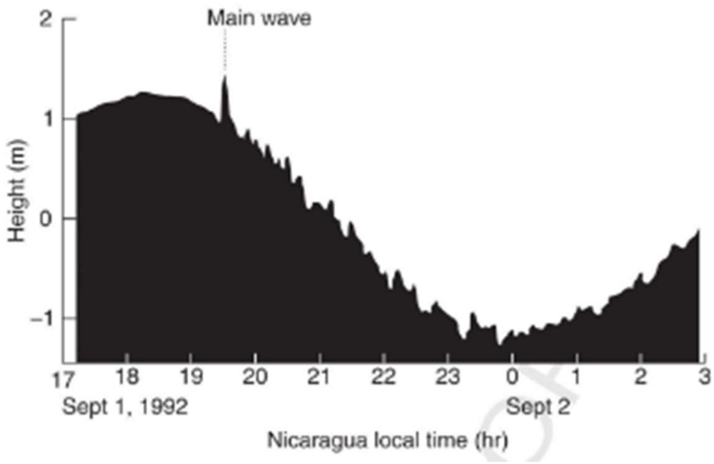

Figure 6-Tide-gauge record of the 1992 Nicaragua tsunami from the port of Corinto, within an embankment (Higman and Bourgeois, 2008)

Later in 1998, Nicaragua was again hardly struck by Hurricane Mitch, originated from Atlantic. Figure 7 shows the excess precipitation during the event compared to the historical average in different areas. It was the most devastating which killed more than 3000 people and affected more than 800 thousand people and cause economic damage of 987.7 million USD (UNDP, 2013). In Chinandega, for example, rainfall increased by more than five times the historical average and thus Corinto and Chinandega were among the highly affected area (ECLAC, 1999).

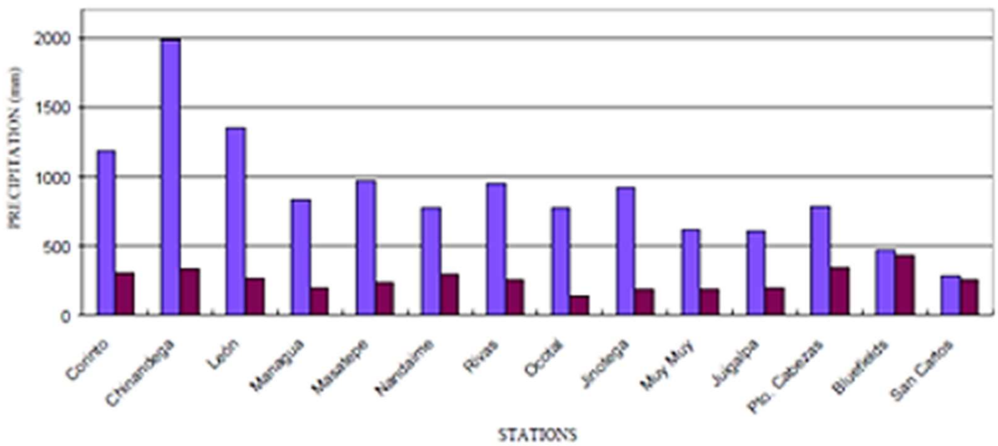

Figure 7-Excess Rain fall during Hurricane Mitch, where light color bars represent the precipitation in October 2008, dark bars represent historical average in October (UNDP, 2013)

3.6 Soil in Corinto

There are two types of soil dominantly found in Corinto: Vertisols and Andisols. As shown in Figure 8, coastal area including the port area is dominated by Vertisol soil type while inland consist of Andisol soil type.

Figure 8-Soil Distribution in Corinto and Al Realejo (FAO, 2006)

The local name used for Vertisols in Nicaragua is 'Sonsosuite'. Vertisols are characterized by clayey soil which shrinks when dry and swell when moistened and therefore wide cracks can often be sighted. Soil moisture regimes in Vertisol can vary with ustic, aridic, udic and xeric and soil temperature regimes that are cryic and warmer. Once the soil is thoroughly wetted and the cracks are closed the rate of water infiltration becomes almost zero (USDA NRCS, 1999). Corinto Port is classified as a sandy coast, the beaches consist of sand deposited by the tide and silty clay soil in low lying coastal areas. Between January and April, Pacific region is relatively dry with precipitation of 97.8 mm (recorded in 2015) while in wet months more than 2500 mm can occur. This makes beaches of Corinto prone to water erosion. Also, in dry period maximum wind speed surface reaching up to 55 km/h occurs thus causing erosion with great ease by the effect of waves and wind currents (ENSOME, 2018).

Andisols can be found along the Pacific Ring of Fire which has active tectonic zones and volcanic area and Nicaragua lies in such zone. It contains pyroclastic material like mixture of volcanic ashes, stones and gases and can have any soil moisture and soil temperature regime. The upper layer has about 60% andic soil properties which is rich in nutrient and mineral like imogolite, ferrihydrite, or aluminum-humus complexes. It has good internal drainage, high porosity, high water infiltration, good aggregate stability so, translocation of compound is usually minimal. These components are very suitable for agricultural activities. (USDA NRCS, 1999). However, the population growth and unsustainable urban infrastructure expansion have changed the land use system causing intensive deterioration of soil quality and productivity potential. Moreover, many of these houses have been built in unsuitable locations with high disaster risks and without proper sanitation services (ENSOME, 2018).

3.7 Ecosystems of Corinto

Corinto island has diverse ecosystems which are mangrove, estuarine, beaches and marine ecosystems (González P., 1997). Almost two third of Corinto is occupied by mangroves and sandy beaches, making mangroves one of the most present ecosystem in the island while the rest areas are left for urban and port use (González P., 1997; Umanzor and Cant, 2002). Mangrove ecosystem has high ecological, social, and economic value. In addition to providing habitat for different species, it protects people living near the coast from hazards like storms, floods, and natural disasters, and provides substrate for shrimp farming, and thus helps in generating notable revenues.

Next to mangroves, estuaries are also considered as an important ecosystem in that area. They act as transitional zones for the coast and they thrive with biomass production and species diversity. Same as mangroves, estuaries ecosystem also has a high social, ecological, and economical value, and is very crucial to nearby ecosystems such as mangroves and beaches. Unfortunately, both mangroves and estuaries are usually exploited for timber, and firewood, without any supervision or protection from concerned authorities (González P., 1997).

The beaches in the North Pacific shores of Nicaragua are generally used for tourism in summer, and Corinto's sandy beach is no exception where it is primarily used for recreational purposes. Yet, it is critical to mention that the beach ecosystem has considerably lost some of its functions like protection from natural disasters because of unplanned constructions and alteration in its infrastructure. Besides, Corinto has the biggest port in Nicaragua, making its bay ecosystem one of the most valuable in the country. Its bay is also used by small-scale fishers as well as by industries for the anchoring of their ships (González P., 1997).

Other marine ecosystems in the study area include marshes and tidal flats. Marshes are surfaces covered with water, whether natural or artificial, permanent or temporary, stagnant or running, sweet, brackish or salty, including seawater extensions whose depth at low tide does not exceed six meters. They also include their riparian zones or adjacent coasts, as well as islands or extensions of seawater of a depth greater than six meters at low tide, when they are inside the wetland. Tidal flats are coastal wetlands that form the area between the tides, with sediment deposition from rivers (González P., 1997; ENSOME, 2018).

3.8 Policies and programs

The main environmental law in Nicaragua is the Law No.217 formulated in 1996 with an objective to establish norms for the conservation, protection, management, improvement, and restoration of the environment and natural resources, securing the rational and sustainable use of this resources as mention on the Constitution of Nicaragua. Specific to coastal development, Law No.690 is the main and its objective is the recognition of the rational use of the coast natural resources for economic development. It defines the coastal zones into 3 categories depending on their use: 1) coastal zone for public use, 2) coastal zone of restricted use and 3) coastal zone of community use. The third category only applies in the Autonomous Atlantic Region of Nicaragua where indigenous communities are strongly represented. The commission for National Development of Coastal Zones (CDZC) is established under this law, which is the technical institution to oversee the consultation and coordination between the different governmental institutions.

3.8.1 Policy specific to the coastal zones

According to the Corinto Municipality (Martinez Arteaga, 2019), the division of the coastal zones in Corinto is according to the Law No 690 “Development of Coastal Zones”. The Article 19 considers Corinto under “special cases” since it is an island (see below). According to this law, the coasts of Nicaragua are divided into two different zones depending on its uses:

i. Coastal zone of public use:

It is maritime or lacustric beaches under exclusive property rights to the state. In the case of Corinto, it refers to the area between maximum level of high tide (historic average) and five meters inland. This zone is designated for these purposes: touristic development at the beaches; practice of recreational sports; lifesaving, public pedestrians’ access, temporary and removable infrastructure; and vehicle access only for surveillance, lifeguarding and sanitation authorities.

ii. Coastal zone of restricted use:

This area encompasses the land between the end of the “Zone of public use” and 200 meters inland. The allowed activities in this zone are construction and management of touristic services with permanent infrastructure; construction of berths for marine tourism; construction of housing for families and recreational uses; and subsistence agriculture. All the legally protected areas are excluded from this regulation.

3.8.2 Other environmental policies

Additionally, other laws mentioned below have an important role for the protection of the environment in Nicaragua:

- Law No.337 of 2000, created the national system for prevention, mitigation and assessment for disasters.
- Decree No.14 of 1999, establish the regulation for protected areas.
- Decree No.9 of 1996, establish the general regulation for the environmental and natural resources.
- Law No. 462, establish the law for conservation, promotion and sustainable development of the forest sector.
- Law No. 489, Law for fishing and aquaculture.
- Law for agriculture
- Law No.620, General regulation for water and decree No.44 – 2010, establish the norms for all water resources administration, conversation, development, use, sustainable use, equity, quality and quantity preservation.

3.8.3 Programs for environmental conservation

In addition to existing laws, Nicaragua is involved in two important programs to reduce emissions from deforestation, and have an interest in restoring forest, and applying sustainable practices of forest management. The first program is REDD+ (Reducing emissions from deforestation and forest degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries) in partnership with Forest Carbon, and the second program is ERPD (Programa de Reducción de Emisiones para el combate al cambio climático y la pobreza en la Costa Caribe, Reserva de Biosfera BOSAWAS y Reserva Biológica Indio Maíz) in partnership with the Carbon Fund (Forest Carbon Partnership Facility, 2019).

In 1997, the Ministry of Environment and Natural Resources (MANRENA) proposed the first draft for plan for sustainable management of coastal resources of Nicaragua called “MaizCo” (MARENA, 1997); also, in cooperation with the Governments of the Netherlands and Denmark. First, the coastal zones status was diagnosed according to ecological problems, social indicators, economic diagnosis and institutional management capacity. Civil society were involved in the planning process and the recommendations collected were used as guideline to form an action plan and thus, specific areas where chosen for pilot management. However, the project could not be implemented as there was lack of coordination between different stakeholders, insufficiency in legal and institutional terms, unsustainable use of natural resources, non-balanced socio-economic development. This reflects some problems that makes difficult the implementation of ICZM approach in Corinto.

4 Background: Coastal erosion and existing protection measures

Beginning in the 1990s the first documented impacts of coastal erosion and accretion started in Corinto. Both erosion and accretion result from the interaction between the natural movements of sand northward along the Pacific coast (ENSOME, 2018). Erosive processes, both on the seabed or on the beach, are a consequence of waves and currents of high tides during disasters like storm surges, on the beach and tows sediment in the port area (ENSOME, 2018). Moreover, climate change phenomena with adverse disasters, seal level rise, increasing temperature and rainfall, together with anthropogenic activities also triggers erosion. In addition to this, erosion due to deforestation is also very prominent (Webster and Roebuck, 2001).

To mitigate the erosion and other coastal environmental problems in Corinto, various engineered and nature-based measures had been developed and implemented which will be explained in the following sections.

4.1 Infrastructure for coastal protection

Two major infrastructures, a breakwater and a dyke where constructed to control erosion in the beach and port. Additionally, in 2016 a project on the installation of geotubes was implemented (MACCAFERRY, 2017).

4.1.1 Breakwater and dykes

The coastal protection infrastructure build in Corinto are the breakwater and the dyke. Both can be seen in Figure 9 and 10 respectively. The main objective of the breakwater is the protection of the western coast of Corinto from erosion caused by waves and currents and reduce the sedimentation near the berthing areas of the ships (Hans *et al.*, 1996) while the sand dyke is designed to partially block the approaching waves protecting the inland from damage.

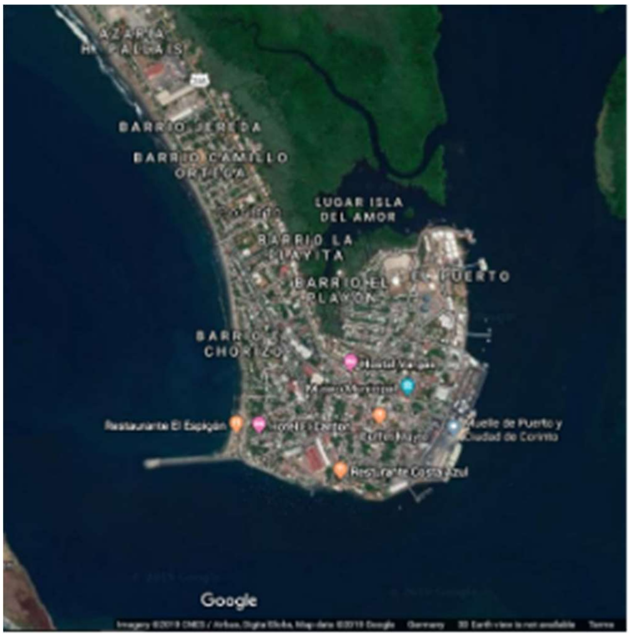

Figure 9-Construction of the Groyne (Breakwater) at Corinto (1993)

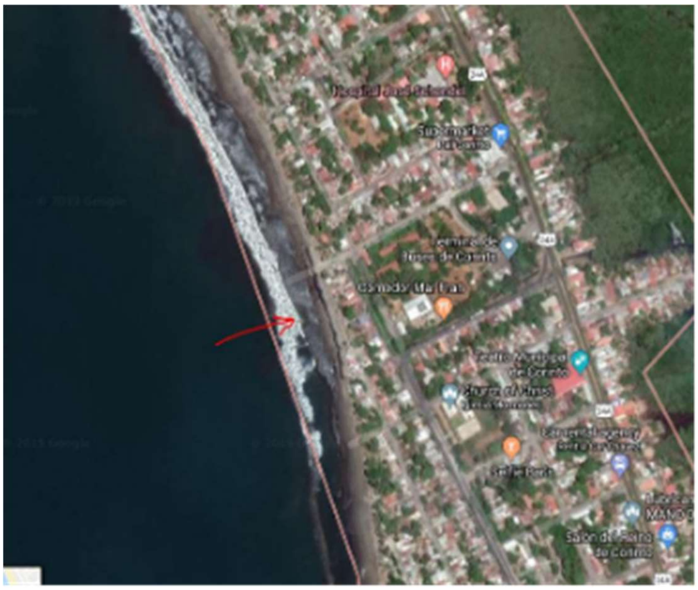

Figure 10-Reinforcement of the Sand Dam (Dyke) begins in Corinto (Nov. 2010)

4.1.2 Geotubes

Geotubes are the engineering solution for coastal areas, mainly to restore beaches, protect property, create breakwaters or even to create entire islands. The process includes using large tubes made of specially engineered textile (polyester based) filled with sand and fine sediments, lined them up along the shoreline. Each tube can be hundreds of meters long, and the installation is often permanent. They can be used as one level or stacked above each other in a pyramid shape to achieve higher heights as seen in Figure 11 (Tencate, 2005).

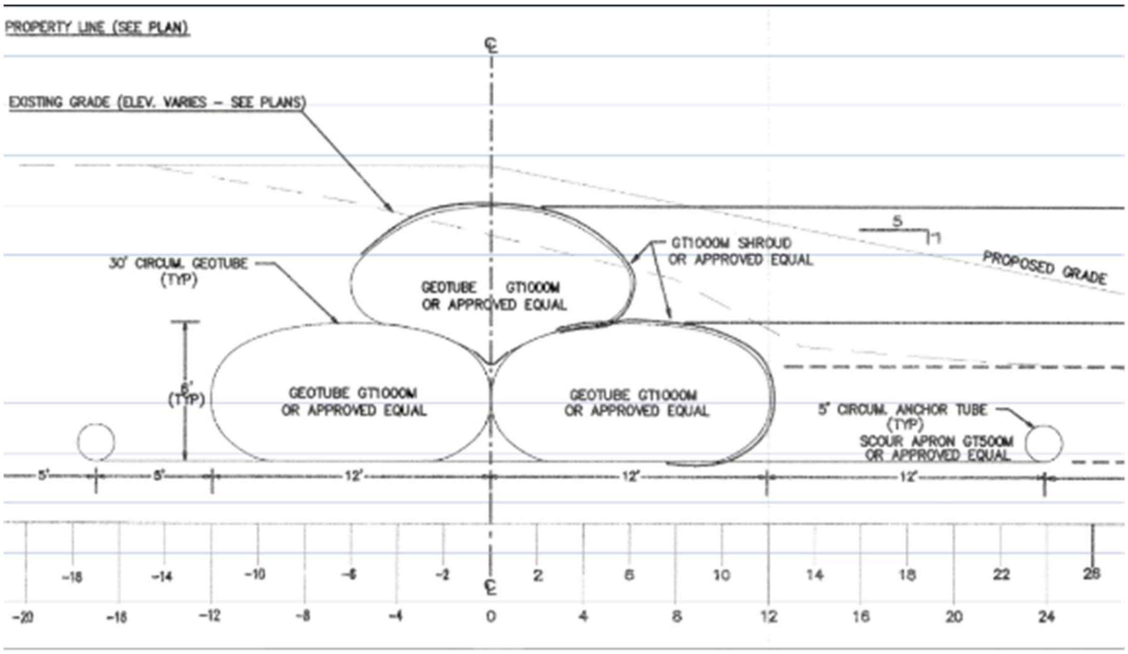

Figure 11-Cross-sectional view of the pyramid designed geotubes. (New Jersey Dept of Environmental Protection, 2010)

Function of Geotubes in coastal protection

In cases of storms or intense weather, the tubes block the sand from eroding and prevents property damage. This can be accompanied by transferring sand to the beach after the geotube line also called erosion-line and installing a submerged geotube around 60 m offshore parallel to the shore which slows down the current, allowing sedimentation and reducing erosion on the recreated beach as shown in Figure 12. One of the main advantages of using geotubes is that the original slope of the beach can be reconstructed (Tencate, 2005). The geotubes can be covered by sand and light vegetation which protects them and makes them more effective. To prevent failure, it is important to keep the geotubes covered with sand, maintain a beach in front of them through beach nourishment, and rapidly repair any damage in the fabric (Gibeaut *et al.*, 2003).

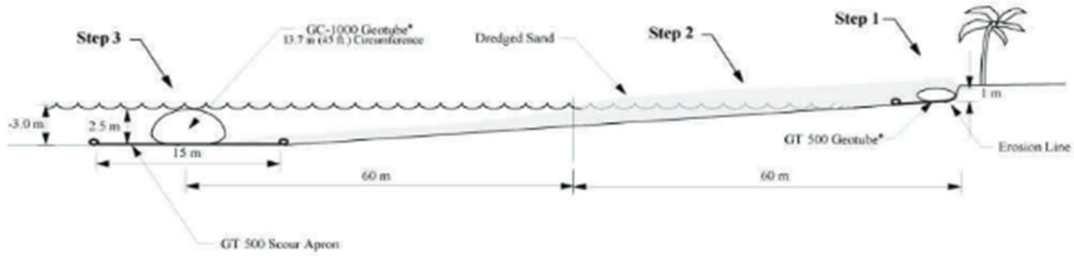

Figure 12-Cross-sectional view of the submerged offshore geotube and the onshore geotube. (Tencate, 2005)

Geotube implementation in Corinto

This mega project is focused on the installation of geotubes on Corinto coast, that will mitigate the erosion caused by the tides and will also provide protection to the coast. The government, through the Alcaldia de Corinto, the Empresa Portuaria Nacional (EPN) and the Ministerio de Transporte e infraestructura (MTI), made this project possible (MACCAFERRY, 2017). The installation of the geotube took place in 2016, over a length of 2,130 linear meters of the beach, in the areas most affected by the tides. The project was executed by Maccaferri Centroamerica (MACCAFERRY, 2017). AXIS INGENIERIA was hired by Maccaferri Centroamerica as a collaborating company to provide technical assistance to the project and capacitate of the workforce and local divers (Axisima, 2016).

Maccaferri MacTube® in Figure 13aa was developed for coastal protection and is used for sea protection, dune reconstruction, breakwaters and groynes. This was the material used for geotubes installed in Corinto. The MacTube® W1 17S, manufactured with a special protective woven coast geo-textile with a polypropylene fibers, characterized by having a high mechanical resistance, that can resist high biological degradation and UV rays (*Maccaferri,*, 2019). The final project consists of six breakwater structures with an average high of 1.5m, a length between 125 m to 200 m each, the volume used for each geotube is 16,000 m^3 of sand, obtained from ocean banks as shown in Figure 13 b and was placed along the coast line as shown in Figure 13 c (Axisima, 2016).

Figure 13a-Geotubes technical sheet (Vision Corinteña, 2015)

Figure 13 b-Geotubes arrival in Corinto (Vision Corinteña, 2015)

Figure 13 c-Geotubes location and technical data (Axisima, 2016)

Geotubes are an economical solution, as they are characterized by relatively low capital costs, low maintenance costs, simplicity of construction and placement at the coast. Also, they have minimum negative impact on the environment; especially when compared to concrete and breakwaters structures which require higher costs for excavation, placement and rock transport to the coast. In addition to that, the hard structures have high negative impact on the environment in the form of the produced CO^2 emissions during construction and disturb the habitats of aquatic species. On the other hand, geotubes can be vegetated and can accommodate diverse species, which leads to ecological growth in the coast area (Shabankareh, Ketabdari and Shabankareh, 2017).

4.2 Mangroves for coastal protection

It has been widely accepted that mangroves play a key role in protecting coasts from natural hazard and reduce coastal erosion. Mangroves capture sediments to build soil, attenuate the wave power as a result modifying the coastline, and it can reduce the intensity of hazards, saving both lives and property. The effectiveness of mangroves in enhancing coastal protection depends on the specific site characteristics and its local hazards (Spalding *et al.*, 2014)

4.2.1 Function of mangroves in coastal protection

Mangroves have different functions for coastal protection as discussed previously. More description about these functions can be found below:

Reducing wind & swell waves

Mangroves reduces the ability of wind and swell waves that goes through them to cause erosion and damage to dikes and other structures. When the see tides rises, and waves go through the tangled and above ground branches of mangrove forests, they tend to lose energy and height from 13% to 66% every 100 meters of mangroves. When that happens, waves cannot carry sediments away. Mangroves has also the ability to reduce wind speed and thus preventing waves propagation and reformation. Since waves lose more energy when passing through obstacles of higher density, then mangroves that has aerial roots tends to have greater attenuation properties than those without (Spalding *et al.*, 2014).

Reducing storm damage

When mangroves are broad, they can diminish a storm surge as it streams inland. Whereas storm surge may decrease from 5-50 cm every one-kilometer width of mangroves, a little diminishment in water level could enormously decrease the degree of flooding in low depth zones beyond the mangroves. Debris motion can be minimized by mangroves, where the complex structure of branches and roots can trap huge moving bodies. (Spalding et al., 2014)

Reducing tsunami damage

Evidences that mangroves can lower destructive energy of tsunami and help mitigating it has been growing especially after the Indian Ocean tsunami in 2004. The height of tsunami can be decreased from 5% to 30% over few hundred meters of mangrove areas. The wider the mangrove's belt is, the more it's able to reduce a tsunami's altitude, and the speed of water. However, these data don't really apply for larger and more intense tsunamis (greater than 4 meters), for those, can destroy and damage the mangroves and eventually they become less effective (Spalding *et al.*, 2014).

4.3 Reducing erosion & binding soil

One of the many benefits of mangroves is reducing erosion. The dense roots of mangroves help in binding and building up soils. When the water flows between its roots, the flow slows down which leads to sediments deposition and eventually erosion reduction. Waves and currents are constantly changing coastlines profiles, in some cases they cause erosion and land loss, while other times, they enhance sedimentation especially when mangrove vegetation is present. In simple words, mangroves can reduce erosion by slowing down water flow thus reducing its capability to remove and wash away sediments from the mangrove area. Simultaneously, a slower flow of water will permit previously suspended sediments to settle out, leading to improved settlement deposition. (Spalding *et al.*, 2014)

4.3.1 Mangrove cover in Corinto

The mangrove ecosystem surrounding Corinto extend from Salinas Grandes to Isla Maderas Negras. The total area occupied by mangroves is approximately estimated to be 68,700 hectares, along a length of 58 kilometers. The species of mangroves found in the area are: *Rizophora harrisoni* (red mangrove), *Luguncularia racemosa* (white mangrove), *Avicenia germinans* (black mangrove) and *Conocarpus erectus* (button mangrove). The predominant mangrove species are *Rizophora* and *Avicenia*. Table 1 below shows the cover area of mangroves in Corinto, the data is from 2003

Table 1-Mangroves in Corinto areas (Martinez Arteaga, 2016)

Stratum	Extension (ha)
Red mangrove total	7,051
Red mangrove high forest	600
Red mangrove lower forest	6,451
Black mangrove total	1,469
Black mangrove high forest	250
Black mangrove lower forest	1,399
Total	**8,700**

Unfortunately, Corinto is historically known for the deterioration of its mangrove ecosystem due to different factors. Red mangrove is the one that receives the most pressure of exploitation. The mangrove trees in the study area have an average diameter of 5.5 cm. This small diameter indicates that trees are severely limited in their growth by environmental conditions or are harvested before reaching its largest size (Martinez Arteaga, 2016). The main causes of mangrove destruction are:

- Shrimp farming: From 1995, the mangroves surrounding Corinto began to be used for shrimp farming. Currently there are two large shrimp farms, first located in the Barquito Matting an area of 120 hectares and the other to the east side of the island Guerrero also known as the vault 50 hectares.
- Unemployment: the lack of job opportunities leads the population around the mangroves to engage in timber extraction for their own survival. The timbers are used for firewood in homes or for sale in local consumption shops in the municipality of Chinandega. For example, the red mangrove burns easily and is cheaper that bottled gas or kerosene, the community prefer using this for cooking.
- Mangrove exploitation: the decrease of the species of Rizosphora is due to the inefficient extraction of this resource. Nowadays finding a mature tree i.e. with more than 8 cm diameters, is almost impossible as they are cut before reaching this state.

All the above factors along with the lack of economic alternative for the population, and the lack of implementation of environmental laws had led to the reduction of mangrove cover and thus made Corinto more prone to erosion and floods (Martinez Arteaga, 2016).

4.3.2 “Protege tu Mangle”

As a nature-based solution, in 2015, the program “Protege tu mangle” (Protect your mangroves) was initiated by 5 students from the University of Cologne in collaboration with the “Asociación Comunal Centro de Menores de Corinto”, Circo COLORINTO (Circus Asociation), Cristiano Guillermo Delgadillo (School), The Municipality of Corinto and the environmentalist movement “Guardabarranco”. This program promotes environmental education in schools, women groups and the general public; making posters, brochures and videos. Another result was the creation of the “Festival Municipal del Mangle. In 2016, 7373 mangrove seedlings were planted and in 2017, 7200 in Corinto and El Realejo.

5 Rationale of the study

Analyzing the information from the previous chapter, it is quite well reflected that Corinto island has diverse coastal ecosystems e.g. sandy beaches, mangroves and estuaries; which are very important for the socio-economic development of the area. However, the topography and climatic condition, together with anthropogenic activities in Corinto affect these ecosystems and are prone to coastal erosion and disasters. The soil type, precipitation, tidal effect, wave current, wind velocity as explained in chapter 2 are causes for erosion in the sandy beaches. Nevertheless, natural disasters like tsunami, storm surges and hurricanes are frequent in the area due to subduction between oceanic plates and landmasses and extreme climatic condition of El Niño and La Niña. These disasters greatly impact not only the economy but also the coastal systems in Corinto.

On the other hand, the sandy beaches of Corinto are of recreational attraction and infrastructures to support these activities started to grow over the time. Although such activities facilitate economy generation, at the same time, it exacerbates disaster vulnerability. The mangrove and estuaries ecosystem have a high potential to prevent disasters and control erosion. However, these ecosystems are over-exploited for timber collection and shrimp farming, and their important role on disaster prevention and supporting services are often overlooked. This resembles that there is need of an approach that addresses the natural and anthropogenic factors negatively affecting the coasts of Corinto.

Corinto has adopted some approaches for coastal protection as mentioned in chapter 3. Geotubes were installed as infrastructure-based solution to erosion-control along the sandy beaches in 2016. Similarly, nature-based solutions e.g. mangrove plantations were initiated to restore the mangrove ecosystem was also initiated in 2015. However, both initiatives were completely detached from one another and was implemented by varied interest. The geotubes installation was a reactive measure to respond to erosion in a fast way however, concrete information on erosion rate still lacks and monitoring after installation is found to be fragile. Similarly, mangrove plantation needs long-term strategic planning to make sure the ecosystem is resilient to withstand the coastal hazards. The coastal zones in Corinto are designated based on the use value which also make difficult to implement strategic solution. Thus, in order to achieve the sustainable coastal management, a holistic approach for integrating the projects and strengthening data base is required in Corinto. Therefore, scope of application of integrated coastal zone management (ICZM) approach is crucial to be studied in Corinto.

6 Objectives

1. Assess the progress of the coastal protection approaches: Geotubes and mangroves.
2. Propose an ICZM approach (coastal zoning) to Corinto based on the Netherlands' best practice.
3. Recommend success indicators of coastal programs and integrated coastal zoning implementation in Corinto.

7 Methodology

To achieve our report's objectives, a certain methodology was followed. It consisted of a literature review, secondary data collection, interviewing experts; and a field visit to the Netherlands to review the best ICZM practices in Egmond aan Zee and analyze the possibility of applying them in Corinto. The literature review was carried out in order to define the characteristics of the study area, describe the problems in the area and the causes of erosion. It also included a research of ICZM, to discuss the importance of this approach in protecting coastal areas from erosion, and to explore the current coastal protection methods implemented in Corinto and examine their success. In addition, this research also reviewed the best ICZM practices in the Netherlands and analyzed the possibility of implementation of this approach of coastal management in Corinto.

Secondary data were collected from different research papers, and articles that helped gather information about the characteristics of Corinto and the coastal protection solutions implemented there. Mainly these data tackled the installation of the Geotubes in 2016, and the mangrove cover that existed in the study area, plus the recent mangrove restoration projects. Interview questions were answered by Richard Martinez, a local expert that works at the municipality of Corinto. Martinez answered questions regarding the protection measurements (Geotubes, mangroves) adopted by the municipality, and their success. Unfortunately, currently there is no scientific monitoring taking place. Thus, a recommendation section was included in this report to propose a monitoring-scheme to the municipality for measuring the success of these two projects and merging them into a more efficient ICZM approach. Another interview was conducted by teleconference with Edgar Lampenscherf, a former student from the University of Cologne who visited Corinto with his colleagues in 2015. This group of students started a mangrove protection campaign which included social awareness about the importance of this ecosystem, and ecosystems-restoration actions. Edgar's input gave us a better understanding of the mangrove restoration project ("Protege tu Mangle").

Furthermore, GIS maps were generated for Corinto and El Realejo region-based on open data sources and using ESRI ArcGIS. An excursion to the Netherlands took place to observe and learn from the ICZM practices in this region. The excursion included visits to the Afsluitdijk dyke, a 29 km long dike that was constructed in 1932 and serves as a protection from floods and as motorway at the same time. Another location was the Zuiderzeewerke, which consists of multiple large dykes with the aim of forming new lands (polders) that protected the coast from floods and expand agricultural territories (Wiedermeier, 2019). Other visited locations included large dunes near the Egmond aan Zee region.

8 Results

8.1 The Coastal protection approaches in Corinto

8.1.1 Infrastructure and coastal protection

The coastal protection solutions in Corinto (the sand dyke, breakwater, and geotubes) had a positive impact in controlling the erosion and sedimentation process. They also worked as a barrier to protect the coast from disasters up to a certain extent. The breakwater reduced the rate of sedimentation in the docks of the port, while having an opposite effect at the northern part of the breakwater where the sedimentation rate has increased, thus decreasing the erosion of the coast (ENSOME, 2018). This is due to the reduced velocities of the water currents flowing to the southeast direction. On the other hand, the sand dyke protects the inland structures from waves and high tides but was continuously damaged and maintenance is currently required. This dyke could have negative or positive impact on the erosion since it interrupts the natural tidal process. The geotubes reduced the wave intensity protecting the sand dyke and clocked the sand from eroding. Natural controls of coastal erosion are governed by the dyke, breakwater and geotubes, these coastal structures attenuate coastal erosion, the direct results were observed within months after the projects. Regarding the construction of a highway bridge north of the city, there is no scientific evidence that affected the erosion process, although it is a possibility since the bridge stops the water currently circulating around the island (Martinez Arteaga, 2019).

8.1.2 Mangroves and coastal protection

Within the project of “Protege tu Mangle”, 7373 and 7200 Mangrove seedlings were planted in the years 2016 and 2017 respectively. Although this project had positive feedback within the community, a scientific monitoring and evaluation technique was not planned and implemented. Therefore, it is challenging to measure the effectiveness of this project in terms of coastal protection. Hence, a list of monitoring steps and success indicators is proposed in section 8.2 of this report. While mangroves can mitigate erosion and disasters, they cannot always be a stand-alone solution for coastal protection especially from large risks such as tsunamis and cyclones. To achieve better protection levels and erosion reduction, the preservation of mangroves must be consolidated into wider coastal zone administration in order to ideally contribute to hazard abatement. They got to be secured and reestablished. On the other hand, firm defense structures might also cause a negative effect and interrupt sediments flow and stimulate erosion. Recently, different coastal zone management approaches have been developed, where nature-based solutions (mangroves), and engineered solutions (e.g. geotubes & dykes) have been integrated into one full system for coastal protection. This approach has led to promising results where humans went from working against nature to working alongside nature into achieving the required goals (Spalding *et al.*, 2014).

8.2 Implementing ICZM in Corinto based on Netherlands best practice

After conducting the interviews with the local contact from the municipality of Corinto, it was found that the mangroves restoration and geotubes were individual projects. While the municipality of Corinto was involved in both projects, there was not coordination between the other parties involved. In addition to that, the coastal zones were not well defined according to their function and nature prior to these projects and hence, not effectively considered. Therefore, after implementing these projects, several conflicts may arise with the competing functions such as tourism, fishing, trade, ecosystems and coastal protection functions. Considering all factors mentioned above, it can be deduced that the ICZM approached is not properly implemented. For that, we conducted literature review about this approach in the Netherlands and an excursion to various coastal areas in the Netherlands to formulate a best practice approach to recommend for coastal management in Corinto.

The coastline of The Netherlands is about 350 km long. Around 290 km consists of dunes and flat beaches; while the remaining 60 km is protected by dikes, dams and storm surge barriers. The beaches and shoreface, in fact the 'foundation' of the Dutch coastal zone, consist almost completely of sand. More than half of the coastline is subject to coastal erosion and Figure 14 shows the severity of this process in various coastal towns. Before 1990, the coastal retreat was estimated at 20 ha/year, since then, the authorities decided to take a 'dynamic preservation' approach. Which primarily aims at ensuring safety against flooding, sustainable preservation of the values and interests attached to the dunes and beaches (de Ruig, 1998). Also, the main target of this plan was to stop the retreat of the coastline at the 1990 level keeping a small variation to make possible the occurrence of the natural processes. Main solutions included the use of artificial sand nourishment, protection of existing sand dunes, creation of new sand dunes, and in some areas the use of dykes and breakwaters. These solutions were accompanied by the proper classification of the coastal zones according to its uses and functions. Moreover, the sand dunes area is used for several functions other than coastal protection as shown in Figure 15, such as eco-tourism, small-scale agricultural farms, protection of biodiversity and in some cases drinking water purification (v. Oldenbeek, 2016). The Netherlands were able to reach these solutions by a series of policies, strategies, and management approaches.

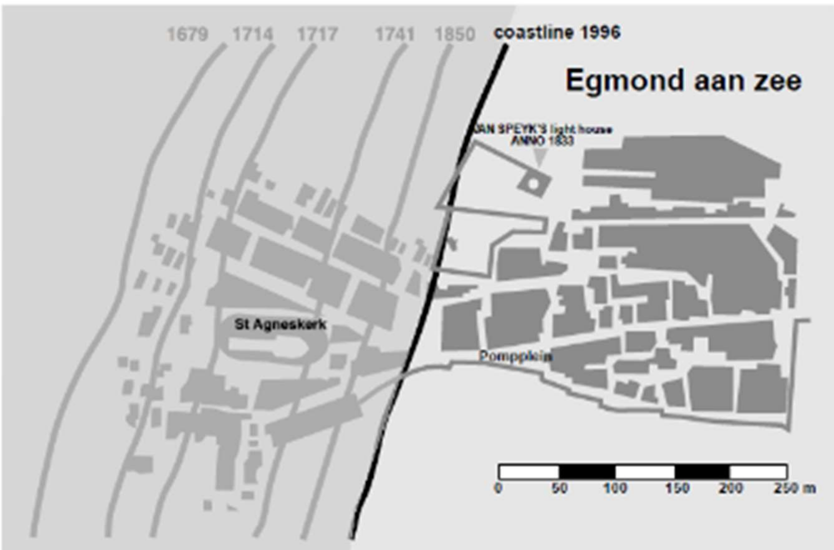

Figure 14-Map showing the impact of coastal erosion on the original village of Egmond aan Zee, North Holland over the past centuries (de Ruig, 1998).

Figure 15-Sand Dunes Zone in Egmond aan Zee, Netherlands (Photo credits: Raghid Shehayeb, 2019)

Timeline of main policy developments

1990: The First Policy Document on Coastal Areas (Eerste Kustnota) aimed to achieve sustainable flood protection and preserve the functions of the sand dunes area. Because of this policy document, the coastline was preserved creating more space in wide areas of dunes for natural processes like sand drift and the development of tidal gullies.

2000: The Third Policy Document on Coastal Areas (Derde Kustnota) transferred the aim of "more resilient water systems" that was derived from the "Fourth National Policy Document on Water Management - 1998" to the coastal zone. The "Derde Kustnota" recognized weaknesses in the coastal flood defenses and the increasing risk of storm damage in seafront settlements. The main recommendation is to apply soft solutions (sediment-based) whenever possible and hard solutions (structures) only when necessary.

2005: National Spatial Strategy

The basic principle of the National Spatial Strategy is that the implementation of spatial policy should be decentralized wherever possible and centralized only where necessary. This implies that regional authorities will have more scope to work with other stakeholders, civil society organizations, residents and businesses to devise effective solutions, exploit opportunities and adopt an approach custom-made to local conditions.

Organization of Coastal Zone Management and Policy (National Institute for Coastal and Marine Management (RWS RIKZ), 2005)

1. Several management authorities:

Management authorities are commonly responsible for multiple functions. For example, nature management in large sections of the dunes is in the hands of authorities whose primary task is the collection of drinking water. The water boards, under the supervision of the provinces, manage the coastal defenses that protect the inland area from storm flooding. Municipalities and provinces are responsible for spatial zoning to protect the benefits coming from the different coastal zones.

2. Organization of the management:

Decisions tend to be taken in multi-stakeholder platforms and consultative committees. These platforms can be regional or sector specific, and they facilitate an efficient way for the authorities and stakeholders to work together.

3. Organization of the policy:

National government policies related to the coastal zone are developed via a process of close cooperation between all the relevant ministries where the National Spatial Strategy of 2005 was first to contain planning policies for the coastal zone according to the special context.

Although the soft solutions implemented in Netherlands do not seem to be complex and are relatively cheaper than hard solutions, it is not applicable in all cases. This being said, sand dunes are not the solution for Corinto, which has a different nature than the coasts of Netherlands. Therefore, it is wise to make use of the approach of the Netherlands towards ICZM and at the same time study the implementation of solutions from other cases similar in climate and geography to Corinto such as i.e. Colombia.

9 Discussion and recommendations

9.1 Success indicators for Geotubes

In geotubes implementation project, is important to take some factors in consideration that might create problems in the future like the tidal variation, the wave strength variation and degradation of the geotubes by ultraviolet sun radiation. The tidal variations and wave power could cause failure of the geotubes if not considered during the design and selection of the geotubes to be installed. Such a case was at Condolim beach in India, they noticed that there was a tidal difference of 2.53 m between high and low tide along with variation on wave strength which lead to the damage of the geotubes, as a result the filling came outside, as shown in Figure 16. A change in the design was required. The new design was to use one tube above the other with additional protection using riprap (R Parab *et al.*, 2019).

Figure 16-failure of Geotubes at Candolim beach in India (R Parab et al., 2019).

At areas with high wave actions there a high chance of abrasion to the geotubes which required the used of material with high tensile strength and/or multi-layer tubes. In areas with high ultraviolet sun radiation, there is a higher degradation to the outer layer of the geotubes which required a resistance layer of carbon black coating to lessen this effect (Lee *et al.*, 2014).

To be able to monitor the geoutube performance and success the following step are to follow (Gibeaut *et al.*, 2003)**:**

1.Comparing the shore width and erosion rates:

a. Calculate the shore width from a fixed point inside land to the mean shoreline (MSL) over a period of years (5 or 10 years) in the segments where the geotubes where installed and the segments adjacent to the geotubes (could be affected as well). (Calculate the width as well as the average (yearly) erosion rate.
b. Compare the numbers to the historical data of the width of the shore
c. Compare the numbers to the rate of erosion (e.g. yearly rate); (is the rate increasing/decreasing/constant after/before the project?)

d. A topographic airborne survey can be done, to the area where geotubes are located and the adjacent areas to check the width of the beach, as shown in Figure 17. Normally the are in front of the tubes is narrower compared to neighboring areas where geotubes are not applied, due to the movement of the sediments towards the tubes and other areas of the beach (Gibeaut *et al.*, 2003).

Figure 17-Image of the southwest end of the Pirates Beach geotube project and the northeast end of Galveston Island State Park along the gulf of mexico , arrows represent the beach's width (Gibeaut et al., 2003)

e. If there is lack of historical data, compare with neighboring coastal area with similar conditions
f. Take into account climatic changes throughout time (e.g. number of storms in a period of 5 years, sea level rise, intensity of storms...)

2. Comparing the Economic Losses over a period of 5-10 years before and after the geotube project taking into account the climatic changes as well as the change in the structures (e.g. Buildings, Port, roads...) in the area.
3. To avoid any risk of failure of the geotubes and assess their functionality, a periodic visual inspection is required to detect any holes in the fabric of the tubes and to check their exposure.

9.2 Success indicators for mangroves

In Mangrove restoration projects, it is important to establish measurable success parameters in order to monitor and evaluate the progress of these projects. Setting a goal or an objective for the restoration projects is the first step in creating quantitative measurements. Different examples of a goal to set are planting a certain type of mangrove for later harvest, to restore certain ecological species, to mitigate erosion or restore the coastline. Although each goal will probably lead to define a specific success criteria approach, however the success of one goal can also leads to the fulfillment of other objectives (Lewis, 2009). Unfortunately, Corinto city does not conduct any monitoring activities currently, not even after the installment of the Geotubes in 2016 and the recent mangrove restoration projects.

After Establishing the success criteria, and implementing the mangrove restoration project, monitoring of the study area should begin. A normal schedule for monitoring and measuring is as follows:

Table 2-Monitoring schedule for mangrove restoration projects (Lewis, 2009)

No of measurement	Time (in months)
1	0
2	0 to 3
3	0 to 6
4	0 to 9
5	0 to 12
6	0 to 18
7	0 to 24
8	0 to 36
9	0 to 48
10	0 to 60

Time 0 will refer to the time directly after every mangrove restoration project has been completed. Photographs from a fixed location should be taken at the start and beyond. Note that in the early years, the monitoring period intervals is shorter, and that is to make sure that in case any problems arise, it can be solved quickly. (Lewis, 2009)

According to a study in the Philippines (Menéndez *et al.*, 2018), another method to measure the success of mangrove restoration projects is to assess population exposed to floods, economic losses due to floods after implementation, and compare it to historical data if available. Keeping in mind the intensity of natural hazards in each year.

9.3 Implementation of coastal zoning

As it was mentioned before this report assumes that one of the problems for the heavy erosion in the zone is the lack of integration in the coastal management approach. Colombia, Brazil, Costa Rica and Chile belong to the most outstanding cases of ICZM in the region of Latin America according to the Network of Integrated Coastal Management (IBERMAR) (Milanés Batista *et al.*, 2014). The process of developing, adopting, implementing and evaluating a plan for ICZM is complex, being the reason why this report will only focus on the recommendation about the introduction of zoning concept mentioned in the introduction. The diagram below Figure 18 shows the process of implementing an ICZM approach elaborated by the Colombian Government (Rojas Giraldo *et al.*, 2010).

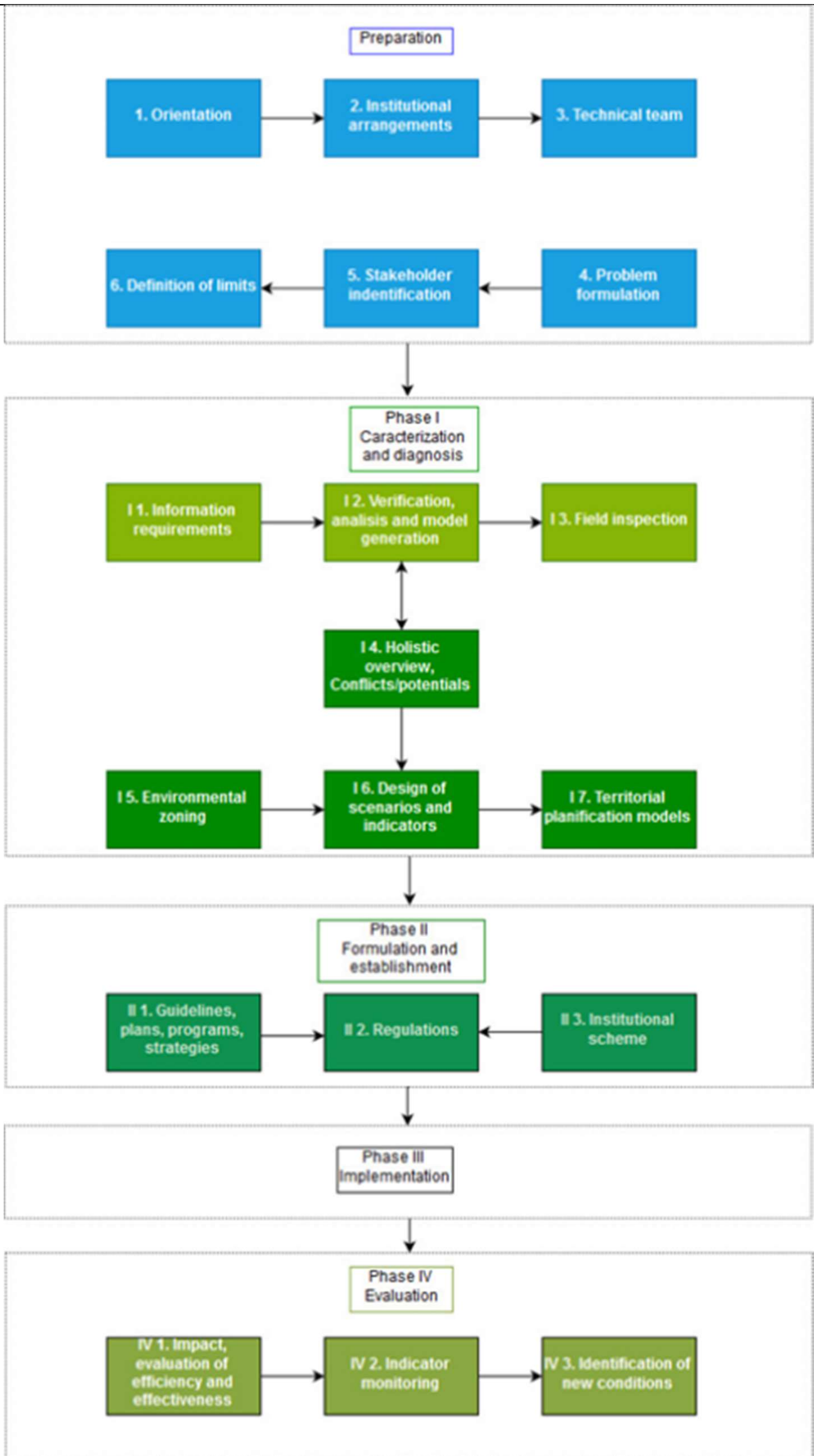

Figure 18-Methodology to approach an ICZM process. Modified after (Rojas Giraldo et al., 2010)

The zoning process consists of determining spatial units that present a homogeneous land use, considering biotic, physical, socio-cultural and economic aspects. Being aware of the potentials, limitations and weaknesses occurring in the structure and functionality of the coastal zone (Rojas Giraldo *et al.*, 2010). For the ecological zoning "Ecological Landscape Units" (ELU) have to be determined based on the holistic and integral view of the landscape.

According to Colombia's plan of ICZM the environmental zoning process is divided into 4 different steps:

Step 1) The first step consists of <u>defining the coastal zoning categories</u>. For this, firstly, a review of previous coastal zoning categorizations must be done. The definition of the new zones to be introduced should be based upon the concept of uses and activities carried out in the different zones. These concepts should be interlinked according to their requirements for development and their compatibility. Some of these categories could e.g. zone of human settlements, zone for carrying out sustainable economic activities, zone for protection of marine and coastal ecosystems, zone of cultural protection and zone of recovery. A clear definition of each of these zones should be done.

Step 2) The next step is the <u>definition of the criteria</u> for the coastal zoning. Therefore, a review of literature about common criteria for different type of zoning must be done. After that a comparison of the results, with available information from the study area, must be done. Next, the chosen evaluation parameters must be established. Afterward, evaluation scale should be prepared. For this scale the criteria need to be applied on the ELU for each of the categories adopted for the study case in step 2 (e.g. alteration of the coastline, threats in the coastline, pollution level (points from 1-4, 1 being very low and 4 being high). Criteria in this case could be the conditions that must be complied for the ELU to be assigned to a management category.

Step 3) The third step consists of <u>assigning the categories</u> through the ELUs, depending on the fulfillment of criteria previously established.

Step 4) Lastly, an <u>elaboration of the zoning map</u> is to be done. Therefore, every ELU is to be put into a zoning category with the help of GIS tools. Next the spatial, ecological, biotic, physical, socio-cultural and economic concepts must be analyzed, in order to obtain a zoning that is true to reality and the current needs of the local community. The obtained graph should cover the zoning categories resulting during the process of environmental zoning. The area will now be divided into new "unities". These unities will allow the next steps in the process of ICZM (scenarios and perspectives).

10 Conclusion

During this case study, defining the socioeconomic, governance, laws, and environmental aspect of the area was necessary, to be able to access the situation in Corinto. Coastal erosion is present in the area and is a natural phenomenon that has been aggravated due to a combination of natural and anthropogenic factors. However, there is no scientific evidence on how erosion was developed in the coast of Corinto. In addition, the area is prone to natural hazards which have an impact on the coast and the population.

As a result, Corinto has adopted two approaches for coastal protection against erosion and disaster. An infrastructure-based solution (dyke, breakwater and geotubes) and nature-based solution (mangrove restoration). After understanding the functions and implementation of these solutions in protecting the coast, different methodologies were applied in this report to evaluate these current coastal protection methods implemented in Corinto and examine their success.

The findings from the study indicated that there is inadequate data available to measure the success of these methods in reducing erosion. Furthermore, the coastal zones were not well-defined which conflicts with socio-economic activities and ecosystems and coastal protection functions after implementation. Hence, a recommendation section was included in this report, about how to measure the success of these projects and how to implement integrated coastal zoning system. To be able to recommend best practices of ICZM, the case of Netherlands was chosen as a guideline. However, the coastal environment differed from Corinto. For instance, Egmond aan Zee does not have mangroves and Corinto does not have sand dunes. Thus, there was a need to select a country with similar conditions, so we selected the case of Colombia and made success indicators for coastal management were identified.

11 Limitations

During this research different challenges and difficulties affected the result. The limited availability of data narrowed the scope of our analysis. The reason for this is the inefficient monitoring of the implemented solutions in Corinto for coastal protection. The language of the literature available for data and information collection was in Spanish, thus, was a limitation for the group. Most group members are familiar with English language but not Spanish, so only some members of the group were able to analyze this data. We also had time constraint in analyzing the case of the mangroves project. It required a periodic assessment every year and requires few years to be able to assess the success of the reforestation after implementation. Economic resources were limited which affected the quality of some of the spatial data. The use of public data downgraded the quality of the resolution and limited the access to specific maps. Availability of resources would improve the overall quality of the project. However, all these limitations are an opportunity to improve the quality of future research project to be done in the study area.

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