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Evaluation of Coastal Erosion in the Jurisdiction of the Municipalities of Puerto Colombia and Tubará, Atlántico, Colombia in Google Earth Engine with Landsat and Sentinel 2 Images

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***Abstract*—**The coastal zones are home to mangrove swamps, coral reefs, and seagrass ecosystems, which are the most biodiverse and fragile on the planet. These areas support a great diversity of marine life; they are also extraordinarily important for humans in the provision of food, water, wood, and other associated goods and services; they also contribute to climate regulation. The lack of an automated model that generates information on the dynamics of changes in coastlines and coastal erosion is identified as a central problem. In this paper, coastlines were determined from 1984 to 2020 on the Google Earth Engine platform from Landsat and Sentinel images. Then, we determined the Modified Normalized Difference Water Index (MNDWI) and used Digital Shoreline Analysis System (DSAS) v5.0. Starting from the 2020 coastline; the 10-year prediction (Year 2031) was determined with the erosion of 238.32 hectares and an accretion of 181.96 hectares. For the 20-year prediction (Year 2041) will be presented an erosion of 544.04 hectares and an accretion of 133.94 hectares. The erosion and accretion of Playa Muelle in the municipality of Puerto Colombia were established, which will register the highest value of erosion. The coverage that presented the greatest change was that of artificialized territories.

***Keywords*—**Coastline, coastal erosion, MNDWI, Google Earth Engine, Colombia.

I. Introduction

THE coastal and insular areas of the world have the most biodiverse and fragile ecosystems such as mangroves, coral reefs and seagrass beds, on which around two thirds of marine biodiversity depend, in addition to housing half of the world's population and great variety of human activities in its areas of influence [1].

All coastal countries must deal with the coastal erosion, as is the case in Europe where 20% of its territory has been affected by severe impacts, with an effective retreat of the coastline of 15,100 km and an area affected by erosion of 15 km^2 [2].

Colombia is no stranger to this situation; It has a coastal marine area of 892,102 km^2 on the Pacific Sea and the Caribbean Sea, approximately 50% of the total area of Colombia. It has a coastline of 6,969 km, which includes the continental, insular continental margin and insular oceanic margin [3].

In the 1970s and 1980s, coastal erosion in the Caribbean region seems to have been accelerated by the growth of cities [4] and has strongly increased in the Caribbean in recent years, affecting essential beaches. The beaches are very important for tourism in the region [5], which have been affected by erosion.

As a consequence of coastal erosion, there are impacts such as the loss of surface, which has an economic, social and ecological value; the destruction of coastal natural defenses and the deterioration of protection works [6].

The Colombian Caribbean coast is made up of the departments of La Guajira, Magdalena, Atlántico, Bolívar, Sucre, Córdoba, Antioquia and Chocó, in 45 municipalities, 7 port captaincies, 9 regional autonomous corporations and 2 administrative technical departments [3]. This project is developed between the municipalities of Tubará and Puerto Colombia (Atlántico), in an approximate length of 20 km. According to the National Administrative Department of Statistics [7], these municipalities present percentages of Unsatisfied Basic Needs of 16.13% and 9.17%, respectively.

One of the main coastal natural defenses is the mangrove ecosystem, which offers multiple environmental services, such as coastal protection, food supply, climate regulation, recreation and tourism, among many others, for which its recovery is also necessary. [8]. In the mangrove ecosystem is the red mangrove species, which has some of the tallest trees in the world, as well as being a refuge for young fish that feed and depend on the nutrient-rich waters around the mangrove ecosystem [9]. In that sense, the degradation of coasts and their ecosystems has reduced the availability of high-value wild foods, which contributes to food insecurity in coastal areas [10].

To carry out the evaluation of coastal erosion, there are remote sensors, in this case, satellite technology. This technology offers multiple advantages over others, since it is cheaper and faster. With satellite technology, large areas can also be analyzed compared to aerial photography or field work. Consequently, areas can be surveyed on a regional scale and not limited to political or geographic borders, with up-to-date information because satellite imagery is available within a couple of hours of capture. It also presents a precise and detailed representation of the earth's surface, among the most important characteristics of satellite technology [11].

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In accordance with the above, this work has the purpose of determining the change of the coastline, as well as the erosion and accretion in the main beaches of the municipalities of Puerto Colombia and Tubará, from Landsat and Sentinel 2 images and their Cloud processing with *Google Earth Engine* (GEE) and software *Arcgis with the Digital Shoreline* module *Analysis System* (DSAS) v5.0.

This research also has the purpose of contributing and assisting in decision-making by different entities with competence in monitoring the coastline for land use planning and erosion control measures. The information generated is extremely important for entities such as the General Maritime Directorate (DIMAR), the mayors of Cartagena and Barranquilla, the Marine and Coastal Research Institute (INVEMAR), among others. Likewise, the information is significant, mainly, for the National Environmental System (SINA) where geographic information generated by different government entities such as INVEMAR, Regional Autonomous Corporations (CAR), National Environmental Licenses Authority (ANLA) and the Special Administrative Unit of the System of National Natural Parks of Colombia (UAESPNN).

This research can provide inputs for the National Environmental Policy in what has to do with the sustainable development of ocean spaces and coastal and insular areas of Colombia, since one of its objectives is to include marine and coastal systems in the ordering territory of the country. Likewise, the National Environmental Policy allows establishing environmental guidelines for the development of productive activities, defining conservation, rehabilitation and restoration measures for Colombian ecosystems, in order to contribute to a healthy marine and coastal environment for quality improvement of life of the coastal population [12].

Finally, it is expected that the products derived from this study, such as the coastline, prediction for the years 2031 and 2041 and changes in coverage, can be used as inputs in the Land Management Plans, adaptation plans to change climate, reports on the state of marine resources, reforestation programs or coastal erosion control measures, among others, that will help improve the quality of life of the inhabitants of the Colombian Caribbean coastal areas.

The present study generated twelve images from collections of the 1984, 1987, 1990, 1996, 1999, 2002, 2005, 2008, 2011, 2014, 2017 and 2020 Landsat 5, 7 and 8 and Sentinel 2 sensors at *Google Earth Engine* and determine the coastlines. For the period between 1984 and 2020, the maximum Average Net Movement (NSM) for erosion was -1931.1 meters per year, while for accretion the maximum NSM was 1937.7 meters per year. Similarly, the end point rate (EPR) shows that the highest erosion was -152.9 meters per year, while the highest accretion was 164.9 meters per year. The prediction for the 10 years (year 2031) provided as a result the erosion of 238.32 ha and accretion of 181.96 ha, while for the prediction of 20 years (year 2041) there will be an erosion of 544.04 ha and accretion of 133.94 ha.

A. Coastal Erosion from Landsat and Sentinel Data at the International Level

The use of satellite images to determine the changes of the coastline is widely studied in the world. In this sense in China, Zhang et al. [13] determined the changes in the spatial and temporal coastline of the southern delta of the Yellow River (Huanghe) between 1976 and 2016 with 364 Landsat images. They calculated the historical sea levels using the relationship between the simulated tide heights and the instantaneous positions on the coast, and thus determined the spatial and temporal changes of the coast, which is favorable for the analysis of evolutions and trends of the coast, while Pardo-Pascual et al. [14] evaluated the mean annual position of the coast from Landsat 5, 7 and 8 images between 2000 and 2014 as an indicator of coastal evolution in the medium term, in a 9 km stretch of sandy beach in El Saler (Valencia, Spain). Pardo-Pascual et al. [15] continue their studies with the evaluation of the accuracy of the coasts automatically extracted on natural beaches from Landsat 7, Landsat 8 and Sentinel-2 images (infrared bands), along the Valencian coast (Spanish Mediterranean); however, they showed that the SWIR-1 band is more reliable in terms of natural sea dynamics, while the NIR bands are more affected by white water and sea foam. Likewise, this study verified that the coasts obtained from bands 11 and 12 of Sentinel-2 and bands 6 and 7 of Landsat 8 are very similar.

Subsequently, Cabezas-Rabadán et al. [16] used the SWIR-1 band (band 11) with 20 m spatial resolution of high-frequency Sentinel 2 in the coastal segment between Cabo de Cullera and Puerto de Dénia (Valencia-Spain) and showed the characterization of beach changes using derived coastlines. The results show that with the methodology used, it is possible to characterize the changes in the position of the coast with respect to natural events and artificial actions, either locally or in large regions. In the same sense, Almonacid-Caballero et al. [17], develop the system for the extraction of coastlines SHOREX, in the laboratory of the Polytechnic University of Valencia, monitoring the response of Mediterranean beaches to natural phenomena and actions through Landsat 5 and 7 (band 5) and Landsat 8 (band 6) images between June 1984 and September 1987 and between July 1999 and June 2014, covering a coastal sector of 8 km of coastline and located in the middle south of the Gulf of Valencia (Spain). The results show its usefulness for describing the state and changes of the beaches, enabling their monitoring and diagnosis, which helps to detect and quantify changes on the coast directly related to the effects of natural events and human actions (dykes or breakwaters) such as dumping and extraction of sand. On the north coast of the Netherlands, Do et al. [18] performed estimation and evaluation of shoreline locations, rates of shoreline change, and changes in shoreline volume derived from 13 Landsat images (1985 to 2010) and JARKUS data (Dutch database). They [18] found that satellite-derived shoreline change rates show a high correlation coefficient (R2.0.78) compared to JARKUS-derived shoreline change rates during a period of 20 and 25 years. The results show that using Landsat imagery to derive coastlines, rates of coastline change, and volume change have accuracies comparable to observed JARKUS-based values

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when considering decade scales of measurements. The advantage of this study is that it focuses on the methodology used and the comparison of data taken in the field such as remote sensing.

On the other hand, Kuleli et al. [19] carried out the automatic detection of coastline change in five Ramsar coastal wetlands in Turkey, from Landsat images 1972-2009, where accretion or erosion processes were observed. DSAS (*Digital Shoreline Analysis System*) was used as a reliable statistical approach for the rate of shoreline change, while Landsat images were geometrically and radiometrically corrected for quantitative shoreline delineation analysis. The results show remarkable changes in the coast (more than 765 meters of extraction and -20.68 meters per year of erosion in Yumurtalik, 650 meters of extraction and -25.99 meters per year of erosion in Goksu, 660 meters of extraction and -16.10 meters per year of erosion in Kizilirmak and 640 meters of extraction and -4.91 meters per year of erosion in Yesilirmak) during three periods (1989, 1999 and 2009) and the advantage of the study is the applied methodology. Similarly, on the east coast of India, Kumar et al. [20] used DSAS to assess coastal vulnerability with Landsat 1970, 1980, 2000 images with the Coastal Vulnerability Index (CVI), generating coastal vulnerability maps, however, these studies use a small amount of imaging.

There are various spectral indices for the analysis of land surface elements, one of those is the Modified Normalized Water Difference Index (MNDWI). Using the MNDWI, Saravanan [21] tracked changes in the coastline of the Cuddalore region (India) in space and time with Landsat images (2000, 2005, 2010, 2015), and then delineated the coastline. Coastal change detection analyzes were processed in DSAS. To calculate the erosion, it is supported by the ENVI software using the automatic delineation method. The most important result is that the modified index significantly improved the analysis in terms of contrast between coastlines and coastal objects for clear recognition and delimitation, in addition the results show the role that artificial structures play in modifying the positions of the coast and active sites of erosion and deposition.

Behling et al. [22] evaluated the spatio-temporal shoreline dynamics of the Walvis Bay and Sandwich coastal lagoons Harbour, which are located on the western coast of Namibia, used Landsat images from TM, ETM+ and OLI sensors covering a 30-year period between 1984 and 2014. He proposed a WLMO (Water-Land MOnitor) to monitor spatio-temporal shoreline changes and the approach uses a hierarchical classification system based on temporal MNDWI trajectories. This approach was able to identify detailed progressions of accretion and erosion in these lagoons. The main advantage of the approach is the opportunity to analyze detailed spatio-temporal shoreline changes, as it would show that the observed long-term accretion and erosion processes underwent large variations over time and not as linear processes. Finally, the approach has the potential to be used in other coastal areas with other types of satellite sensors such as Sentinel 2.

Also, Hagenaars et al. [23] evaluated the accuracy of automated shoreline detection derived from satellite images (Landsat 5,7 and 8 and Sentinel 2A) in the coastal stretch of Sand Motor (Netherlands), which comprises approximately 4.5 km of coastline length, for the period 2011-08-01 to 2016-07-01. Reflectance values were calculated with TOA (Top - Of - Atmosphere) and MNDWI per pixel, within its methodology, which is recommended for use in other studies, however, the small number of images used is a disadvantage. One of the conclusions indicates that the pansharping technique is not considered suitable for coastal areas.

Another index used is the Normalized Differential Water Index (NDWI), Abu Zed et al. [24] carried out the evaluation of the use of satellite images to detect the change of coastline along the coastal zone of El-Arish, Sinai (Egypt). This research used 10 Landsat images 1, 4, 5, 8 between 1972 and 2016. The study applied three modules for the extraction of the coast from the satellite image, later two attempts were used to evaluate the use of the satellite image to detect the change of the coast and choose the best method. Its main conclusion is that NDWI offers the best result, since 90% of its error does not exceed 25 m, which is considered within the resolution of the satellite image. In addition, it showed that the behavior of man-made constructions throughout the area is to interrupt the transport of sediments from the coast that causes severe changes and recommends an integrated management of the coastal zone to achieve sustainable development. The advantage of the study is based on its appropriate image processing methodology to be replicated.

Similarly, Choung and Jo [25] conducted the assessment of coastline change for various types of coastlines using Landsat images between 1994 and 2014 of the east coast of South Korea, with a length of 200 km. The region was selected as it experiences significant coastal erosion annually. The methodology for the evaluation of the change in the coast consisted of generating the NDWI, extracting the coasts from each NDWI map through the thresholding method and finally evaluating the changes in the coast in the various types of coasts and using the control points with 1 km intervals. The results showed that 94% of the sandy shorelines and 97% of the rocky shorelines moved inland between 1994 and 2014 due to coastal erosion, while 91% of the shorelines on port shores moved towards the sea during the same period due to land reclamation works. A limitation determined by this study is that detailed coastal forms cannot be extracted from Landsat images due to their low spatial resolution (30 m) and therefore not allowing the assessment of coastline change.

However, El-Ashmawy [26] used two spectral indices (NDWI and MNDWI) in the automatic determination of the coast at the maximum retreat north of the city of Hurghada with around 100 km along the Red Sea coast (Egypt) with Landsat 8 images. The focus of this study depends on three types of information, the first is the location of the current coastline, the second is the mean highest high water level (MHHWL) and the third is topography of the coastal area. Limits of the reflectance values of B6 and B7, the ratio between B3 and B6, and B4 and B5, and the NDWI and MNDWI indices were used to extract the water body from the satellite image, which had an accuracy of 15 m for the shoreline extracted based on field observations.

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Unlike the use of water indices, Gonçalves et al. [27] used the Normalized Difference Vegetation Index (NDVI) with a fuzzy model that integrates changes in the coastline and settlement influences for the classification of human impact in in Itamaraca (Brazil) coastal area from Landsat images. Some conclusions presented are that the proposed fuzzy model provides an alternative way of integrating data and the implementation of the proposed fuzzy model by integrating the shoreline change, NDVI and settlement datasets (i.e. geomorphological aspects, in situ images and satellite) shows an improvement in the evaluation of human impacts in the coastal zone. The applied methodology is an advantage shown by the study.

Statistical methods such as EPR, LRR (Linear Regression Rate), SCE (Shoreline Change Envelope), and NSM (Net Shoreline Movement). In this sense, Ciritci & Turk [28] developed the automatic detection of coast change in the Goksu Delta (Turkey), since it is one of the 14 wetlands registered as a Ramsar site in Turkey, using Landsat 5 TM satellite images that cover a period of 27 years between 1984 and 2011. The SCE method determined that the maximum change in the coast between 1984 and 2011 was 826.85 m, while a maximum change in the coast of -30.64 meters per year was obtained by the EPR method and -30.99 meters per year by the LRR method. The advantage of this study lies in its methodology, which can be used in different places on the planet.

Meanwhile, Li et al. [29] determined the change in the Chongming coast Dongtan (China) and response to river sediment load using eight Landsat 5 and 7 images from 1987 to 2010, using NDVI and including EPR. Image enhancement, haze reduction, and geometric correction were performed and obtained a root mean square error (RMSE) of less than 0.5 pixels for all images. The maximum average rate of change of the coast of +115.5 meters per year occurred in the interval of 1987-1990 and the minimum rate of +20.4 meters per year occurred from 2006 to 2008.

Instead, Özpolata & Demir [30] evaluated the spatiotemporal coastal dynamics of a delta under natural and anthropogenic conditions from 1950 to 2018, in the Seyhan Delta, the largest delta in Turkey and the largest delta in the Mediterranean after the Nile Delta. They used two aerial photographs and five multispectral Landsat satellite images to observe the changes in the coastline along almost 17 km between 1950 and 2018. The DSAS tool with the SCE, EPR and LRR statistics was used for quantitative analysis, considering the natural and anthropogenic drivers of shoreline changes in the Seyhan Delta. The results obtained indicate that the shoreline increased by almost +131 meters with a maximum rate of +22.9 m yr from 1950 to 1956. After the construction of the Seyhan Dam in 1956, the shoreline retreated −2293 meters at the mouth of the river, with a maximum withdrawal rate of -37 meters per year. The main cause of this withdrawal is the capture behind the Seyhan Dam of sediment carried by the Seyhan River. With the above, it affirms that, due to anthropogenic effects, the withdrawal from the coast of the Seyhan Delta will continue with greater severity in the coming years. Likewise, Esmail et al. [31] used DSAS with EPR and LRR, in addition to the help of semi-automatic extraction techniques, they carried out the evaluation and prediction of coastline change using satellite images from Landsat 5 (1990) and Landsat 7 (1999, 2003 and 2015) and multi-temporal statistics of the coast of Damietta (Egypt) with a length of 25 km. Separate gr breakwaters, wharves and dikes have been built to protect the coastline. This study focuses on the evaluation of the coast due to the existence of these structures from 1990 to 2015, in addition to predicting the future changes of the coast in 2020, 2025 and 2035. Three semi-automatic extraction techniques were also used: the iso cluster technique, threshold method and on-screen digitizing method to select the optimum. The disadvantage of the study lies in the use of only five satellite images.

In addition, Nandi et al. [32] used DSAS with EPR and LRR to determine and predict shoreline displacement at Sagar Island, West Bengal, India, utilizing multi-temporal satellite data from Landsat MSS (1975), Landsat TM (1989, 1991) and Landsat ETM + (1999, 2002, 2005, 2008 and 2011). In the Segment A of studies, the results are related to the fact that the total change of the coast of ± 3.20 meters per year and the erosion rate was −7.91 and −7.01 meters per year for the periods 1975–2002 and 2002–2011, respectively. In Study Segment B, the mean rate of shoreline change was high with values of −6.46 meters per year (1975–2002) but the rate decreased to −5.25 meters per year during the later period (2002–2011). Most of the southern part of Sagar Island is vulnerable to the high rate of shoreline erosion. The advantage is shown in its methodology and the analysis period.

However, Goswami et al. [33] used DSAS only with EPR to monitor the dynamics and quantify the rate of change of the coast using Landsat images for 1988, 2000 and 2017, in a coastal stretch of 120 kilometers in Chilika (India). It was concluded that the coast of Chilika is experiencing processes of erosion and accretion with a very high rate of erosion of -13.6 meters per year and accretion of 13.5 meters per year, at the mouth of Lake Chilika, with an average rate of erosion and accretion -1.13 meters per year and 1.41 meters per year for the study area. The advantage of the study is the applied methodology.

Additionally, using DSAS with EPR, LRR and SCE, Manjulavani et al. [34] analyzed NSM to perform coastal change detection along the coastline between Kanyakumari and Tuticorin (India). Landsat-7 images were used for 5 years 2011-2015. The Tuticorin shoreline has experienced heavy accumulation from 1969 to 2006, with a large amount of erosion in 2004, while this study found that from 2011 to 2015, erosion has been controlled. When comparing the studies, they reflect short- and long-term changes such as water-land boundaries. The limitation is the short period of time of analysis, only five years. In that same sense, using DSAS with NSM and EPR, Misra & Balaji [35] elaborated a study on the changes in the coast and land use in three coastal districts of Surat, Navsari and Valsad, located in the south of Gujarat, along the Gulf of Khambat (India), using Landsat 5, 7 and 8 images. The results are related to the endpoint rate of -0.54 meters per year, since it highlights the erosion tendency of the coastline, as well as noting that urbanization leads to immense pressure on

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nearby coastal resources. The advantages are the evaluation of both the coastline and the surrounding soil change. Muskananfola et al. [36] then performed the spatiotemporal analysis of coastline change along Sayung Demak, Central Java, Indonesia, using RBI maps and satellite images (1994, 2000, 2005, 2011, 2018) from Landsat 5.7 and Sentinel 2A. The results show that EPR was -25 meters per year and NSM was -592 meters recorded. Severe erosion was found at Sriwulan, Bedono, and Timbulsoko. The study shows that the southwestern section (Sriwulan and Bedono) is eroding much faster towards land than the northeastern section (Timbusloko and Surodadi), which may be due to different characteristics of the mangrove-covered coastal morphology, bathymetry shapes and water depth.

In contrast, Ozturk and Sesli [37] used NSM, EPR SCE with NDWI, MNDWI, in addition to the Automated Water Withdrawal Index (AWEI – Automated Toilet Extraction Index) conducted the shoreline change analysis of the Kizilirmak lagoon series, in the Kizilirmak Delta, which is one of the 14 wetlands in Turkey that are protected by the Ramsar Convention, which determines the changes that have occurred on the coastline of the series of Kizilirmak lagoons between 1962 and 2013. Landsat satellite images (MSS-TM-OLI) and 1:100,000 scale topographic maps were used to measure the coastlines. Net shoreline motion (NSM), EPR, and SCE methods were used for analysis to determine changes in shoreline delta. The maximum erosion along the delta shorelines was 827 meters, and the total shrinkage in the lagoon areas was 963.7 hectares between 1962 and 2013. The methodology is an advantage of this study.

On the other hand, Qiaoa et al. [38] used DSAS with NSM and EPR, in addition to weighted linear rate regression (WLR), analyzed 55-year (1960–2015) spatiotemporal coastline change with DISP images and Landsat with a spatial resolution of 30 meters from 1985 to 2015. The length of the entire coastline was found to have increased by 25.7% from 472.6 kilometers in 1960 to 594.2 kilometers in 2015. Due to changes in coastline, Shanghai's area expanded by 1,192.5 square kilometers in 2015, which is an increase of 19.9% from its 1960 area. The results determined that Shanghai 's coastline increased by 25.7% length, and the resulting land area caused by the change in coastline increased by 19.9%. The advantage of the study lies in the long evaluation period.

B. Coastal Erosion from Landsat and Sentinel Data at the National Level

On the Colombian Caribbean coast, the Center for Oceanographic and Hydrographic Research (CIOH) [39] on the island of Tierrabomba, digitized coasts from satellite images, orthophotographs, and aerial photographs between 1954 and 2013, with the aim of identifying flood zones and erosion and accretion zones. CIOH used DSAS with EPR.

This study found that the general tendency of the coast is erosive, with accretion zones generated by artisanal anthropic works developed by the indigenous people. The maximum rate of erosion was 2.22 meters per year in the northern part of the Island and the maximum accretion was 1.31 meters per year in the eastern part of the island. Therefore, a total of 52.5 ha eroded and 10.1 ha accumulated between 1954 and 2013 were determined for the study area.

Meanwhile, Gómez [40] evaluated the changes in the coastal landscape from 1988 to 2017, in the northwestern part of the departments of Bolívar and Sucre through Landsat 4 (April 1988) and Landsat 8 (July 2017) satellite images, obtaining as a result the changes in the vegetal cover and the land uses during the last 29 years, as well as the coastal erosion processes in the bays of Cartagena and Barbacoas, in addition to the sedimentation processes in the Labrace sector in the part south of the area. For 1988, the main covers were identified as bare soil and pastures, while for 2017 the main covers are pastures, followed by the urban area, forests and shrimp farms. The Landsat 8 image made it possible to identify areas of sediment supply to the sea at the mouths of the dike channel, in the bay of Cartagena and in the bay of Barbacoas.

On the Pacific Coast, Niño and Oviedo [41], based on aerial photographs, carried out a multitemporal analysis of the evolution of the Tumaco Bay coastline, by identifying, describing, vectoring, and evaluating changes due to erosion, accretion, and anthropogenic invasions, to which the coastline is subjected. It was found that towards the north of the bay erosion processes predominate, towards the south sediment accretion predominates, while towards the center of the bay there is a relative stability of the terrain and no significant changes occur. Of the total extension of the coastline of the bay, 43.16% has remained stable or has not undergone significant changes, 31.14% presents accretion, while 24.18% has been eroding. 1.52% of the intertidal spaces have been invaded with stilt houses and in some cases have been filled with different materials to raise the land and prevent flooding during high tide.

On the other hand, Cifuentes et al. [42], based on Landsat 5 (1986), Landsat 7 (2001) and Landsat 8, evaluated the magnitude of the change of the coastline north of the Buenaventura District, during a period of 30 years. On the coast of the study area there are beaches, cliffs, estuaries, deltas and marshes. The historical positions of the coastline were found, in order to identify the processes of erosion and accretion, from 1986 to 2015. DSAS with NSM and EPR was used. The results obtained show a rate of change of (-) 0.21 meters per year in the coastlines, which reflects their erosive tendency and with maximum EPR values of 26.92 meters of accretion and (-) 21.01 meters of coastal erosion. The advantage of the study is presented in the long period of analysis.

As for the socioeconomic impact, according to the information reported by the Ministry of Environment and Sustainable Development (MADS) [43], it refers that the Institute of Marine and Coastal Research (Invemar) estimated that said impact caused by coastal erosion for 2001 of 1.7% of the country's population and 1.5% of the Gross Domestic Product (GDP). In this same sense, for 2030 it estimates an affectation of 2% of the population of the coastal areas of the country and an affectation of the GDP of 2.2%, mainly on the Caribbean coast. Therefore, it is necessary to take policies aimed at mitigating coastal erosion.

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II. Materials and Methods

A. Study Area and Image Acquisition

The study area is located on the Colombian Caribbean coast, in the department of Atlántico, in the jurisdiction of the municipalities of Tubará and Puerto Colombia. The coastal area to be analyzed is located between the coordinates 74º52'34"W 11º2'43"N and 75º1'43"W 10º56'15"N (Fig. 1). This area is important for the development of economic activities such as tourism, especially for its beaches.

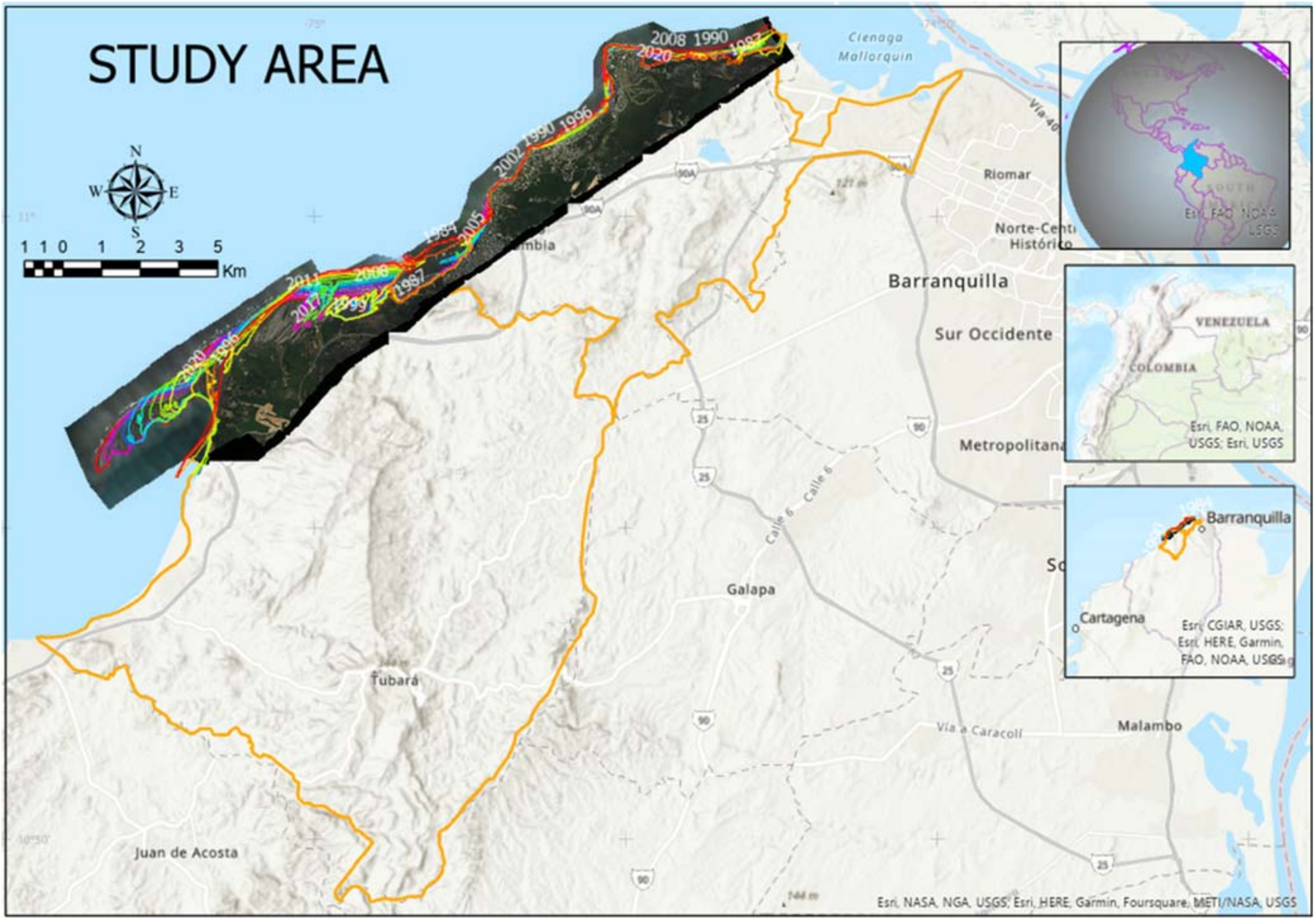

Fig. 1 Location of the study area in the municipalities of Tubará and Puerto Colombia

TABLE I
List of Image Collections Used

Year	Sensor	GEE Catalog	Total images
1984	Landsat 5TM	LANDSAT/LT05/C01/T1_SR	3
1987	Landsat 5TM	LANDSAT/LT05/C01/T1_SR	22
1990	Landsat 5TM	LANDSAT/LT05/C01/T1_SR	11
1996	Landsat 5TM	LANDSAT/LT05/C01/T1_SR	19
1999	Landsat 5TM	LANDSAT/LT05/C01/T1_SR	27
2002	Landsat 7TM	LANDSAT/LE07/C01/T1_SR	21
2005	Landsat 7TM	LANDSAT/LE07/C01/T1_SR	41
2008	Landsat 5TM	LANDSAT/LT05/C01/T1_SR	2
2011	Landsat 7TM	LANDSAT/LE07/C01/T1_SR	48
2014	Landsat 8 OLI	LANDSAT/LC08/C01/T1_SR	59
2017	Landsat 8 OLI	LANDSAT/LC08/C01/T1_SR	64
2020	Sentinel 2	COPERNICUS/S2	119
Total			436

1. Time Dimension Analyzed

This project focused on the decades from 1980 to 2020 and for this the collection of satellite images presented in Table I, which were acquired on the *Google Earth platform Engine* (GEE) of *Landsat* and *Sentinel* 2, with a total of 436 images used for the mentioned period.

B. Methodology

To evaluate the coastal erosion of the study area, the methodology presented in Fig. 2 was proposed, which is composed of six main steps:

1. The review and analysis of literature related to coastal erosion, coastline, among other documents, was carried out in order to define and adjust the methodology, in addition to structuring this document.
2. To determine and evaluate the change in the coastline, the GEE platform is used, where the collections of the selected years are extracted, later the MNDWI is implemented, which uses the green and Short Wave Infrared (SWIR) bands, which allows to enhance the elements found in the open sea, also decreases those related to built-up areas that are often correlated with the open sea in other indices [44].

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Collections are downloaded for each year.

3. Subsequently, the coastline extraction is performed using the process recommended by the company *Esri* for *ArcGis Pro* [45]. Then, the shoreline change is analyzed with the *Digital Shoreline module Analysis System* (DSAS) v5.0 [46], developed by *The United States Geological Survey* (USGS) in ArcGis 10.5, which allows calculating statistics of rates of change from multiple historical positions of the coastline, in addition to predicting the coast in 10 and/or 20 years in areas of uncertainty [46]. The statistics to determine are: EPR, this is calculated by dividing the distance of the movement of the coast by the time elapsed between the oldest and the most recent coast; NSM, which is the distance between the oldest and youngest coastline for each transect and the units are in meters and SCE reports a distance (in meters), not a rate; said SCE value represents the greatest distance between all the coasts that intersect a given transect.

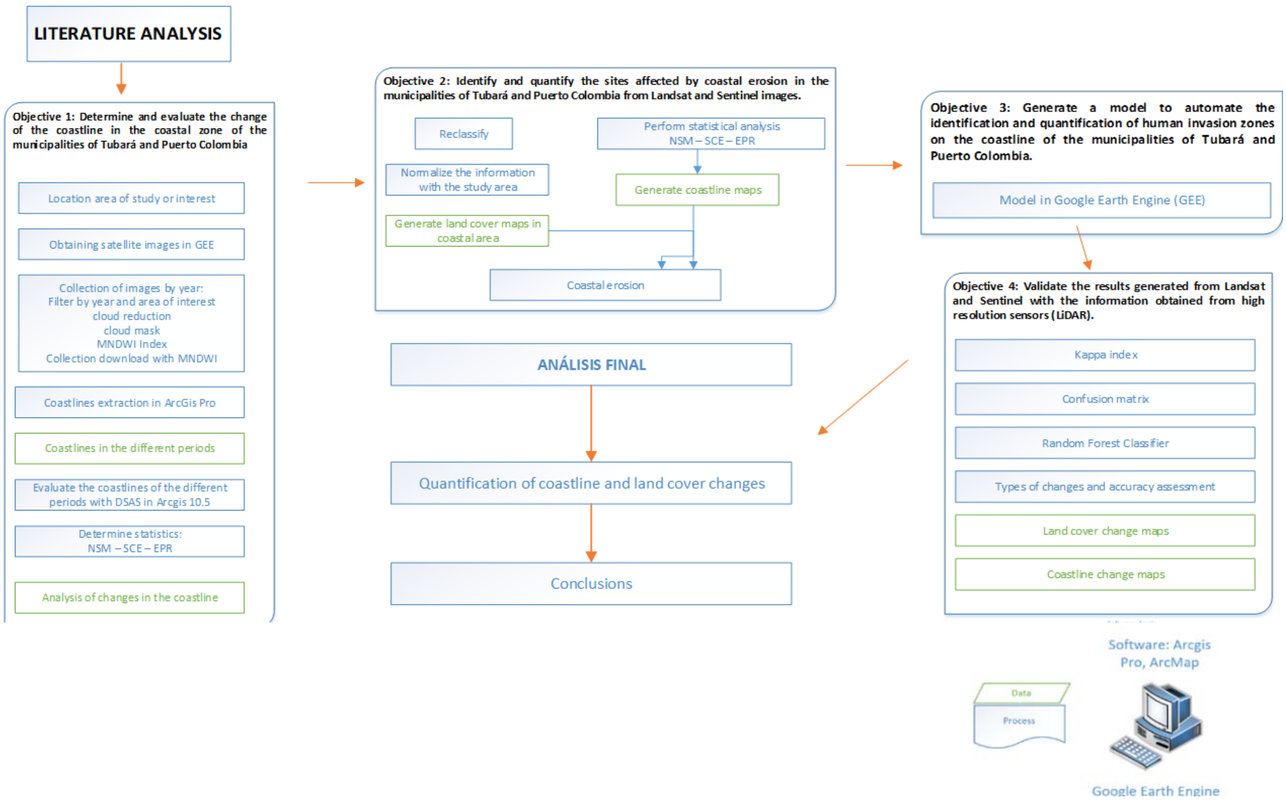

Fig. 2 Flowchart of the methodology

4. Identify and quantify the erosion and accretion on the beaches of the municipalities of Puerto Colombia and Tubará, based on the 10 and 20-year predictions in ArcGis Pro, based on information from the GEE platform, where the coverage classification is carried out for 1987, 1997, 2002, 2011 and 2020. Likewise, the Random Forest classifier is used, with which the soil cover is determined and its changes in the study area are calculated.
5. The validation of the land cover data is carried out in the GEE platform, where the Kappa index, Confusion matrix and the general accuracy of the classifier are calculated, which allows evaluating the accuracy in the classification of the covers.
6. The proposed model is used in the GEE platform with Landsat 5 [47], Landsat 7 [48], Landsat 8 [49] and Sentinel [50]. The code has been taken from various repositories in *Google Earth Engine* and *GitHub*, and video tutorials on *Youtube*. The code is adjusted to the needs of the spectral index to be used and the study area.
7. Finally, the discussion is carried out between the results obtained from different studies in the area of the present study, both locally and internationally, to later give the conclusions found in this study and the recommendations that emerge from the study.

III. Results

According to the methodology used, the following products are obtained per stage, as shown in Fig. 3.

The image processing was carried out through the GEE platform, where twelve images of collections from 1984, 1987, 1990, 1996, 1999, 2002, 2005, 2008, 2011, 2014, 2017 and 2020 were generated. The images come from the Landsat 5, 7 and 8 and Sentinel 2 satellites. From *Google Earth repositories Engine* and *Github*, mainly, script models were taken and adjusted to the study area, which allowed the atmospheric correction, the compiled satellite products, in addition to obtaining the MNDWI for each year.

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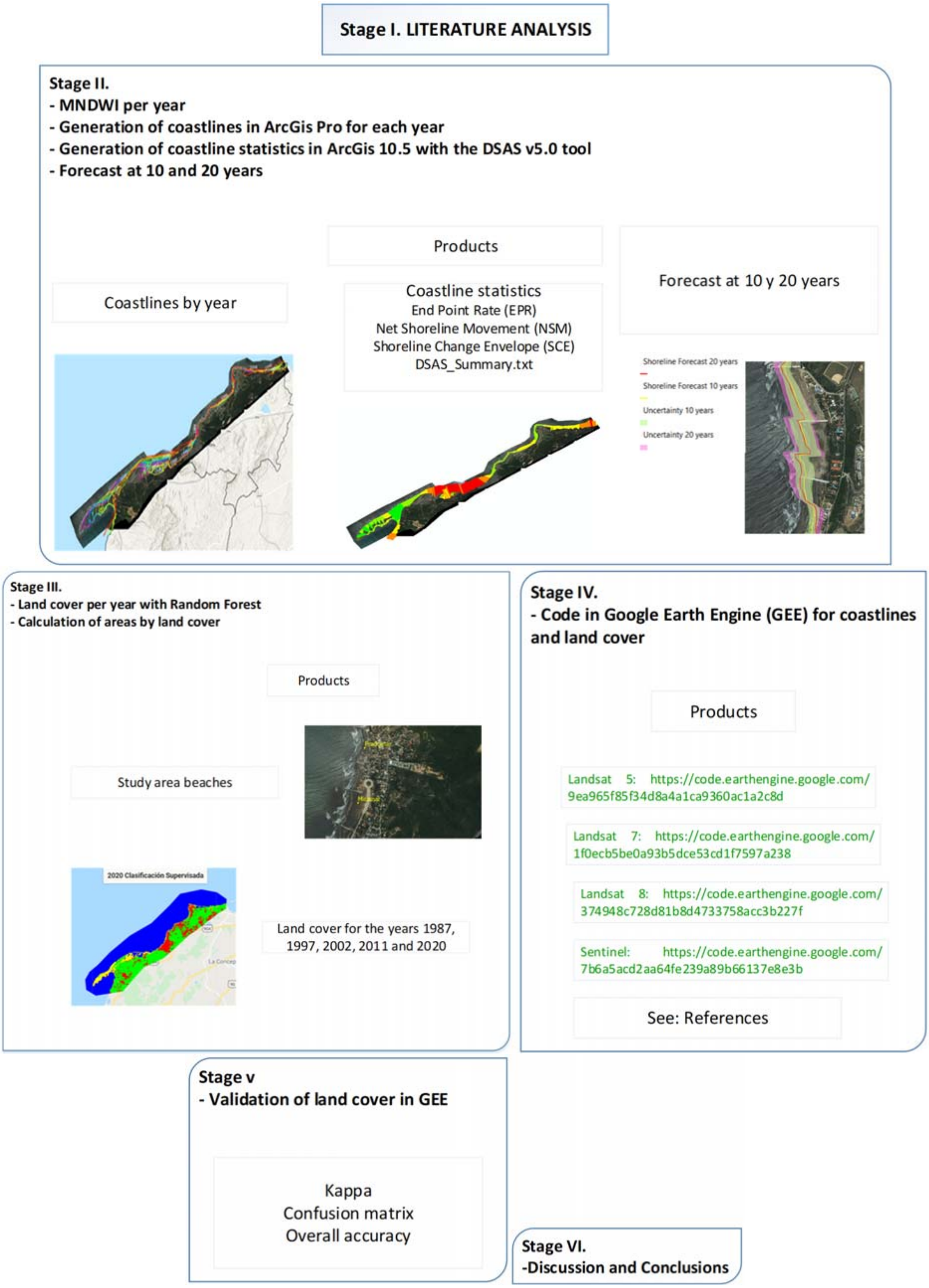

Fig. 3 Products obtained by stage

The images were processed freely, with a total number of 463, as can be seen in Table I. The products obtained (collection of images) are saved in the cloud and downloaded at the time of further processing to obtain the coastline.

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Subsequently, twelve images obtained with the MNDWI were downloaded, in the 36-year time series and processed in *ArcGis Pro* to obtain the coastline for each year, and then processed with the DSAS v5 tool in *ArcGis* 10.5.

From the results obtained in the coastline, the change that exists in the study period was demonstrated, as shown in Fig. 4.

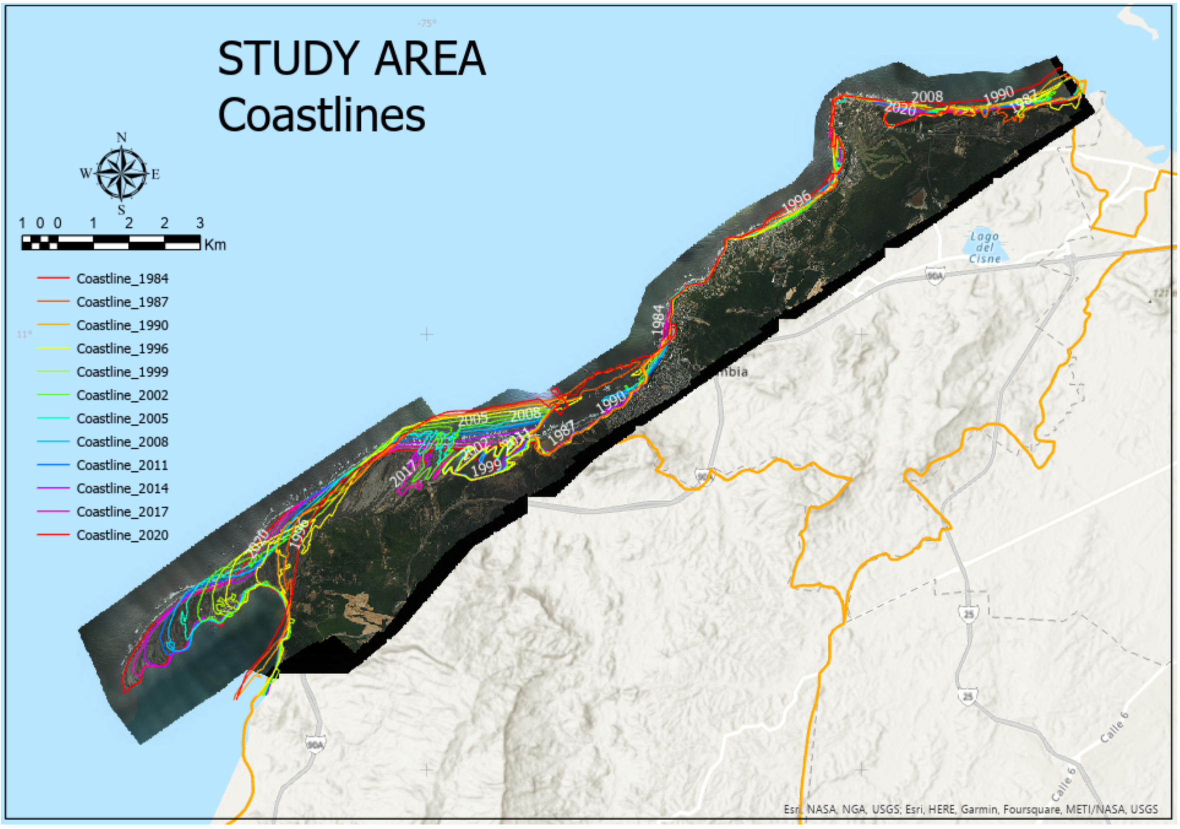

Fig. 4 Coastlines of the analyzed time dimension.

Fig. 5 shows the NSM of the coastline along the coastal zone section, showing that negative values imply erosion, while positive values imply accretion.

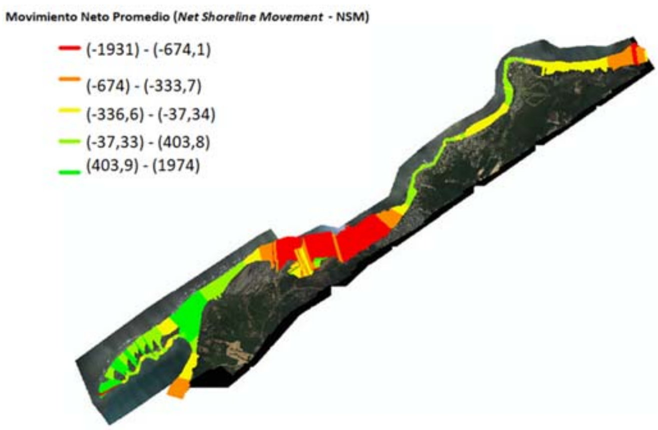

Fig. 5 NSM in the study period

While, Fig. 6 shows the EPR of the coastline along the section of the coastal zone, where it is shown that negative values imply erosion, while positive values imply accretion.

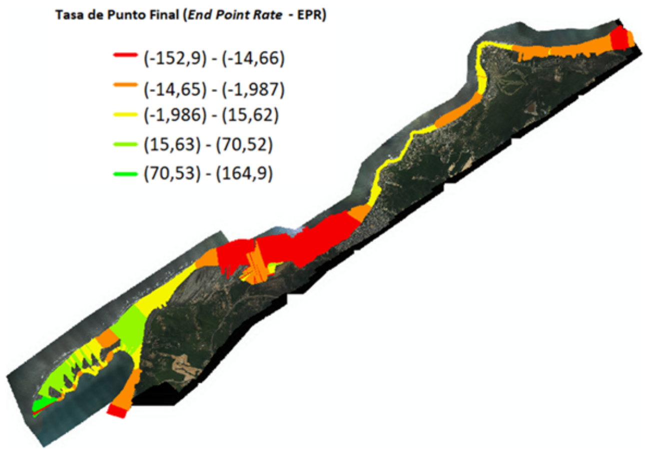

Fig. 6 EPR in the study period

TABLE II
DESCRIPTIVE STATISTICS OF THE EROSION AND ACCRETION OF THE COAST BETWEEN TUBARÁ AND PUERTO COLOMBIA

Coastline Classification	Coastline Statistics		1984-2020 (meters per year)	Total Transects (amount)	% of total Transects
Erosion	EPR	Max	-152.9	1147	61
	NSM	Max	-1931.1	1147	61
Accretion	EPR	Max	164.9	736	39
	NSM	Max	1937.7	736	39

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With the DSAS v5.0 tool, it was determined that during the period between 1984 and 2020, the maximum NSM for erosion was -1931.1 meters per year, while for accretion the maximum NSM was 1937.7 meters per year. Similarly, the highest erosion was -152.9 meters per year, while the highest accretion was 164.9 meters per year, as shown in Table II.

Regarding the general averages of the coastline change envelope (SCE), the following results were presented:

- ✓ Total number of transects: 1883
- ✓ Average distance: 442.57m
- ✓ Maximum distance of 1979.47 m in the ID 974 transect
- ✓ Minimum distance of 6.74 m in the transect ID 290 4

The DSAS v5.0 tool allowed to predict the location of the coastline at 10 and 20 years as shown in Fig. 7. The results show, for the study area, an erosion of 238.32 ha and accretion of 181.96 ha in the 10-year prediction (2031), while for the 20-year prediction (2041) there is an erosion of 544.04 ha and accretion of 133.94 ha.

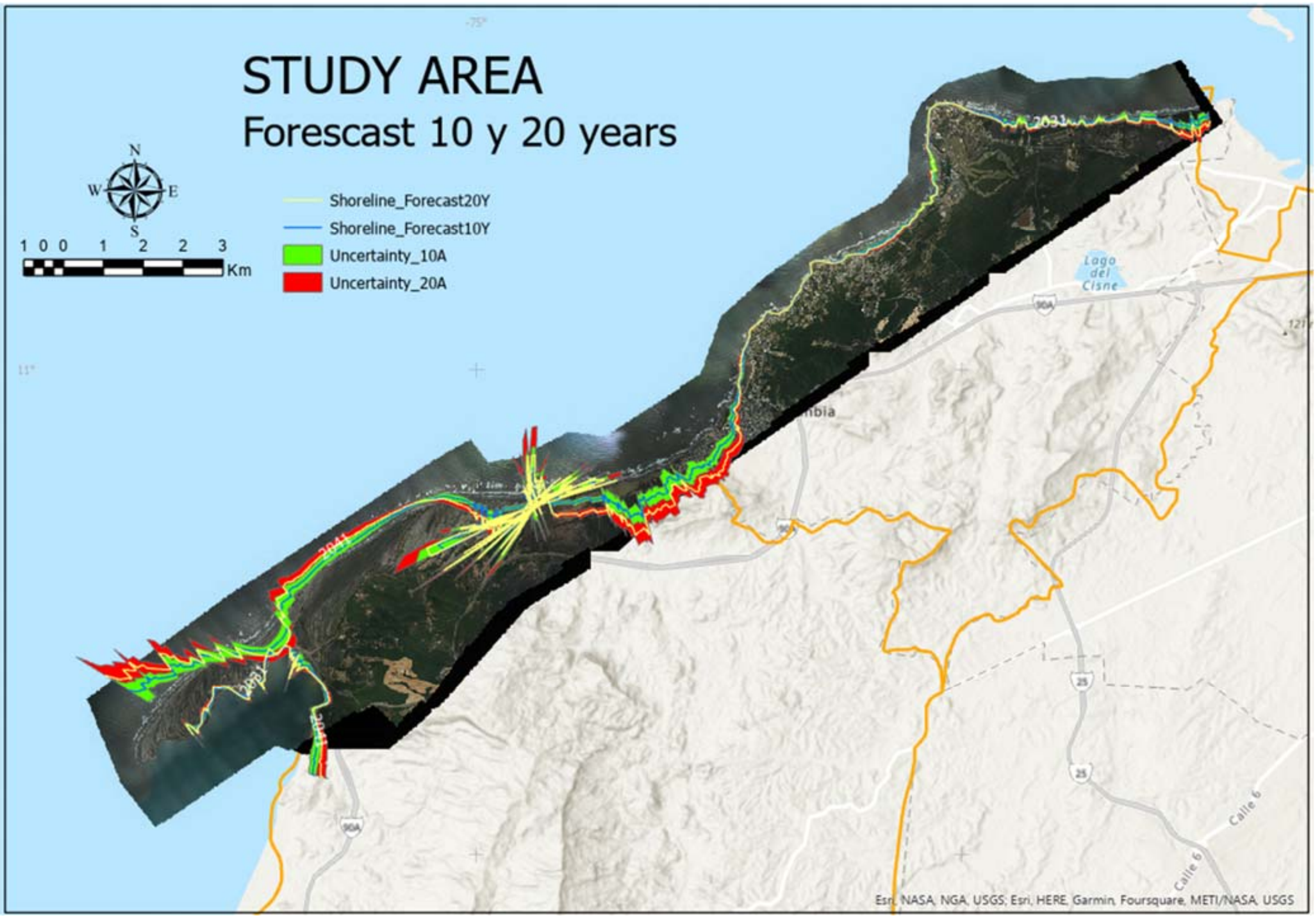

Fig. 7 Prediction of the coast in the study area in the next 10 and 20 years

TABLE III
LOSS OF THE MAIN TUBARÁ AND PUERTO COLOMBIA BEACHES

Beach	Meters of beach loss	
	2031	2041
Sabanilla	44.44	24.98
Salgar	81.78	104.29
Pradomar	8.63	7.39
Miramar	40.54	26.4
Muelle	406.63	607.65

Taking into account that in the area of this study the beaches of Sabanilla, Salgar, Pradomar, Miramar and Muelle [51] are located in the jurisdiction of the municipality of Puerto Colombia and Puerto Velero in the municipality of Tubará, which are very important for the tourism of the aforementioned municipalities and the Caribbean region of Colombia, based on the results for the predictions at 10 and 20 years, the loss of beach was determined from the coastline of 2020, as detailed in Table III.

While for Puerto Velero Beach, accretion will continue to occur for 2031 and 2041, according to the dynamics that have been occurring in the sector, that is, accumulation of sediments along the beach.

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(a) Sabanilla Beach

(b) Salgar Beach

(c) Pradomar and Miramar beaches

(d) Muelle Beach

Fig. 8 (e) Velero Beach

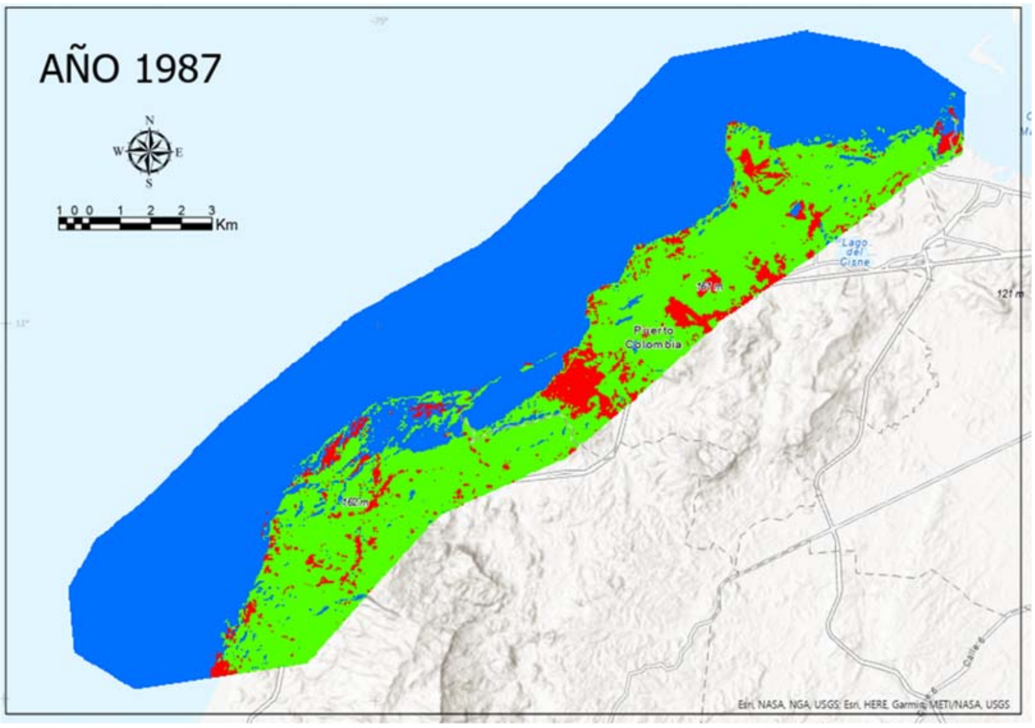
Fig. 8 Beaches in the municipalities of Puerto Colombia and Tubará (Atlántico, Colombia)

Similarly, the supervised classification was carried out on the GEE platform with the *Random Forest algorithm* for 1987, 1997, 2002, 2011 and 2020 with three large coverages according to *Corine Land Cover* (CLC), Fig. 9 shows the changes in the analyzed covers.

From the maps obtained with *Random Forest* in GEE, in the study period, it was shown that the Water Surfaces remained relatively constant (average 59.8%), as well as the Agricultural Territories (31.8%), while that the artificialized Territories presented a strong change between 2011 and 2020, with an increase of 33.9% of the area. The values are detailed in Table IV and Fig. 9.

TABLE IV
AREAS (HA) OF LAND COVER OBTAINED PER YEAR OF THE STUDY AREA

Land Cover	1987	1997	2002	2011	2020
Water surfaces					
Ha	7990.5	7906.9	8084.5	7262.7	6992.2
%	62.5	61.8	63.2	56.8	54.7
Agricultural territories					
Ha	4108.7	4031.6	3795.8	4373.1	4050.9
%	32.1	31.5	29.7	34.2	31.7
Artificialized territories					
Ha	692.1	852.9	911.0	1155.5	1748.3
%	5.4	6.7	7.1	9.0	13.7
Total (ha)	12791.4	12791.4	12791.4	12791.4	12791.4



(a) Land cover for 1987

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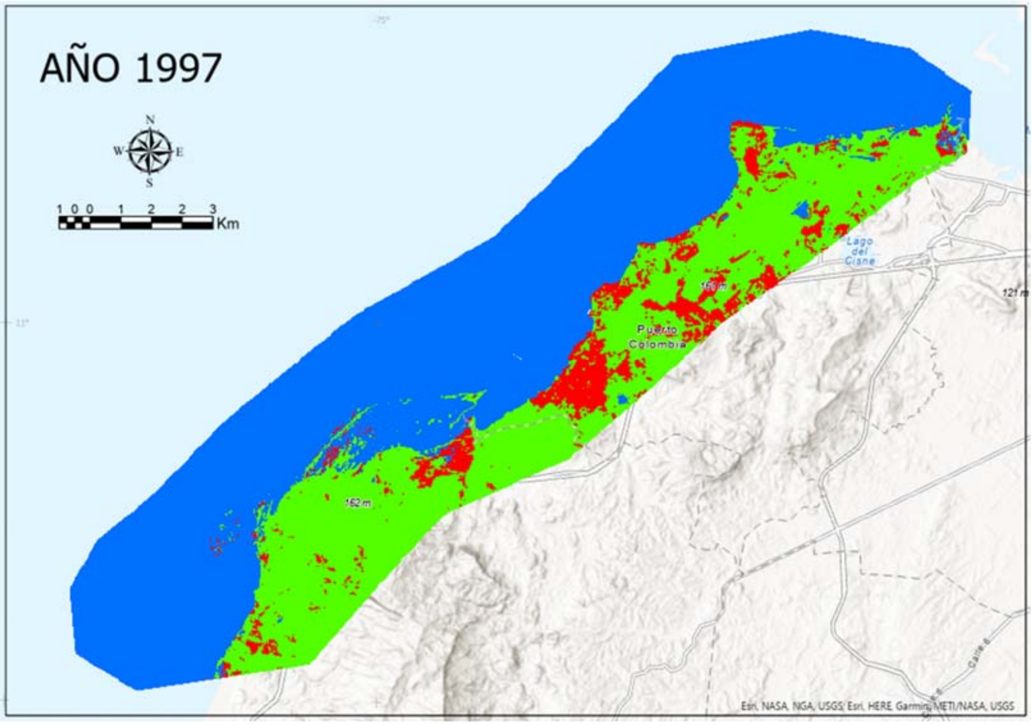
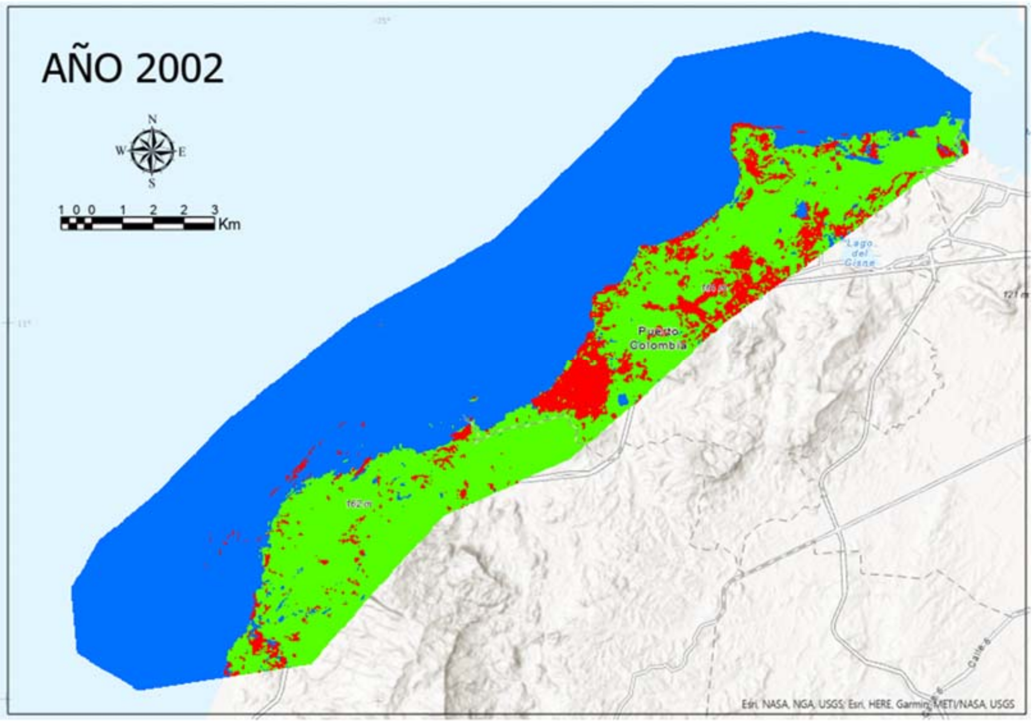


(b) Land cover for 1997



(c) Land cover for 2002

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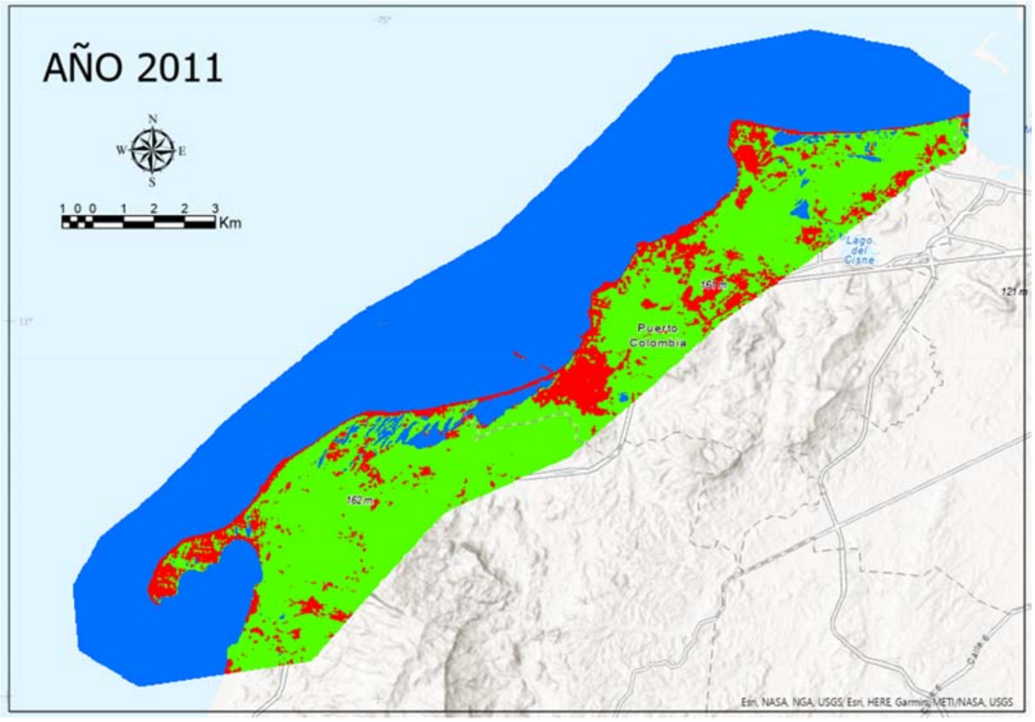
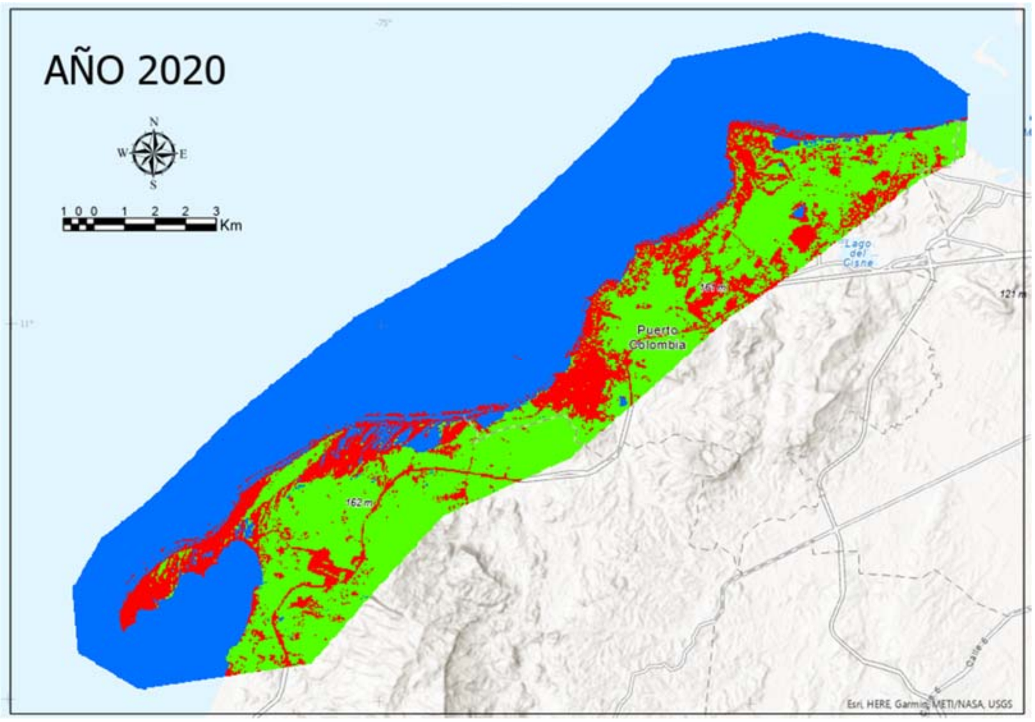


(d) Land cover for 2011



(e) Land cover for 2020

1. Artificialized territories
2.Agricultural territories
5.Water surfaces

Fig. 9 Land cover according to CLC for the study area

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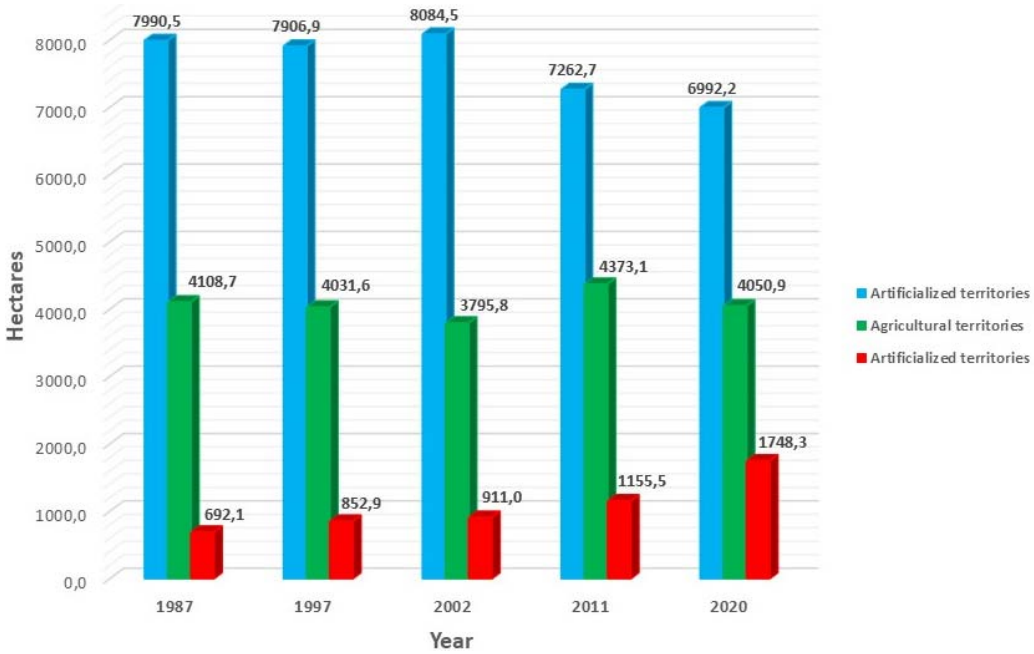

Fig. 10 Supervised classification with the *Random Forest algorithm* for 1987, 1997, 2002, 2011 and 2020 for the study area

TABLE V
CONFUSION MATRIX AND KAPPA INDEX FOR 1987

Land Cover classes	Agricultural territories	Artificialized territories	Water surfaces
Agricultural territories	3	0	0
Artificialized territories	0	Two	0
Water surfaces	0	0	8
	Overall Accuracy: 100%	Kappa: 1	

TABLE VI
CONFUSION MATRIX AND KAPPA INDEX FOR 1997

Land Cover classes	Agricultural territories	Artificialized territories	Water surfaces
Agricultural territories	3	0	0
Artificialized territories	0	Two	0
Water surfaces	0	0	12
	Overall Accuracy: 100%	Kappa: 1	

TABLE VII
CONFUSION MATRIX AND KAPPA INDEX FOR 2002

Land Cover classes	Agricultural territories	Artificialized territories	Water surfaces
Agricultural territories	1	0	0
Artificialized territories	0	5	0
Water surfaces	0	0	8
	Overall Accuracy: 100%	Kappa: 1	

TABLE VIII
CONFUSION MATRIX AND KAPPA INDEX FOR 2011

Land Cover classes	Agricultural territories	Artificialized territories	Water surfaces
Agricultural territories	13	0	0
Artificialized territories	0	10	0
Water surfaces	0	0	23
	Overall Accuracy: 100%	Kappa: 1	

In the evaluation of the thematic accuracy carried out for the five different years (1987, 1997, 2002, 2011 and 2020), global accuracies were obtained ranging from 100% in 1987 to 96.3% in 2020, with a Kappa index between 1 in 1987 to 0.94 in 2020. The results of the confusion matrix are presented in Tables V-IX.

TABLE IX
CONFUSION MATRIX AND KAPPA INDEX FOR 2020

Land Cover classes	Agricultural territories	Artificialized territories	Water surfaces
Agricultural territories	3	0	0
Artificialized territories	1	8	0
Water surfaces	0	0	fifteen
	Overall Accuracy: 96.30%	Kappa: 0.94	

IV. DISCUSSION

Coastal areas present environmental, social and economic problems that affect the quality of life of the inhabitants who live in these regions. Among the environmental aspects, the erosion of the coast stands out, which occurs due to various factors, among them [4]:

- Natural factors:
  - ✓ Precipitation
  - ✓ Tectonic uplift and subsidence
  - ✓ Underwater landslides
  - ✓ Hurricanes and cyclones
- Anthropic factors:
  - ✓ Material Extraction
  - ✓ Damming of rivers
  - ✓ Modification of coastlines
  - ✓ Construction of fixed works

Mentaschi et al. [52], in the sixth and last report of the year 2021 in the Intergovernmental Panel on Climate Change

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(IPCC), reports the loss of coastal area during a period of 30 years (1984-2015), along the Pacific coast of America South of 250 km^2 and along the Atlantic coast of 780 km^2 of loss of coastal area. Although in the present study similar values of erosion and accretion were found in the study area, it is necessary to take into account the general dynamics of the coasts in the Atlantic of South America, as mentioned.

The present work determined, in the coastlines, that the movement of the EPR as the Net Coastal Movement (NSM) presented similar values for both erosion and accretion. Finally, the SCE presented an average distance of 442.57 meters, which demonstrates the great dynamics of the study area.

Taking into account the values found that are presented in Table II, Figs. 5 and 6, for the place and the period of analysis, there was more accretion than erosion. The previous situation probably arose because breakwaters were built in Bocas de Ceniza (mouth of the Magdalena River), which caused the disappearance of some islands such as Isla de Carpinteros, Isla Verde, Isla Sabanilla and Isla del Medio according to what was reported in the Maritime Historical Atlas of Colombia - XIX century [53]. Therefore, the above allowed the littoral drift (transportation of materials along the coast) to accumulate and will make it possible to start the molding of the arrow or sand hook in Puerto Velero, located in the area of this study, as shown in Fig. 10. Likewise, the area was affected by the sediments generated by the Magdalena River [53] and its direction along the coast, as shown in Fig. 11, taken from the Maritime Historical Atlas of Colombia - XIX Century [53].

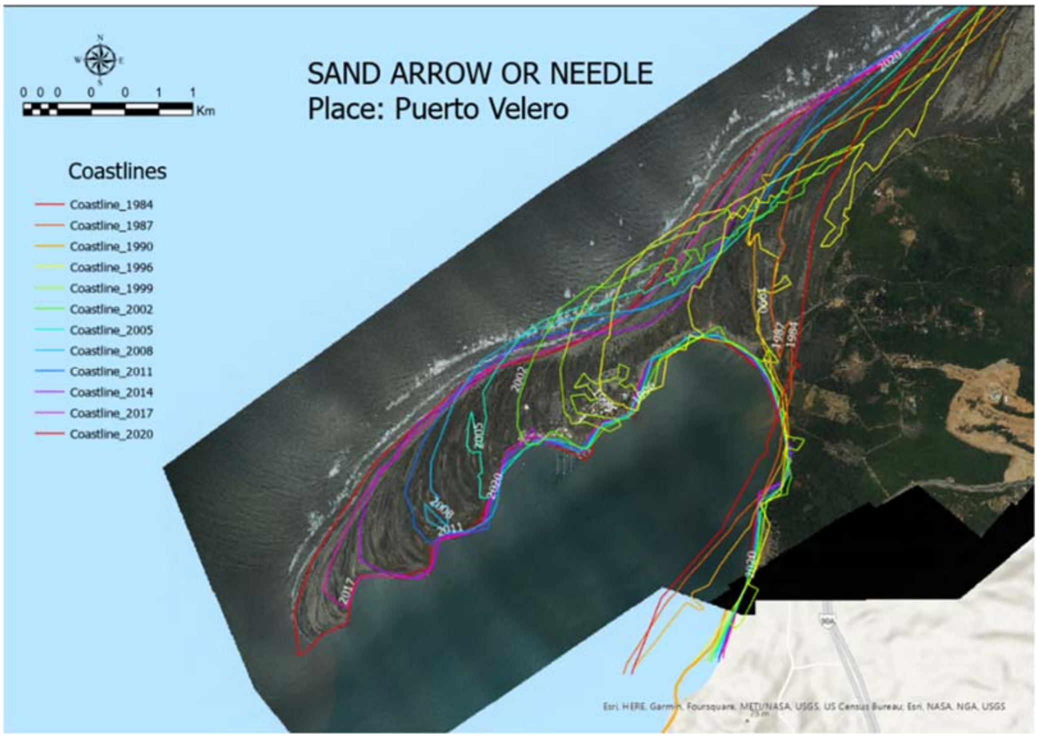

Fig. 10 Site of greatest accretion in the study area

However, when making the prediction of the coastline for the study area, an erosion of 238.32 ha and accretion of 181.96 ha were determined for the 10-year prediction (2031), while the 20-year prediction (2041) shows erosion of 544.04 ha and accretion of 133.94 ha, which is consistent with the predictions of the IPCC [52] when mentioning that throughout the 21st century, coastal areas will experience a continuous rise in sea level, which will contribute to coastal erosion and that coastal flooding will be more severe and frequent in low-lying areas. In addition, it was determined that the analyzed beaches will present greater erosion than accretion and there will be greater erosion in Muelle beach in the municipality of Puerto Colombia, with 406.63 meters (10-year prediction) and 607.65 meters (20-year prediction), caused by the rise in sea level throughout the 21st century according to the predictions of the IPCC [52].

Likewise, an accretion of 181.96 hectares was determined for the 10-year prediction (2031) and 133.94 hectares for the 20-year prediction (2041). It is necessary to take into account an important social consideration, which is the phenomenon of coastal invasions, caused by the installation of houses in these areas. The foregoing causes the loss of natural coverage, degradation of coastal ecosystems and demand for basic services; this due to the valuation of the use of the coastal zone as places of visual, recreational, cultural and social attraction for different economic, political and cultural activities [54]. Added to the above, there is a potential generation of risks to the safety of the population due to natural events, by locating residential and commercial areas in places unsuitable for these purposes.

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It is necessary to mention that one of the limitations of the study is related to the fact that the *Digital Shoreline tool Analysis System* DSAS v5.0, only takes into account the coastlines of the different years, but it is not possible to include other issues such as changes in coverage, social or environmental factors typical of the region, so they must be taken into account, but separately, for later studies. In this regard, the present study determined that the coverage that presented the greatest change in the study area was that of artificialized territories, which went from having 1,155.5 ha in 2011 to having 1,909.9 ha in 2020, related, particularly with the accretion that has been occurring during the last decades in the Puerto Velero sector (Municipality of Tubará), as well as the dynamics and population increase and its affectation of the agricultural territories, which have decreased during the period 2011-2020, to go from 4373.1 ha to 3726.8 ha. Therefore, it will be necessary to implement measures aimed at land management and proper use of the land, in order to mitigate the effects of changes in land use.

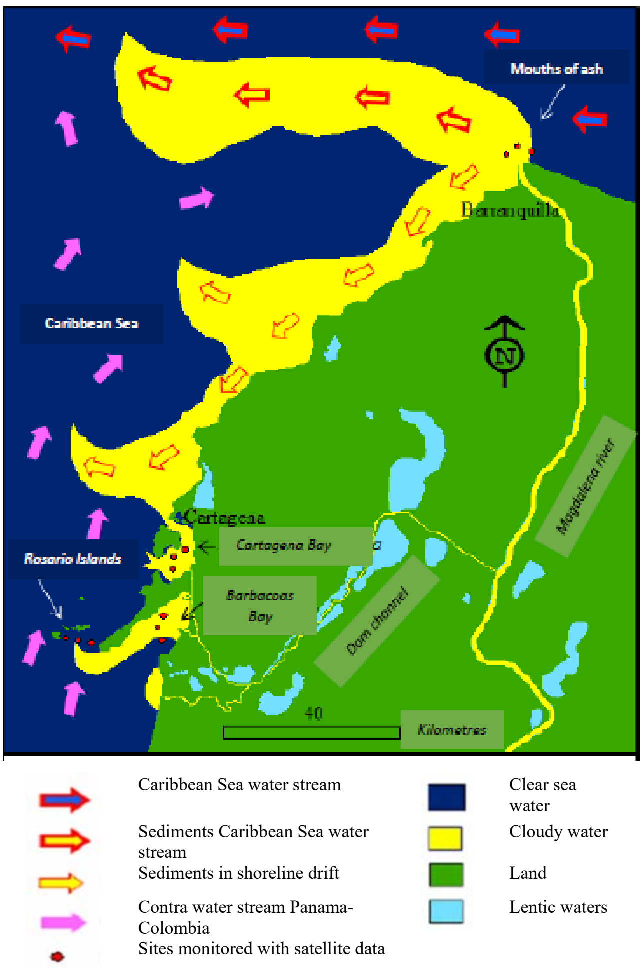

Fig. 11 Sediment dispersion of the Magdalena River in the Caribbean Sea (taken from Maritime Historical Atlas of Colombia XIX Century [53])

The scripts in the present study can be found in References. The scripts were used from the official website *Google Earth Engine* and *YouTube* tutorials, mainly. They were adjusted to the study area and the spectral index.

V. Conclusions

The coastlines for the proposed years were determined through the GEE platform, since it is a tool that supports the analysis of a large number of satellite images, from different periods, and their analysis in the cloud such as calculation of areas, coverage, different spectral indices, among others. Likewise, the use of the *Digital Shoreline tool Analysis System* DSAS v5.0 made it possible to calculate the rate of change statistics for multiple coastlines and predict them. The present semi-automated method can be replicated and allows the analysis of the coastal zone in different places on the planet.

The predictions for 10 and 20 years allowed us to establish that there will be greater erosion than accretion, especially on the beaches of Salgar and Muelle, which are an important element in the economic development of the region. Although it is not the object of this study, it is highlighted that coastal erosion will occur in the urban area of the municipality of Puerto Colombia.

Regarding the use of the MNDWI index, it worked very well to separate water and land, according to that recommended in previous studies, and thus determine the coastline for each of the years selected in this study.

This study is a tool that will enable the understanding of the dynamics of the coastal zone to the Mayors, Governors, General Maritime Directorate (DIMAR), Institute of Marine and Coastal Research (INVEMAR), National Environmental System (SINA), Regional Autonomous Corporations (CAR), National Authority for Environmental Licenses (ANLA), Special Administrative Unit of the System of National Natural Parks of Colombia (UAESPNN), will often help implement policies and measures aimed at mitigating the effects of sea level rise and, consequently, of the change in the coastline of the Colombian Caribbean.

Finally, based on this study, it is possible to carry out work in the field to verify the coastline and monitor its change in a short period of time, as well as to use it in places such as the Pacific Coast. take into account its difficult climatic conditions.

References

[1] National Planning Department (DNP).; Marine and Coastal Research Institute (INVEMAR). *Basic elements for the Integrated Management of Coastal Zones*. Editorial Gente Nueva: Bogotá DC, Colombia, 2008. ISBN: 978-958-8340-36-4.

[2] Eurosion – European Commission. *Living with Coastal Erosion in Europe, Sediments and Space for Sustainability, Eurosion Study Results*. Office for Official Publications of the European Community: Luxembourg, 2005. ISBN: 92-894-9918-4.

[3] Marine and Coastal Research Institute (INVEMAR). *Report on the State of the Marine and Coastal Environments and Resources of Colombia*. Periodic Publications Series No. 3: Santa Marta, Colombia, 2021. ISSN: 1692-5025.

[4] Navarrete-Ramirez, S. (2014). *Protocol Indicator Variation Coastline: Beach Profiles*. Invemar General Publications Series No. 73: Santa Marta, Colombia, 2014. ISBN: 978-958-8448-81-7.

[5] Steer, R.; Arias-Isaza F.; Ramos A.; Sierra-Correa P.; Alonso D.; Ocampo P. *Base document for the elaboration of the "National Policy of Integrated Management of the Colombian Coastal Zones". Consultancy document for the Ministry of the Environment*. Special Publications Series

Open Science Index, Geological and Environmental Engineering Vol:17, No:10, 2023 publications.waset.org/10013289.pdf

No. 6: Bogotá DC, Colombia, 1997.

[6] National Administrative Department of Statistics. Available online: https://www.dane.gov.co/index.php/estadisticas-por-tema/pobreza-y-condiciones-de-vida/necesidades-basicas-insatisfechas-nbi (accessed 08 March 2021).

[7] Posada, B.; Hainaut, William. *Diagnosis of coastal erosion in the Colombian Caribbean*. Invemar General Publications Series No. 13: Santa Marta, Colombia, 2008.

[8] Rojas-Aguirre, AS; L. Cardona-Acuña, M. A; Mutis- Martinezguerra, DI; Gomez-Lopez, J. Vega; C. Daza. *20 years (1999-2018) of monitoring mangroves in the islands of San Andrés and Providencia*. Invemar General Publications Series No. 107: Santa Marta, Colombia, 2019. ISBN: 978-958-8935-50-8.

[9] Alzate A., OA, & López R., JD *A Food Security Strategy for the Colombian Pacific from the Perspective of the Communities*. DFID Project, Buenaventura, Colombia, 2003.

[10] Mohamed-Katerere, J.; Smith, M. *The role of ecosystems in food security* 2013, *Volume 64.* 14-22.

[11] Cardozo, O. D., & Da Silva, C. J. (2013). *Urban Applications of Remote Sensing*. Digital Geographic Magazine. Digital Geographic Magazine. Faculty of Humanities: Argentina, 2013. ISSN 1668-5180.

[12] Ministry of Environment. *National environmental policy for the sustainable development of ocean spaces and coastal and insular areas of Colombia.* Forms and Printed SA: Bogotá DC, Colombia, 2000. ISBN: 958969721-6.

[13] Zhang, X., Yang, Z., Zhang, Y., Ji, Y., Wang, H., Lv , K., & Lu, Z.; Spatial and temporal shoreline changes of the southern Yellow River (Huanghe) Delta in 1976–2016. *Marine Geology* 2018, 188-197.

[14] Pardo-Pascual, JE, Almonacid-Caballer, J., Sánchez-García, E., Balaguer-Beser, AA, & Palomar-Vázquez, J; Evaluation of annual mean shoreline position deduced from Landsat imagery as a mid-term coastal evolution indicator. *Marine Geology* 2016, 79-88.

[15] Pardo-Pascual, JE, García, ES, Almonacid-Caballer, Palomar-Vázquez, Jesús, J., Priego de los Santos, E., Balaguer-Beser, Á; Assessing the Accuracy of Automatically Extracted Shorelines on Microtidal Beaches from Landsat 7, Landsat 8 and Sentinel-2 Imagery. *remote sensing* 2018.

[16] Cabezas - Rabadán, C., Pardo-Pascual, J., Palomar-Vázquez, J., & Fernández- Sarría, A.; Characterizing beach changes using high-frequency Sentinel-2 derived shorelines on the Valencian coast (Spanish Mediterranean). *Science of the Total Environment* 2019; 216-231.

[17] Almonacid-Caballer, J., Cabezas-Rabadán, C., E., P.-PJ, Palomar-Vázquez, J., & Fernández- Sarría, A; Monitoring of the response of Mediterranean beaches to storms and anthropic actions using Landsat images. *International Journal of Geographic Information Science and Technology* 2019; 119-139.

[18] Do, ATK; de Vries, S., and Stive, MJF; The estimation and evaluation of shoreline locations, shoreline-change rates, and coastal volume changes derived from Landsat images. *Journal of Coastal Research* 2019; 35(1), 56–71, ISSN 0749-0208.

[19] Kuleli , T., Guneroglu , A., Karsli, F., & Dihkan , M.; Automatic detection of shoreline change on coastal Ramsar wetlands of Turkey. *Ocean Engineering* 2011; 1141-1149.

[20] Kumar, TS, Mahendra, RS, Nayak, S., Radhakrishnan, K., & Sahu, K.; Coastal Vulnerability Assessment for Orissa State, East Coast of India. *Journal of Coastal Research* 2010; 523-534.

[21] Saravanan, S., KSS, P., & Vishnuprasath, S.; Monitoring Spatial and Temporal Scales of Shoreline Changes in the Cuddalore Region, India. *Coastal Zone Management* 2019; 99-112.

[22] Behling, R., Milewski, R., & Chabrillat, S.; Spatiotemporal shoreline dynamics of Namibian coastal lagoons derived by a dense remote sensing time series approach. *Int J Appl Earth Obs Geoinformation* 2018; 262-271.

[23] Hagenaars, G., De Vries, S., Luijendijk, AP, De Boer, WP, & Reniers, AJ; On the accuracy of automated shoreline detection derived from satellite imagery: A case study of the sand motor mega-scale nourishment. *Coastal Engineering* 2018; 113-125.

[24] Abu Zed, A., Soliman, M., & Yassin, A.; Evaluation of using satellite image in detecting long. Alexandria Engineering Journal 2018; 2687–2702.

[25] Choung, Y.-J., & Jo, M.-H.; Shoreline change assessment for various types of coasts using multi-temporal Landsat imagery of the east coast of South Korea. *Remote Sensing Letters* 2016; 91-100.

[26] El-Ashmawy, N. Automatic determination of shoreline at maximum retreating. *The Egyptian Journal of Remote Sensing and Space Sciences* 2019; 247-252.

[27] Mikosz Gonçalves, R., Saleem, A., Queiroz, HA, & Awange, JL; A fuzzy model integrating shoreline changes, NDVI and settlement influences for coastal zone human impact classification. *Applied Geography* 2019.

[28] Ciritci, D., & Turk, T.; Automatic Detection of Shoreline Change by Geographical Information System (GIS) and Remote Sensing in the Goksu Delta, Turkey. *Journal of the Indian Society of Remote Sensing* 2019 233-243.

[29] Li, X., Zhou, Y., Zhang, L., & Kuang, R.; Shoreline change of Chongming Dongtan and response to river sediment load: A remote sensing assessment. *Journal of Hydrology* 2014; 432-442.

[30] Özpolata, E., & Demir, T.; The spatiotemporal shoreline dynamics of a delta under natural and anthropogenic conditions from 1950 to 2018: A dramatic case from the Eastern Mediterranean. *Ocean and Coastal Management* 2019.

[31] Esmail, M., Mahmoda, WE, & Fatha, H.; Assessment and prediction of shoreline change using multi-temporal satellite images and statistics: Case study of Damietta coast, Egypt. *Applied Ocean Research* 2019; 274-282.

[32] Nandi, S., Ghosh, M., Kundu, A., Dutta, D., & Baksi, M.; Shoreline shifting and its prediction using remote sensing and GIS techniques: a case study of Sagar Island, West Bengal (India). *Journal of Coastal Conservation* 2015.

[33] G, V., Goswami, S., Samal, R., & Choudhury, S.; Monitoring of Chilika Lake mouth dynamics and quantifying rate of shoreline change using 30m multi-temporal Landsat data. *Data in Brief* 2019; 595-600.

[34] Manjulavani , K., Supriya, M., Suhrullekha , M., & B., H.; Detection of Shoreline Change using Geo-Spatial Techniques along the Coast between Kanyakumari and Tuticorin. *IEEE International Conference on Power, Control, Signals and Instrumentation Engineering* 2017; 2822-2825.

[35] Misra, A., & Balaji, R.; A study on the shoreline changes and Land-use/land-cover along the South Gujarat coastline. *Procedia Engineering* 2015; 381-389.

[36] Muskananfola, M., Supriharyono, & Febrianto, S.; Spatio-temporal analysis of shoreline change along the coast of Sayung Demak, Indonesia using Digital Shoreline Analysis System. *Regional Studies in Marine Science* 2020.

[37] Ozturk, D., & Sesli, FA; Shoreline change analysis of the Kizilirmak Lagoon Series. *Ocean & Coastal Management* 2015; 1-19.

[38] Qiaoa, G., Mia, H., Wanga, W., Tonga, X., Lib, Z., Lia, T., & Liua, S.; 55-year (1960–2015) spatiotemporal shoreline change analysis using historical DISP and Landsat time series data in Shanghai. *Int J Appl Earth Obs Geoinformation* 2018; 238-251.

[39] Castillo Charris, MA & Gamarra Mendoza, EA; Multi-temporal analysis of the coastline on the island of Tierrabomba and projection of the flood map due to mean sea level rise. *CIOH Scientific Bulletin (32)* 2014; 163-177.

[40] Gomez Gualdron, LM; Changes in the coastal landscape to the northwest of the departments of Bolívar and Sucre from 1988 to 2017. 2018 Bogotá.

[41] Nino, DC, & Oviedo, F.; Determination of the coastal morphological variation of the Bay of Tumaco, from multi-temporal analysis with remote sensors. *CIOH Scientific Bulletin (36)* 2018; 71-86.

[42] Cifuentes Ossa, MA, Rosero Henao, LV, & Selvaraj, JJ; Detection of changes in the coastline north of the Buenaventura district through the use of remote sensors. *Marine and Coastal Research Bulletin* 2017; 137-152.

[43] Ministry of Environment and Sustainable Development; Coastal Erosion Master Plan. 2017

[44] Hanqiu, Xu; Modification of normalized difference water index (NDWI) to enhance open water features in remotely sensed imagery. International Journal of Remote Sensing 2006, Volume 27, 3025-3033. 10.1080/01431160600589179.

[45] Coastal Management – Automatic Shoreline Delineation and Change Detection Analysis. Available online: https://www.esri.com/videos/watch?videoid=kYFn0tVVBfE (accessed 08 March 2021).

[46] Digital Shoreline Analysis System (DSAS). Available online: (accessed on 08 April 2021).

[47] Landsat 5: https://code.earthengine.google.com/9ea965f85f34d8a4a1ca9360ac1a2c8d

[48] Landsat 7: https://code.earthengine.google.com/1f0ecb5be0a93b5dce53cd1f7597a238

[49] Landsat 8: https://code.earthengine.google.com/374948c728d81b8d4733758acc3b227f

[50] Sentinel:

https://code.earthengine.google.com/7b6a5acd2aa64fe239a89b66137e8e3b

[51] Puerto Colombia – Municipal Mayor's Office. Available online: https://www.puertocolombia-atlantico.gov.co/MiMunicipio/Paginas/Sitios-de-Interes.aspx (accessed March 22, 2022).

[52] Sixth Assessment Report. Climate Change 2021. The Physical Science Basis. Available online: https://www.ipcc.ch/report/ar6/wg1/ (accessed 13 December 2021).

[53] Mogollón Vélez, JV Of the river and its beaches. In *Maritime Historical Atlas of Colombia XIX Century*, 1ra ed.; Colombian Ocean Commission: Bogotá, Colombia, 2016; pp. 123–169, Print ISBN: 978-958-59232-3-2.

[54] Romero Olivera, LJ Metropolization in coastal areas (ZC) of the Barranquilla-Cartagena corridor: (BAQ-CTG) formation of a new metropolitan fabric from the production of space. Magister Thesis, National University of Colombia, Medellin Campus, November 2018.

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