JOURNAL OF MARITIME RESEARCH

Vol XXI. No. III (2024) pp 356–366

ISSN: 1697-4840, www.jmr.unican.es

Hydrological Analysis of a Coastal Catchment of The Guachaca River - Colombia and Its Relationship with Beach Morphology

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ARTICLE INFO

Article history:
Received 27 Aug 2024;
in revised from 05 Sep 2024;
accepted 16 Sep 2024.

Keywords:
Coastal modelling, coastal morphology, hydrological processes, river catchment.

ABSTRACT

Coastal morphology can be affected by erosion due to the loss of land located at the continent-sea interface, right on the coastal zone. The physical and biological evolution of the coastal zone depends on multiple interactions between geological, climatic and oceanographic processes, including erosion and sedimentation, alteration (physical and chemical) of rocks, geological uplift and subsidence of the land, precipitation, winds, storms, waves, tides and ocean currents. The interaction of these physical processes and their characteristics changing naturally at different velocities along the coastal zone is still unclear. This paper presents an evaluation of the relationship between changes in the hydrological processes of a river catchment and the morphological variations of its surrounding beaches. The case study presented here is located in the Guachaca river catchment and its coastal zone in the city of Santa Marta, Colombia. The evaluation includes an analysis of coastal cells using a mathematical model in a 3D domain within a river catchment approach. The results indicate the contribution of sediments in the coastal area towards Santa Marta city with the influence of the waves direction in this sector. It has been identified zones where a lack of sediments is observed due to erosion in the study area. This approach could provide adequate planning and management tools to assess this coastal zone towards the implementation of effective adaptation and mitigation measures.

1. Introduction.

The geohistorical approach, according to Tovar (1996, p. 38), arises from the geographical conception that understands space as a concrete product or synthesis of the action of human groups on their environment, in order to guarantee its conservation and reproduction, depending on specific historical conditions. From this perspective, the geohistorical approach is defined as a community study that examines geographic space from a social, economic and cultural perspective (Barrios, 2000). This approach reveals the spatial relationships that arise between human groups in society. An essential component of the geohistorical approach is retrospective analysis, which is complemented by inputs generated by field work, documentary sources and the compilation of primary sources. These natural and anthropic processes modify and alter the landscape of coastal spaces, leading them to their current configuration, influenced by the dynamics and planning processes of coastal urban space (Donini, 2021)

However, the breakdown of the dynamic balance to which the coastal system tends is due to sectoral anthropic interventions that often lack adequate consideration for integrated management of the natural environment. The effects of these interventions transcend space and time in each interference (Veneziano and García, 2014, p. 2). It is essential to understand the interconnection between human action and the dynamics of geographical space to adequately address the challenges in the management and conservation of coastal environments. Coastal erosion is a natural process that causes the gradual loss of land and modification of coastlines due to the action of ocean cur-

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rents, waves and other environmental factors. In the case of the Colombian Caribbean, this phenomenon takes on great importance due to its extensive coastline and the challenges it poses for the communities and ecosystems present in the region. (Posada Jaramillo, 2013).

To effectively understand and address coastal erosion in the Colombian Caribbean, it is essential to adopt a catchment perspective. This implies considering not only the processes that occur on the coast itself, but also those that take place in the catchment that flows into the coastal areas. The interaction between factors such as sedimentation, geomorphology, sea level fluctuations, climate change processes and water resources management play a crucial role in the dynamics of coastal erosion. (Masselink, 2015). To address this problem, a comprehensive study is being carried out that analyzes and synthesizes the information collected from various previous studies carried out in the region. These studies, like those mentioned by Ricaurte (2018); Posada (2008); and Alexandrakis (2014), offer valuable methodological approaches and perspectives that allow us to understand both the physical and socioeconomic factors related to coastal erosion.

Today, riparian zones are vulnerable and among the most threatened ecosystems globally, especially in the context of Coastal erosion (Siddle, 2018). This problem manifests itself with the degradation or loss of vegetation cover in riparian areas, which in turn leads to the degradation of water bodies, having a substantial impact on the functions, services and resources that these ecosystems offer. Therefore, it is of utmost importance to prioritize the conservation of these areas, given the elevated threat they face in contrast to their critical role in protecting biological diversity and providing ecosystem services, particularly in mitigating coastal erosion (Gonzales, 2019).

Riparian vegetation performs a wide variety of environmental functions that highlight its relevance as a key indicator in the management and planning of areas affected by coastal erosion (Milanys, 2018). The inclusion of riparian vegetation as an essential component in the assessment of the ecological status of aquatic ecosystems becomes a fundamental element to effectively address coastal erosion. In this context, riparian vegetation plays crucial roles, its main function being to act as a natural filter, capturing and eliminating sediments and contaminants present in the water. This function is essential to preserve water quality and protect aquatic ecosystems from coastal erosion (Carrasco, 2015). In Colombian coastal areas, the direct effects of climate change, such as increased temperatures in the sea, air and soil, aggravate coastal erosion and increase the probability of significant flooding (Narváez, 2019).

It is crucial to consider that interventions carried out in river catchments must take into account that rivers not only transport liquid flows, but also a significant solid load that plays an essential role in shaping the basin and, in particular, in coastal areas affected by erosion. Therefore, a comprehensive approach is required in the design and management of hydraulic works, which takes into account the interaction between liquid and solid flows in rivers. Rivers in equilibrium tend to form sediment deposits on both sides of the channel, where excess solid load is deposited when the velocity of the water can no longer carry it due to the increase in channel width and depth (Gonzales, 2019). In contrast, channelized river channels are unstable, with low lateral sedimentation rates and susceptible to erosion of the base of the slope, resulting in the release of soil blocks and an increase in the river solid load. This means that the artificialization of the basin through canalization increases the amount of solid load that reaches coastal areas, thus exacerbating the erosion problem (Carrasco-Navas, 2019).

The effects of human influence on catchments increase the vulnerability of these systems to coastal hazards, such as sea level rise, salt intrusion, and hurricanes, ultimately threatening the socio-ecological systems that depend on them (Renaud et al., 2016). In addition to these threats derived from human activity, the loss of ecosystems and biodiversity, soil degradation, air pollution and the decrease in water availability represent additional threats to the present and future of humanity. These concerns are compounded by warming of the atmosphere and oceans (Brown, 1992), underscoring the urgency of addressing coastal erosion and protecting riparian zones in the context of conservation and sustainable management of these delicate ecosystems.

The Colombian coast has been subjected to an erosion process, both in its island and continental areas, for several years. This problem has worsened due to factors such as storms, extreme tides and droughts related to the El Niño phenomenon, which occur with greater intensity and frequency. Furthermore, human interventions in the coastal zone have contributed to the increased threat of coastal erosion, with an increase of 33% on the Caribbean coasts and 27% on the Pacific coasts. (Botello, 2018). Projections for the future of this century indicate that the Colombian coastline will continue to retreat, which represents one of the most significant challenges facing the country today (Enfen, 2017). This situation has important implications in social, economic and ecological terms. More than 6 million people currently reside along the coastline, exposing them to significant risks. In addition, coastal economic activities are threatened, and there is a loss of strategic ecosystems such as mangroves, coastal lagoons, beaches and cliffs, among others (Ricaurte, V. 2018).

In 2015, the National Disaster Risk Management Plan of Colombia (PNGRD) was formulated, which is an instrument of Law 1523 and defines the objectives, programs, actions, responsible parties and budgets to carry out risk awareness processes, risk reduction and disaster management within the framework of national development planning. Through a detailed analysis of the background and the collection of geospatial, hydrological, oceanographic, socioeconomic and environmental data, key aspects will be addressed to understand the dynamics of coastal erosion in the Colombian Caribbean. It is expected that the results obtained will be useful for decision-making in coastal planning and management, allowing the implementation of effective adaptation and mitigation measures against this constantly changing phenomenon (Juarez, 2018).

This study is based on the analysis of geospatial, hydrological, oceanographic, socioeconomic and environmental data. It aims to propose an evaluation of the relationship between changes in the hydrological processes of a river catchment and the morphological variations involved in coastal erosion in the Colombian Caribbean. The results of the analysis will generate a solid knowledge base to provide adequate planning and management tools to assess this coastal zone towards the implementation of effective adaptation and mitigation measures. (Prieto, 2017).

2. Methodology.

2.1. Catchment analysis.

In order to obtain a catchment description, the data used in this study includes hydrometeorological data, surface water network, catchment geometry, shape parameters, shape factor, circularity coefficient, gravellius index, parameters related to the drainage network, drainage density, channel sinuosity, catchment order of classification, mean catchment slope, main stream slope, time of concentration, channel classification and catchment geology.

2.2. Stochastic analysis.

A stochastic analysis was also accomplished. Data collected from rainfall, flow and level gauges along with wave data information from NOAA-WWIII were used in order to know the general state of the area. The Minitab statistical software was used to find data trends, patterns, best fit data and relationships between variables.

2.3. Sediment transport modelling.

The Delf3D software was used to model the morphological development of the Guachaca river catchment. It is important to differentiate transport limited by flow capacity in relation to transport of suspended material limited by washing load. The wash load material is finer than the bottom material, this would have an impact on the morphology and delta deposits. Thus, the main objective is to analyze the ideal location of the depositable catchment sediments in any area of the coastal slope. For this purpose, 3 meshes were defined to propagate the maritime climate cases from deep waters, the case is made up of 3 domains nested in a single direction (unidirectional nesting). The hydrodynamic process was analyzed for the vertical discretization using three layers. The wave processes, being superficial, are sensitive to the surface discretization of the model so that 1% surface layer was maintained to produce a correct interaction between the waves and the currents. Gradients were used according to the sea level (Posada Jaramillo, 2013).

2.4. Case Study.

The Guachaca river catchment is located in the department of Magdalena on its northern side, within the slope of the Sierra Nevada de Santa Marta (Fig 1), it belongs to the rural area of the city of Santa Marta, between the coordinates 11° 2’37.21”N and 73°58’39.49”W (upstream of the river) and 11°15’51.80”N and 73°49’13.53”W (where river flows into the Caribbean Sea). The catchment borders with the Caribbean Sea to the north, the Buritaca river catchment to the east, the Mendihuaca river catchment to the south, and the Manzanares and Piedras river catchment to the west.

Figure 1: Geographic location of the Guachaca river catchment.

Source: Authors.

The main channel of the catchment is the Guachaca river, with an approximate length of 47.50 km, which rises to the south in the upper part of the northern slope of the Cuchilla de San Lorenzo in the foothills of the Sierra Nevada de Santa Marta in a landscape mountain with a relief of rows and beams, and finally discharges its waters into the Caribbean Sea. The catchment has its area within the limits of the Caribbean Hydrographic Macrobasin, with a great variety of slopes and elevations, which, added to the geological characteristics of the area, determine the orientation of the riverbed and its tributaries.

3. Results and Discussion.

3.1. Probability distribution for maximum flow rates.

The data for this research were obtained from the flow station located in the riviera of the Guachaca river, once the homogeneity tests were carried out using the T-Cramer method to evaluate the quality of the data and determine if there were inconsistencies. The information provided by Guachaca station is suitable for processing data due to its high quality and reliability, therefore, the Minitab software is used to determine the probability graph that best fits the hydrological behavior.

Table 1 and Table 2 show a comparative analysis between different probability functions, the Lognormal curve presents a greater degree of fit, yielding a probability value of 0.012. Lognormal distribution is selected to build the model of the hydrological behavior of the catchment.

Table 1: Goodness-of-fit test for catchment flows.

Goodness of fit tests			
Distribution	A.D.	Q	LRT P
Normal	3,389	<0.005	
Box-Cox transformation	0.563	0.137	
Lognormal	0.987	0.012	
3-parameter lognormal	0.71	*	0.119
Exponential	7,666	<0.003	
2 parameter exponential	3,019	<0.0010	0
Weibull	2,484	<0.010	
3-parameter Weibull	1,354	<.005	0
smallest extreme value	5,999	<0.010	
Extreme value for maximums	1,172	<0.010	
Gamma	1.59	<0.010	
3-parameter gamma	1,366		0.096
Logistics	1978	<0.005	
Logistics	0.747	0.029	
3-parameter logistics	0.532	*	0.107
Johnson transformation	0.381	0.387	

Source: Authors.

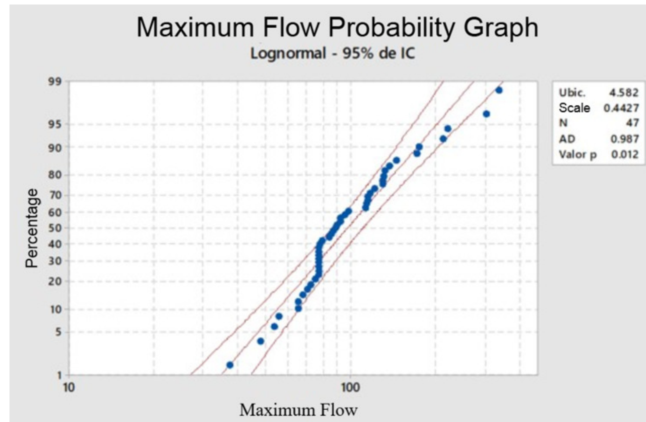
Table 2: Estimation of the basin flow distribution parameters.

ML estimates of distribution parameters				
Distribution	Location	Shape	Scale	Threshold Value
Normal	108.78104		59.50202	
Box-Cox transformation	0.10348		0.02153	
Lognormal	4.58237		0.44268	
3-parameter lognormal	4.27578		0.57993	22.93314
Exponential			108.78103	
2 parameter exponential			73.18822	35.5928
Weibull		1.98602	123.45196	
3-parameter Weibull		1.35723	79.58365	36.2226
smallest extreme value	143.21271		84.61663	
Extreme value for maximums	85.96599		34.60719	
Gamma		4.83485	22.49935	
3-parameter gamma		3.52157	26.34855	15.99159
Logistics	98.69477		27.35505	
Logistics	4.54732		0.23852	
3-parameter logistics	4.17518		0.3435	27.94084
Johnson transformation	-0.03701		0.95829	

Source: Authors.

Figure 2 shows the Lognormal probability fit for discharge series. The maximum synthetic flow based on the Log-Normal distribution is determined with different exceedance periods to have a series of possible data to be used in the Arima model, a statistical procedure that uses variations and regressions of statistical data to find patterns for future prediction.

Figure 2: LogNormal probability fit for discharge series.

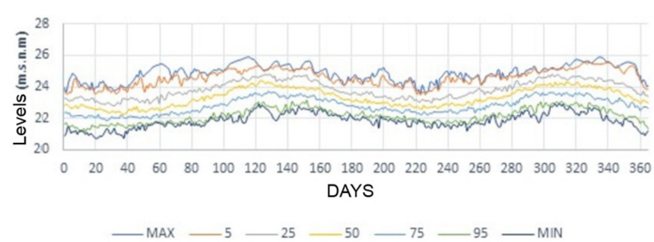


Source: Authors.

3.2. Exceeded flow levels.

The frequency curves of exceeded levels determine the probability that a daily level is exceeded throughout a year and identify the bimodal behavior of the river throughout the year and comparing whether the current conditions correspond to minimum, average or maximum conditions. Figure 3 illustrates the frequency of exceedance of 10, 25, 50, 75 and 90% along with the time series of daily levels.

Figure 3: Frequency curve of exceeded levels Guachaca 1978-2019.



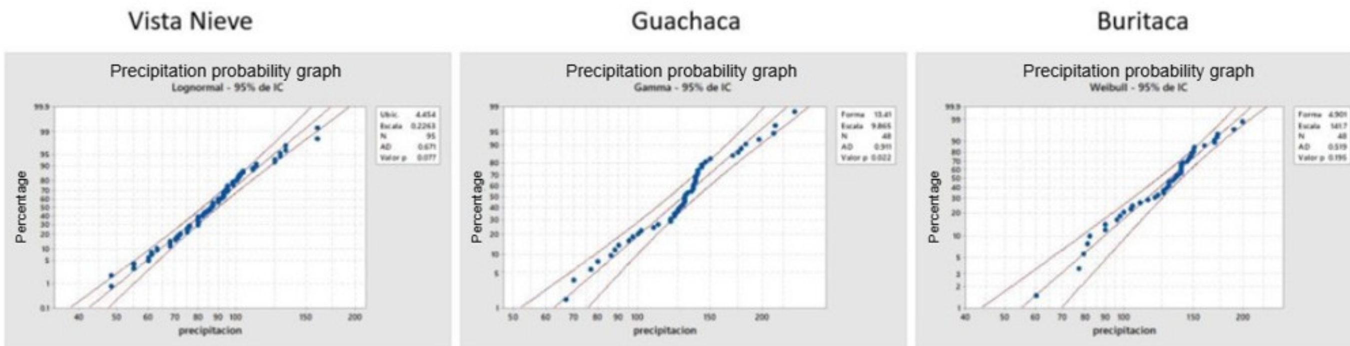
Source: Authors.

Figure 3 shows that in the first half of the year the levels adjust to the 50th percentile. For the second half of the years 1991 and 2003 they continue to adjust to the 50th percentile, but the levels observed in 2010 at this station are maximum in some days and their levels range between the 5th percentile and the maximum.

3.3. Precipitation analysis

The estimation of precipitation was carried out with the information obtained from 3 meteorological stations (Guachaca, Buritaca, Vista Nieve), which have more than 30 years of data in each of them, initially homogeneity tests were carried out using T -Student, Crammer and Standard Normal Homogeneity (SNHT), finding that each of them meets the statistical conditions to be considered in the study, this allows for more accurate

Figure 4: Precipitation probabilities in each season.



Source: Authors.

results in the representation of the behavior of precipitation at the site.

The model that best fits the behavior of the data extracted from each of the stations is estimated with a confidence index of 95% as it is shown in Figure 4.

From Figure 4 results show that Vista Nieve station has a 67.1% representation in the Log Normal model, Guachaca station data is reflected with 91.1% of the data, and Buritaca station is represented with 51.9% of the data behavior using the Weibull method.

The model and methods described above were tested using a 3-year hourly rainfall data from the meteorological stations, data with frequencies of 4, 6, 12, and 24 hours were also analysed. The capacity of the model and estimation methods were tested on the basis of comparing statistics obtained from the model either directly or by simulation with those obtained from the historical sample, these statistics included hourly means, standard deviations and the hourly probabilities of dry periods (or those for the time scale considered) as well as the mean and standard deviation of daily rainfall, the obtained results demonstrate that the ARIMA model can reasonably replicate historical rainfall statistics for various time scales. Understanding the complete data and temporal variability of rainfall and flows in the area is crucial for research as it provides parameters applicable in marine sediment hydraulics, such as channel delivery velocities to the coastline.

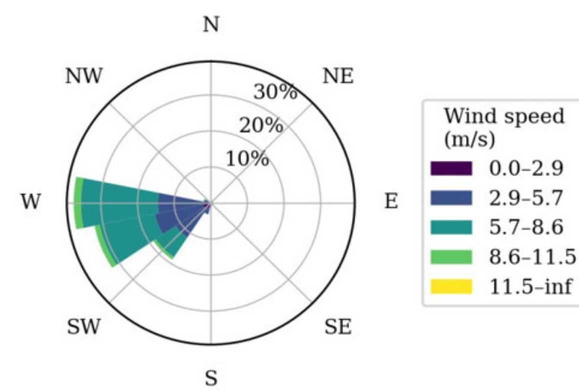
3.4. *Statistical analysis of waves in the Guachaca sector.*

The deep water wave information found in the NOAA - WWIII reanalysis database, developed by NOAA called WW3-NOAA was used The wind rose was estimated for a 42-year time series (Figure 5). The direction determining it with an inclination and south west is highlighted. Similarly, oscillating wind speeds between 2.9 m/s and 11.5 m/s can be also observed.

3.5. *Waves at indefinite depths.*

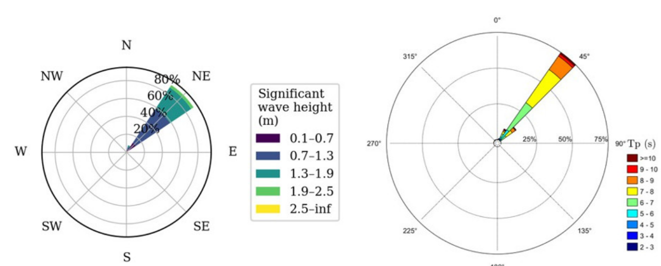
Figure 6 illustrates the variability of wave height over time and the directional distribution of waves, taking into consideration the extremes.

Figure 5: Wind rose, 42-year time series (1979-2020).



Source: Authors.

Figure 6: Deep water surge rose, 40-year time series (1979-2018).



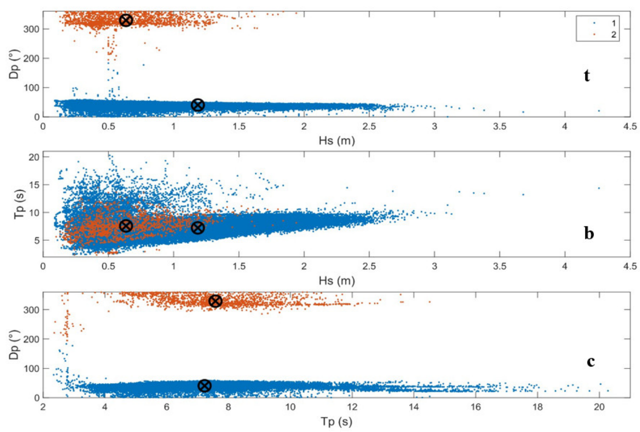
Source: Authors.

A predominant direction of winds and waves NE was observed, with speed winds between 5.7 and 11.5 m/s. In order to determine the average wave and wind regime, it was possible to catalog four climatic periods presented in the Colombian Caribbean, the temporal distribution of the waves was associated with the intensification or weakening of the NE trade winds, exposing a period of waves with more energy in the dry season, bringing its maximum values of wave height between December to March and a period of low wave energy in the season of least and greatest rainfall.

3.6. Modelling cases.

A cluster classification was carried out to determine some modeling cases of the area using the k-means algorithm (KMA), technique evaluated by Camus et al. (2011). Figure 7 presents a KMA cluster classification of wave time series. By reviewing the K values, which is a measure used for cluster analysis or groupings of data that evaluates the cohesion and separation of groups. The set of variables Hs, Tp and Dp use a range from 2 to 10 and the optimal value of this parameter was set to 2.

Figure 7: KMA cluster classification of wave time series.

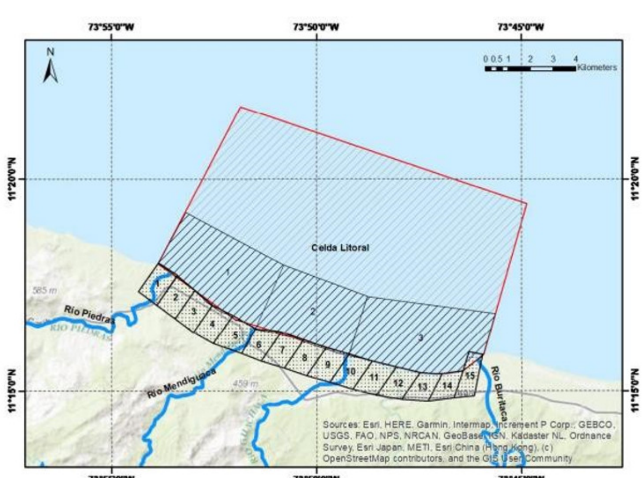


Source: Authors.

3.7. Definition of the littoral cell.

The analysis cell was defined to cover not only the Guachaca river, but a broader area in order to consider all the factors that may increase the vulnerability of the coastal zone. On the right border the Buritaca river was defined as the limit boundary condition, and on the left side to the west, the Piedras river. The definition of the coastal cells and sub-cells was carried out following the methodology of Sekovski et al. (2020), in order to include urban developments the width of the zones was estimated as 1 km approximately and a length of 1.5 km, , Figure 8 shows how the areas within the coastal cell were defined.

Figure 8: Defined littoral cell.



Source: Authors.

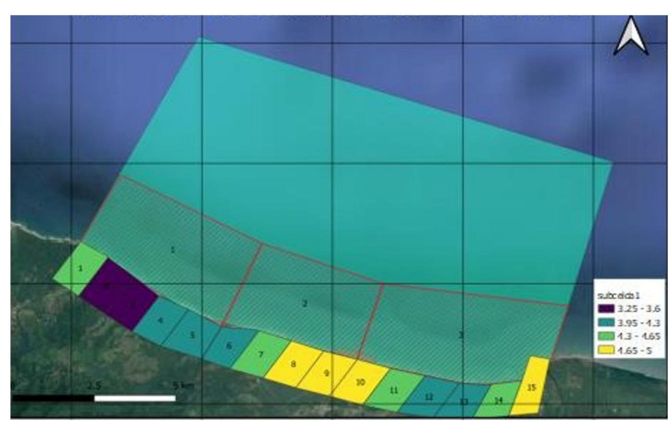
3.8. Vulnerability Analysis.

For the analysis of the coastline, satellite images were used, digitizing for each annual record in each of the seasonal periods of the beach, the evolution of the beaches and their variation with the analysis of the climate of the area. Three (3) seasonal periods were determined: a dry period, a low rainy period and a high rainy period. According to this classification, the satellite images obtained and whose record dates back to 2013 were divided, taking as a source the records of the 17 USGS (US Geological Survey) and the Sentinel images in case a good image was not found for the period analyzed with the USGS (United States Geological Survey).

The dry period includes the months January, February and March; The low rainy period includes the months April, May, June and July; while the high rainy period includes the months of August, September, October, November and December (Guzmán et al., 2014). To carry out the coastline advancement study, the process was divided into three (3) stages: a) the first step was the selection and downloading of images from the USGS portal; b) the second stage included the digitization of satellite images in accordance with the criteria defined for the DSAS software and finally c) the analyzes were carried out based on the results obtained comparing the progress of the periods and progress of the line of coast.

The results of the vulnerability analysis from the most critical point close to the mouth of the channel to the least critical point away from it, are illustrated in Figure 9.

Figure 9: Vulnerability analysis in the coastal cell.



Source: Authors.

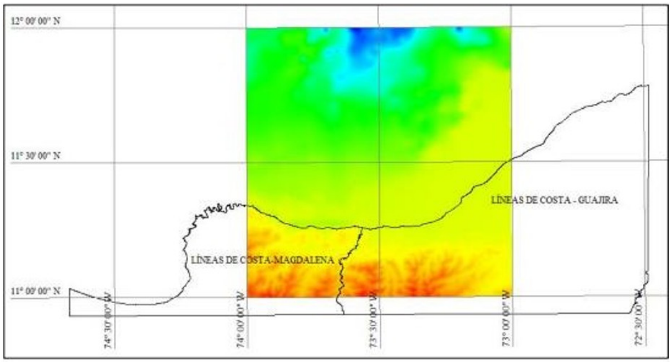
4. Modeling tidal hydrodynamics with delf3d.

4.1. Bathymetry information.

The primary information obtained is in the .tiff format that allows creating a terrain elevation model where the spatial value is given by an RGB color. Figure 10 shows the satellite image used superimposed on the study area.

To carry out the bathymetric survey, the Hypack Max hydrographic program was used, following a detailed procedure, initially the hydrographic lines were planned according to the cartography of the area and the coordinates of the design axis

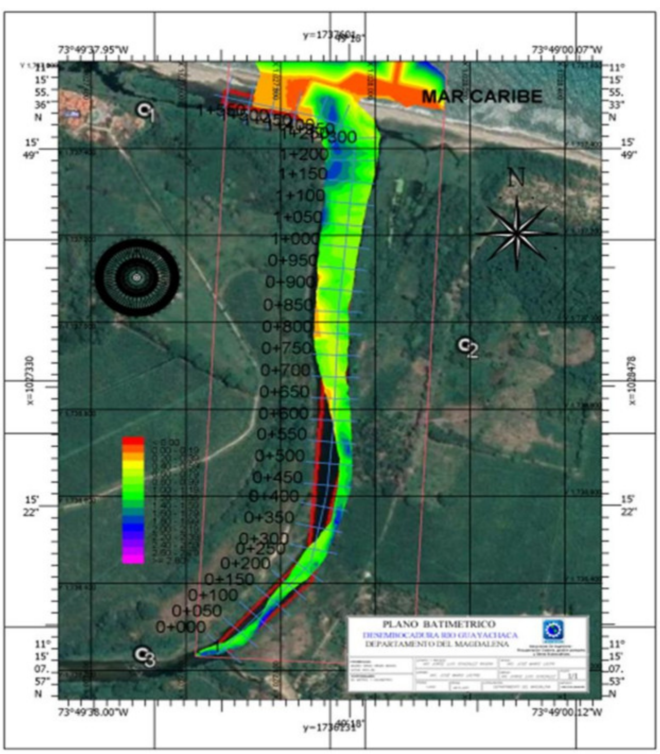
Figure 10: Geographic location with tiff image.



Source: Authors.

and cross section, the devices were configured in the Hypack Max software, establishing communication parameters, the position data was adjusted to the cartography by introducing geodetic parameters and reference level transformation, using the Magna Sirgas Bogotá Central system, subsequently, the necessary equipment was installed in the vessel, including the GPS receiver, the computer and the digital echo sounder, finally, the survey was carried out by following transverse lines, recording the information from the GPS and the echo sounder.

Figure 11: Bathymetry performed in field work.



Source: Authors.

From the Gebco model and the bathymetry carried out in the field (Figure 11), an xyz file was determined with the elevations of each point with a point separation of 200 m in each direction using the Global Mapper software, subsequently the xyz file was treated using Python software and mainly the panda library to adjust the data to the format requested by Delf3D for identification where the depths are positive and the terrain areas are identified with an elevation of -99 so that the model is not calculated in this area .

4.2. Tidal harmonics to model

For Delf3D modelling, it is required to describe the tide through harmonics, a point within the mesh was selected as the location of the buoy, it works as the necessary forcing for the mathematical model, the summary of the location coordinates of the forcing is presented in Table 3.

Table 3: Point location for tide generation in the MOHID model.

Parameter	Value
Longitude	73° 33' 02" W
Latitude	11° 57' 05" N
Coordinate X	659636
Coordinate Y	1321601

Source: Authors.

Table 4 illustrates the value of the harmonics that describe the tide for the port of Santa Marta according to Rivillas (2014), which were used for modelling in the present investigation.

Table 4: Tide components.

Component	*Amplitude (m)*	*Period (h)*
M2	*0.03*	*12.42*
S2	*0.04*	*12.00*
K1	*0.70*	*23.93*
O1	*0.68*	*25.83*

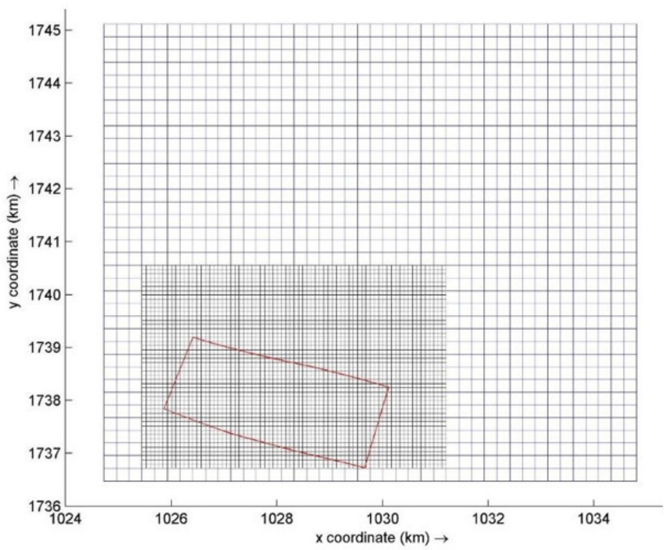
Source: Authors.

4.3. Sediment model.

The Delf3D model was used as a simulator of the morphological development of the Guachaca catchment. . In the selection of this method to model the processes, it is of vital importance to differentiate the transport limited by the flow capacity in relation to the transport of the limited suspended material. The washing load material is finer than that of the bottom, this would have an impact on the morphology and the deposits in the form of a delta, therefore, the main objective is to analyze the ideal location of the sediment from the depositable catchment in any area of the coastal slope. 3 meshes were defined to propagate the maritime climate cases from deep waters, the case includes 3 domains nested in a single direction (one-way nesting) and can be seen in Figure 12 .

For the vertical discretization, the hydrodynamic processes was analyzed, using a 3-layer discretization. The wave processes, being superficial, are sensitive to the surface discretization of the model, so it was determined to maintain a 1% surface layer (Posada Jaramillo, 2013), and in order to produce a correct interaction between the waves and the currents, gradients were used to vary according to sea level.

Figure 12: Wave Computational Mastery.



Source: Authors.

The preliminary analyzes have a duration scale of 5 hours, where variables such as hydrodynamic filling time, hydrodynamic emptying time, and settling times for various sediments were considered, the respective sizes and velocities are illustrated in Table 5.

Table 5: Settlement times for different type of sediments.

Upper Class Limit	Size	Size	Settling Velocity:	Settling Velocity:	Settling Time:
	(mm)	(micron)	ws (m/s)	ws (m/day)	Ts (minutes)
Fine Sand	0.25	250	0.033	2870	0.5
Very Fine Sand	0.125	125	0.012	1075	1.3
Coarse Silt	0.062	62	0.003	294	4.9
Medium Silt	0.031	31	0.001	74	19.5
Fine Silt	0.016	16	0.000	20	72.0
Very Fine Silt	0.008	8	0.000	5	288.0

Source: Authors.

For the analysis of the delta time for the hydrodynamic calculation, two models were generated, one with 3 dimensions of waves with an interval of 5 minutes and the other with 3 dimensions with waves with an interval of 10 minutes. The results (Table 6) show that the waves do not presents significant changes in none of the cases, while the currents and tides are affected by them, giving a differential speed of 0.0031 m/s between both cases.

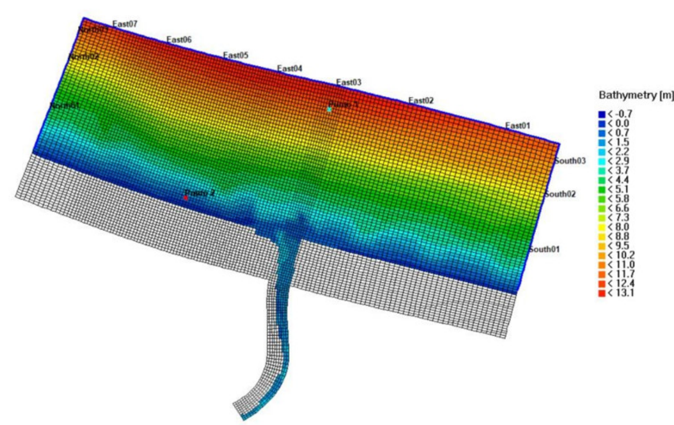
Table 6: Wave results .

Case	Hs (m)	Tp (s)	Dir (°)
1	2.19	8.0	Four. Five
2	3.38	10.0	Four. Five
3	1.19	7.2	40.5
4	0.64	7.6	329.2

Source: Authors.

Three boundaries were defined for the flow domain; since it was a coastal case, it was established to use tidal harmonics to stabilize the model in addition to coupling it with the wave module. Case 1 is composed of Hs = 2.1 m, Tp = 8 s and Dp = 45 degrees, it is observed that due to the effect of protrusion and bottom friction the incident wave manages to reach the coast approximately perpendicularly with a breaking height of 1.5 m (Figure 13).

Figure 13: Flow Computational Domain.

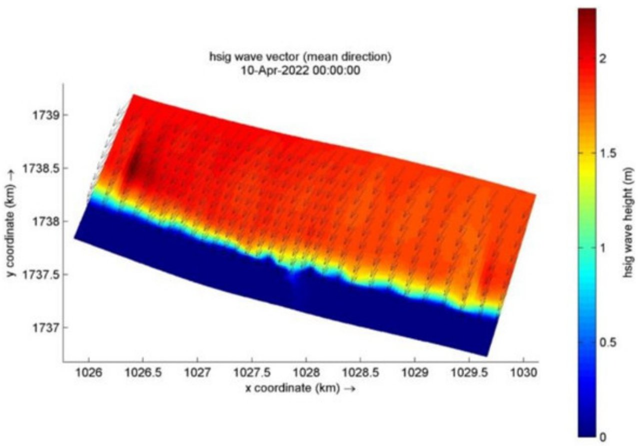


Source: Authors.

In Figure 14, a longitudinal current is observed in an east-west direction with values of up to 0.8 m/s, as well as coastal currents mostly associated with breaking waves. However, it should be noted that the model was forced with an astronomical tide, which is why the effect of the tidal current is included.

Density currents with high sediment concentrations are very effective in removing sediment, as can be observed in the coastal beach area of the Guachaca catchment . Being shallow, the suspended sediment is too mixed vertically for the stratification

Figure 14: Significant wave height Case 1.

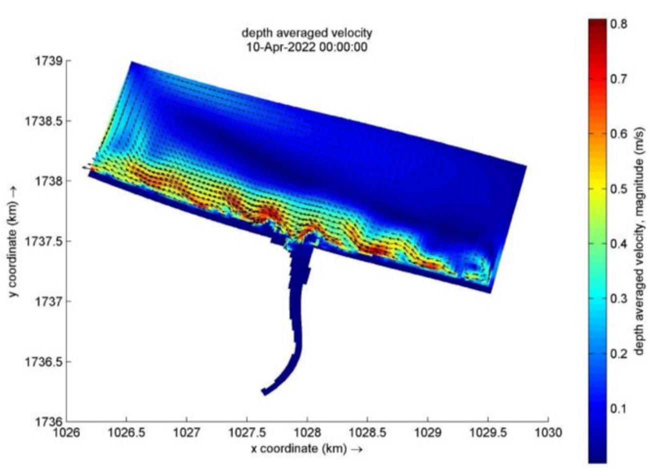


Source: Authors.

phenomenon associated with density to occur.

The model calibration process showed that the most influential factors in the results of the simulations correspond to different processes, such as the inclusion of gravitational forces on the tide, reducing the calculated errors with respect to the tide gauge measurements by 8%. The transport processes significantly modified the circulation patterns of the model, showing a deep circulation phenomenon where the interaction of waves and currents generated significant changes in surface currents, especially in shallow water areas.Finally, to identify the loss or gain of sediment in the erosion and sedimentation zone shown in the region (Velásquez and Rave, 1996; Correa and Vernette, 2004), sediment balances were made along the coastline. from the mouth of the Guachaca river (Figure 15).

Figure 15: Depth-averaged current velocity.



Source: Authors.

From the simulations carried out at different times and with different types of patterns, the areas where the model predicts the loss and gain of sediment along the coastline were obtained, having qualitative results and giving reports of erosion and sedimentation which Picua beach has.

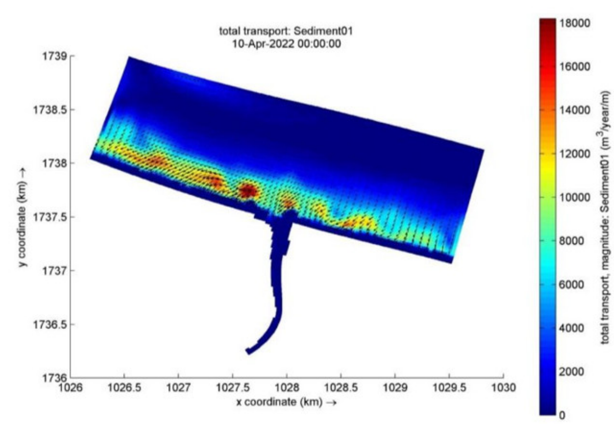
The size and separation of the sections chosen according to the possibilities provided by the software and a sensitivity analysis through which it was found that very long perpendicular sections hide internal responses in coverage areas that end up affecting erosion and sedimentation. This is the clear shape of our delivery point, generating an average length of 400 m and reaching depths ranging between 5 and 3 m.

The results also showed the erosional response near the coasts, linking these events to the increases in winds and waves in the study area, also resulting in a trend of low gain of cohesive particles being generated during periods of humidity, giving dynamics to the fine sediments taking precedence over that of the coarse ones.

A maximum total transport of 18,000 m3/year was calculated, this data considered a specific density of 1600 kg/m3; For non-cohesive sediments, a specific density of 2650 kg/m3, dry bed density of 1600 kg/m3, with an average sediment diameter of 200 μm was found; initial thickness of the sediment layer in the bed of 5 m, worked uniformly, where the littoral transport is transverse to the coast.

In the sedimentation/erosion map (Figure 16), erosion is observed mainly in the failure zone. The sediment through suspension and drag is deposited near the coastline. The above implies that as long as there are low or no river flows, the mouth will tend to close due to the longitudinal transport of sediments that goes from east to west, information confirmed through fieldwork in the study area where this phenomenon was observed for dry seasons.

Figure 16: Total sediment transport (Suspension + Drag).

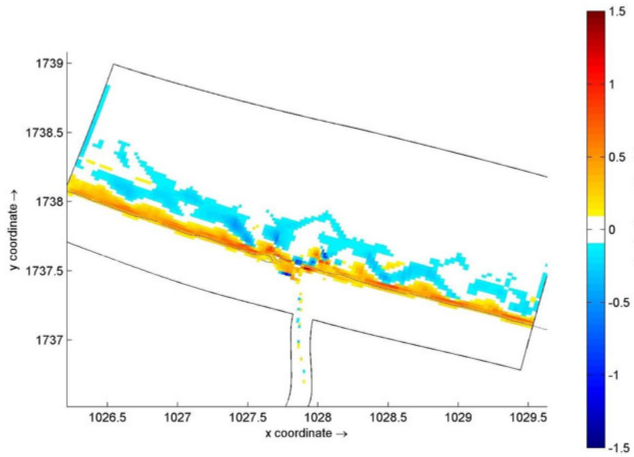


Source: Authors.

Finally, as a verification of the results of the balances carried out in Figure 17, the erosion/sedimentation along the coastal zone of the Guachaca catchment is generally shown, giving as a response an erosional effect that events with winds and extreme waves can occur on the coast.

It is clear how the dynamics of the sands near the coasts are mainly restricted in the dry season and to the high energy event, while in the wet season it was mostly negligible; also considering that the sands are not recovered in calm seasons after an extreme event, which could lead to a conclusion of widespread erosion.

Figure 17: General erosion/sedimentation map.



Source: Authors.

Conclusions.

A sediment transport model was built for the Guachaca river catchment using a catchment approach, analyzing from the beginning the behavior of the river that is responsible for carrying the sediment to the coastline.

The data obtained in the field allowed us to know the area under study, its behavior at different times of the year and the extreme events presented by the catchment . Likewise, they allowed the sediment transport model to be calibrated and validated; Sediment sampling was carried out during a specific climatic season. However, it was important to take into account possible measurement errors, given the large uncertainty associated with the predictions and measurements involved in the process.

The dynamics of suspended sediments are directly related to the magnitude and direction of the wind; The waves, in turn, have marked effects in shallow waters, where the loss of depth increases shear stresses and the suspension processes of bottom particles.

In the dry season, the increase in wind and waves increases turbulence and mixing processes, sediments are transported and deposited with high concentrations, resulting in a continuous contribution of sediments from the Guachaca river to the coastline of its mouth.

The results of the model indicate that during the wet season, the low energy of convergent systems (marine and fluvial) allows sediment transport within the first 5 meters of depth. While in deeper waters the concentrations are not as high, from this the fine sediments are transported to deeper waters where they are finely deposited.

Coastal erosion in the Colombian Caribbean area, especially in the Guachaca river catchment, in addition to being a response to marine conditions, is highly influenced by the resistance of the soil and the geomorphology of the coast. The model worked does not consider erosion or damage due to civil works, which in fact within this basin can be one of the main causes, since upstream in the area where the bridge is located on the riverbanks of the town of Guachaca it becomes very common dredging the soil in order to avoid flooding in the municipality, thereby causing abrupt changes in the general dynamics of the channel and affecting erosion downstream in the coastal area.

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