Characterization of the coastal geomorphology and its associated vegetation cover, through remote sensors, in the Bay of Buenaventura, Valle del Cauca

Caracterización de la geomorfología costera y sus coberturas vegetales asociadas, a través de sensores remotos, en la bahía de Buenaventura, Valle del Cauca

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ABSTRACT

The present investigation comprised between La Bocana and Punta Limones in the municipality of Buenaventura (Valle del Cauca), describes the geomorphological and vegetal coverage characteristics along 95.61 km of the Pacific coast of Colombia, using remote sensing through the airborne Light Detection and Ranging technique LIDAR- and satellite images and their products. Geomorphologically the territory is distributed almost evenly between coastal plains and hills, with slightly more coastal plains with a total of 53.06 % of the area studied (5637.56 ha), which in turn are constituted by flat land and plains with halophyte vegetation, floodplains, not vegetated intertidal platforms, and in a smaller proportion by coastal lagoons and beaches. The mangrove predominates over the first two geoforms, and the herbaceous vegetation of the beach predominates over the latter. The hills (46.93 %) are also present with the high dense forest of firm ground and the non-flooding ferns. In general, for the study area, the vegetation cover that is most prevalent is the High dense forest of firm ground with 44.94 % (3690.47 ha), followed by the mangroves with 37.65 % (3092.54 ha). The idea of making a relationship between the geomorphological characteristics and the vegetation coverage arises from the need to have geographic tools for the planning and management of the Pacific coast.

KEY WORDS: Vegetation cover, geomorphology, Light Detection and Ranging- LiDAR, remote sensing, multiespectral image, coastal zone, GIS.

RESUMEN

La presente investigación comprendida entre La Bocana y Punta Limones en el municipio de Buenaventura (Valle del Cauca), describe las características geomorfológicas y de cobertura vegetal a lo largo de 95,61 km de la costa Pacífica de Colombia, utilizando el sensoramiento remoto a través de la técnica de Light Detection and Ranging –LiDAR aerotransportada e imágenes satelitales y de sus productos. Geomorfológicamente, el territorio está repartido casi que equitativamente entre planicies costeras y colinas, siendo un poco mayor el área de las planicies costeras con un 53.06 % del área total estudiada (5637.56 ha), que a su vez se constituyen por planos y llanuras con vegetación halófita, planos de inundación, plataformas intermareales no vegetadas, y en menor proporción de lagunas costeras y playas. Sobre las dos primeras geoformas predomina el manglar y sobre la última predominan las herbáceas de playa. Las colinas y lomas (46.93 %) también se hacen presentes con los bosques densos altos de tierra firme y los helechales no inundables. En general, para el área de estudio, la cobertura vegetal que más abunda es el bosque denso alto de tierra firme con un 44.94 % (3690.47 ha), seguido por el manglar con 37.65 % (3092.54 ha). La idea de relacionar las características geomorfológicas con las coberturas vegetales surge de la necesidad de contar con herramientas geográficas para el ordenamiento y manejo de la costa Pacífica.

PALABRAS CLAVE: *cobertura vegetal, geomorfología, Light Detection and Ranging- LiDAR , teledetección,* imagen multiespectral, zona costera, SIG.

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Introduction

Traditionally, in order to measure forest parameters such as canopy height, biomass, tree distribution, plant cover limits, or to study the geomorphology, it is necessary to make observations in the field which consume a considerable amount of resources. This is an intense and impractical task when it comes to evaluating long stretches of land (Wannasiri, Nagai, Honda, Santitamnont and Miphokasap, 2013). Regarding the study of geomorphology, remote sensors have allowed the analysis of large areas of land avoiding the need to spend much time on field research. This has focused mainly on describing and classifying the geographical features (Rao, 2002), the characterization of dynamic processes and the association of these geographic features with these processes (Smith & Pain, 2009).

The recognition, planning and administration of the territory is possible thanks to the knowledge of the geomorphology and its associated vegetation cover, which also allows to evaluate the location, quantity and condition of these elements (Bermúdez-Rivas, Álvarez Machuca & Niño Pinzón, 2014). Land planning results from a compromise between the environmental potential (measured in terms of availability of natural resources) and social demand (measured in terms of the requirements of goods and services by specific communities) (Mendoza, Bocco, Granados & Bravo, 2002). Remote sensing helps in the investigation of these issues through its application in these main areas: location and distribution of geographic features, the altitude of the earth's surface, the composition of the earth's surface and its characterization (Smith & Pain, 2009).

The municipality currently has few research works that serve as a basis for the entities responsible for managing and planning this coastal area of the country. Among the works of this type carried out in the municipality of Buenaventura, we mention the Local Committee for the Prevention and Attention of Disasters 2000, called the "Evaluation of natural hazards and bases for the mitigation of risks in the urban area of Buenaventura" which studies the potential of landslides, flood areas, relative zoning due to seismic hazards, in addition to others, generating bases for the mitigation of risks for the Territorial Ordering Plan (Observatorio Seismológico de Occidente- "Western Seismological Observatory", 2000). The achievement of the above is facilitated by cartography, databases of georeferenced attributes, fieldwork, analysis of remote sensing and social cartography workshops. The main challenges of Buenaventura have been identified as: the seismic risk, flooding from the sea and streams, the potential for landslides, risks associated with fires, explosions and contamination by garbage.

The administration and development of the coastal area at the head of the General Maritime Directorate (Dimar), is a central purpose that works on compliance with this background given its regulatory function, director and controller of maritime activities (Decree Law 2324 of 1984); without being alien to the concept of sustainability and coastal management. It is vitally important that it has excellent knowledge of the territory under its care, and it must do so from economic, social, political and environmental perspectives. To achieve this, it must be a generator of knowledge, but at the same time it must use the knowledge generated by other state entities, which are watching over the same coastal territory but from another perspective.

The objective of the research was to identify, spatialize and describe the geomorphology and its associated vegetation cover present in the Bay of Buenaventura through the interpretation of orthophotos and satellite images, the analysis of terrain heights provided by digital surface models (MDS) obtained from LiDAR information and specific activities in the field; to perform the inventory of coastal vegetation cover, geomorphological units and analyze the state thereof with digital surface models. The above will serve as technical input for the administration of the jurisdiction of the General Maritime Directorate; it will also serve as an adviser for the decisions that Harbor Masters must take on issues of public use and protection of the coastal environment.

Study area

The study area is included in the department of Valle del Cauca, specifically in the coastal bay of the municipality of Buenaventura, between the sectors of La Bocana (77°11'49.036''W; 03°50'18.424''N), and Punta Limones (77°06'43.328''W; 03°50'30.696''N), with a coastline extension of 95.61 km and an area of 109.41 km^2, covering the industrial, port and the Biodiversity and Ecotourism district of Buenaventura, located on the island of Cascajal. In the Bay of Buenaventura the Aguadulce, Pichido, El Corral and San Joaquín streams, and the estuaries of Aguacate, Amazonas, Crusecitas, Docientos Pesos, El Piñal, Gamboa, Las Cruces, Limones, San Antonio, and Santa Delicia, all empty into the Dagua river, with a large number of drainages that constitute a deltaic system (Figure 1).

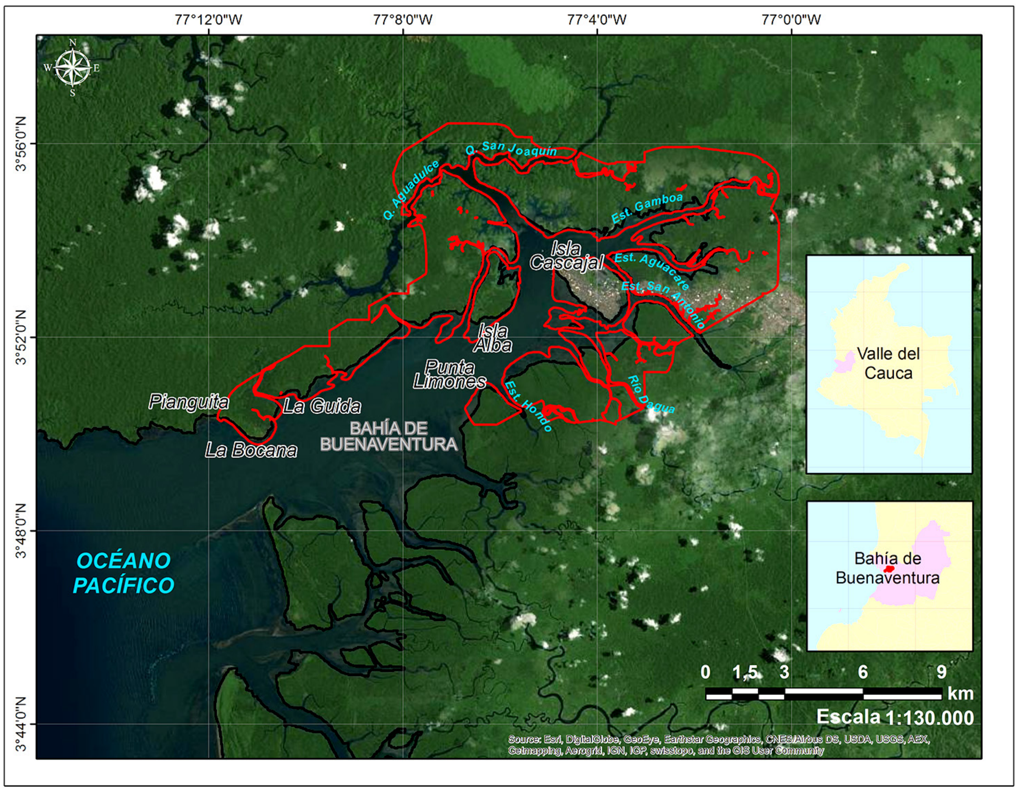

Figure 1. Map of the study area.

Methodology

Data

The spatial data used in this study were orthophotos, captured with a digital metric camera that allowed a spatial resolution of 25 cm per pixel in the images, and the LiDAR point cloud, captured with an airborne ALS40 system in a Cessna 402B aircraft, both taken in 2006.

The calibration parameters of the LiDAR data capture equipment were: FOV scanning 30°, flight height 1219 m, aircraft speed 125 knots, scanning frequency 29 Hz, laser wavelength 1084 nm (16), that comply with the technical specifications for the generation of the digital cartographic database of DIMAR (Division of Coastal and Marine Areas, 2006), which proposes a maximum vertical accuracy of ±15 cm and a maximum horizontal accuracy of ±0.5 m. The average spacing of the point cloud is 1.00 m; a value determined through sampling and it is classified into the following categories: soil, construction, vegetation, and water, among others.

The LiDAR data present the standard of the American Society for Photogrammetry and Remote Sensing (ASPRS) in version 1.0 of May 9, 2003, which normalizes the structure, form and content of the ".LAS" files, to facilitate their exchange, transfer and storage (ASPRS, 2003).

The October 2013 scenes of the LandSat 8 satellite were used and those of June 2003 from LandSat 7 were also used, with a spatial resolution of 30 m. Specifically, a color combination was generated with bands 5 (Near infrared), 6 (Medium infrared) and 4 (Red), corresponding to 4, 5 and 3 for LandSat 7.

Derived products

The derived products arose from several analysis and spatial processes, the first step was to reclassify the LiDAR points assigned by the automatic classification to the non-corresponding return. The second step was to generate a digital terrain model (DTM) with ground return points (Ground - Return 2), which describes the terrain heights of the study area; and the third step was to create a digital vegetation model (DVM) with high, medium and low vegetation returns (High, Medium and Low Vegetation - Returns 3, 4 and 5), which describes the canopy height of vegetation cover (MDV). Both models were created with a resolution of 1m/pixel.

Based on the Digital Terrain Model, slope, curvature, shading and level curves models were generated to support the classification of the geomorphological units, and with the DVM, only the shading model was generated to help in the classification of the vegetation cover.

Other derived products were the RGB 453 and RGB 564 color compositions of the LandSat 7 and 8 bands respectively, which allowed the identification and digitalization of the coastline limit of the geomorphological units and the vegetation cover; this thanks to the notable differentiation between spectral responses of the soil and water.

Creation of the cartography and interpretation of images

The interpretation of images involves the spatial analysis of soil elevation models, vegetation and RGB combinations of satellite images; Accompanied by the recognition of features such as shape, texture, color, size, shading, tone, structure, associations and patterns that facilitate the identification and mapping of geomorphological units and plant cover.

To generate the geomorphological units, the starting point was the separation of the low tide lands and the zones susceptible to the action of the tide. This differentiation was achieved with the tracing of the line of highest tide, obtained from the MDT and the calculation of the maximum elevation levels along the Pacific coast thanks to the H2D hydrodynamic model, which is part of another study (Otero, 2005). Subsequently, the lowest tide line was interpreted and plotted with the RGB 564 (L8) and 453 (L7) compositions of the satellite images, conforming the intertidal zones up to the line of highest tide digitized initially (Dimar-CCCP, 2013). Above these zones are the floodplains that may occasionally be affected by rainwater or extreme tidal events (Vargas Cuervo, 2015).

The use of terrain profiles, 3D models and contour lines (Figure 2) allowed the hills to be digitalized and to differentiate geomorphological features. As well as the use of the vegetable cover layer, the vegetated intertidal zones were separated from the non-vegetated zones.

The layer of vegetation cover was obtained from the direct analysis of the orthophotographs, where the elements belonging to the different types of vegetation were examined and the patterns of texture, color and shape of the tops of the trees and shrubs were established. Once these characteristics were established and supported by the RGB compositions of the satellite images, each coverage could be identified in different areas. To analyze the limits of the different coverages by means of the canopy heights, 3D visualization models were constructed from the LIDAR data, with the GlobalMapper software and terrain profiles in

MARS (Figure 2); this facilitates the process of its identification, delimitation and classification.

The determined vegetation covers were named using the national legend of land cover (Ideam, 2010) developed for scales 1: 100.000, which is an adaptation of the Corine Land Cover methodology for Colombia (Ideam, 2010). However, covers were only detectable at major scales (> 1:2000), so extra classes were created in addition to those belonging to the national legend (Ideam, 2010).

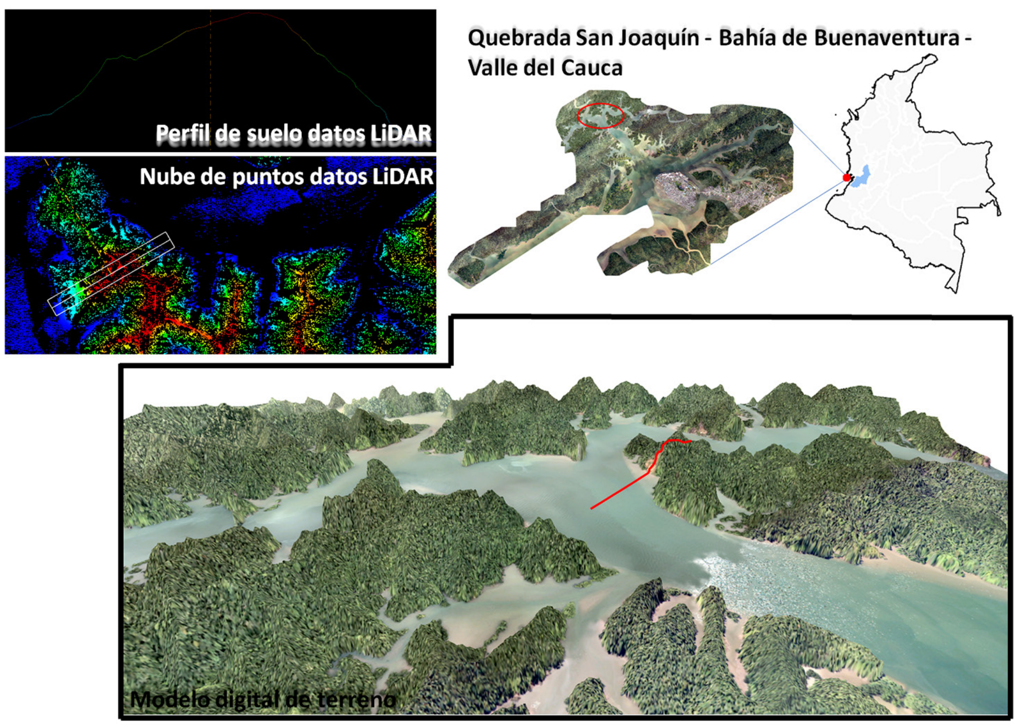

Figure 2. 3D digital model, soil profile and LiDAR data from the forests of the mainland around San Joaquín stream, Buenaventura Bay, Valle del Cauca.

Field phase

Based on the cartography obtained from the derived products, field verification work was carried out on both the vegetation cover and the geomorphology; this is because the interpretation requires verification and subsequent updating through direct recognition on the ground (Melo & Camacho, 2005).

For the sampling sites, visits were made to each type of coverage identified by taking panoramic photographs of evidence, performing a visual analysis of the coastal zone and collecting vegetation samples of the dominant species for their recognition in the laboratory.

As for the geomorphological units, the equality between the cartography and that observed in-situ was verified, with the pertinent corrections being made at places with any inconsistencies.

Results

Geomorphological units

In the Bay of Buenaventura, 3 geomorphological regions, 7 geomorphological units and 2 geomorphological features were identified (Figure 3). The geomorphological regions are represented by deltaic plains, coastal plains and by hills; and the geomorphological units by beaches, non-vegetated intertidal platforms, vegetated intertidal platforms, floodplains, islands, coastal lagoons and hills. The geomorphological regions that occupy the greatest area in the bay, are the delta plains and the hilly areas; the units with the largest area are intertidal vegetated and non-vegetated platforms (Table 1).

Geomorphological regions

. Delta plains. These surfaces, which are associated with the mouths of the bay's rivers, contain geomorphological units such as vegetated intertidal platforms and floodplains. They occur mainly towards the south of Buenaventura Bay, in the sector known as Punta Limones and La Playita.

. Coastal plains. These plains contain recent littoral deposits, including areas with a predominantly flat or low morphology with respect to sea level; a feature that differentiates them from the fluviomarine terraces. Its origin is marine or fluviomarine and, generally, represents a strip of coast that has spread or that is the result of changes in the level of the sea (National Soil Survey Handbook (NSSH), 2008) and that is bordered towards the continent by hills or mountainous areas (Gómez, Carvajal & Otero, 2013). In the bay you can see the SW, NW and NE, mainly towards the base of the hills. In these plains, units such as floodplains and vegetated intertidal platforms can be differentiated..

. Hills. They occur in almost the entire bay to the southwest and northwest (Figure 4), they have smooth to slightly inclined slopes and rounded shapes. The peaks have elongated to rounded forms, covered by high dense forest of firm ground and non-flooded ferns that generally cover the rocky outcrop. The height is on average between 15 and 30 m. (Dimar-CIOH, 2009) (Figure 4).

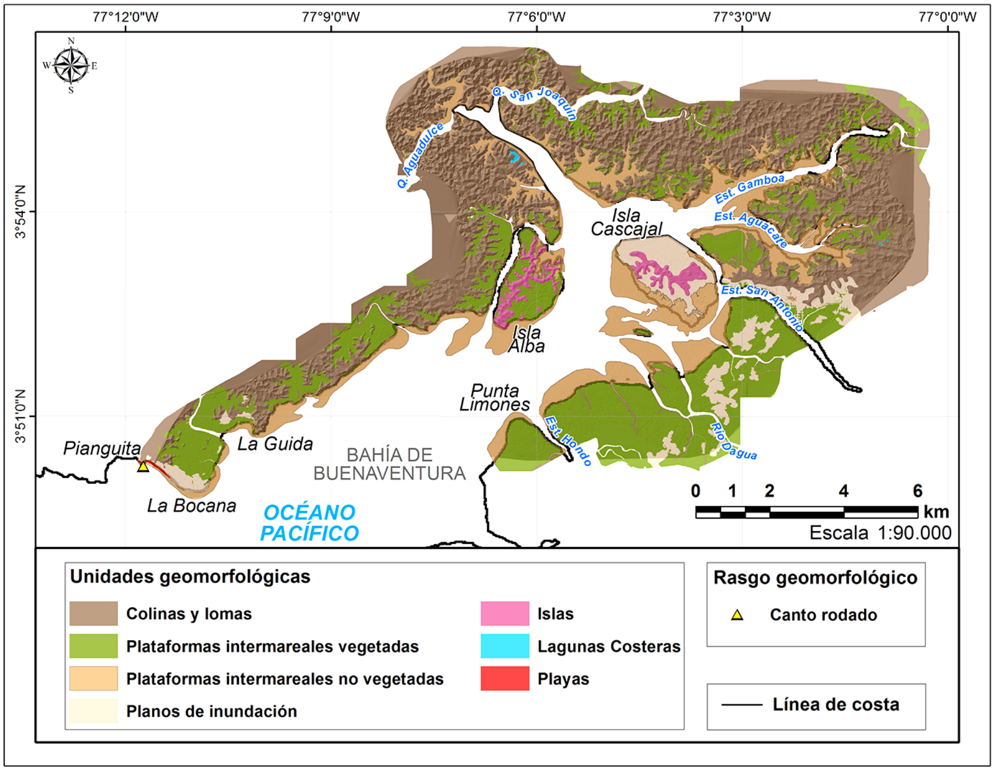

Figure 3. Map of the geomorphological units on the coast of Buenaventura Bay, Valle del Cauca.

Geomorphological units

. ***Beaches.*** The beaches in the Bay of Buenaventura are located in Piangüita and La Bocana, have medium size sand that is dark gray, with abundant ferro-magnesian minerals. They contain herbaceous beach and occupy a total area of 2.7 ha.

. ***Intertidal non-vegetated platforms.*** They are observed in all the Bay of Buenaventura next to the plains with mangroves, the islands, the beaches and hills. These deposits of unconsolidated and non-vegetated sediments are uncovered when the tide is low and are covered when it rises; they are muddy, shallow and are located mainly along the coastline. When these platforms are adjacent to the mangroves, they contain a large amount of organic matter. They occupy a total area of 2190.54 ha.

. ***Intertidal vegetated platforms.*** They are the vegetated zones (halophytic species) that are covered and uncovered by the tide, located at the base of the hills and the hills of the bay. They are very muddy plains of fine sediments and abundant organic matter where mainly mangrove vegetation grows. When the tide is high they are completely flooded. They occupy a total area of 3194.49 ha.

. ***Floodplains.*** In this research this name was given to areas that are at sea level or a little above it that, generally, are not flooded by the tide, are flat to slightly undulating and more stable than the muddy surfaces of intertidal platforms because they do not receive constant flooding. They suffer periodic flooding, as a consequence of high rainfall and a high water table, extreme events or the overflowing of rivers. Its origin is due to the fluviomarine deposition of sediments and can present fern type vegetation and high dense forest of firm ground. These plains are observed in Piangüita and Punta Limones. They occupy a total area of 563.14 ha.

. ***Coastal lagoons.*** They are observed near the "Doscientos pesos" estuary toward the northwest of the bay, occupied partially and totally by water when the tide rises; they are separated from the estuary by a mangrove area. They occupy a total area of 3.92 ha.

. ***Islands.*** In the Bay of Buenaventura there are two islands called Alba and Cascajal and they are rocky. Cascajal is completely urbanized, while Alba contains fern vegetation and is surrounded by vegetated intertidal platforms with mangroves that are covered by the sea when the tide is high. Both islands occupy a total area of 167.33 ha.

. ***Hills.*** In the Bay of Buenaventura we can mainly observe hills with very gentle slopes, with rounded and elongated tops, with heights between 10-30 m and with shrub-like vegetation on them. The hills can be observed from the center of the bay towards the north arm (up to Piangüita); they have heights of up to 70 m, with steep to gentle slopes, with geomorphological features such as cliffs towards the Piangüita sector. In total the area occupied by the hills is 4819.80 ha.

Table 1. Extension of the geomorphological units found in the study area.

Geomorphological units	ha	%
Hills	4819.80	44.04
Vegetated intertidal platforms	3194.49	29.19
Non-vegetated Intertidal platforms	2190.54	20.01
Flood plans	563.14	5.14
Islands	167.33	1.52
Coastal lagoons	3.92	0.03
Beaches	2.70	0.02
Total	**10941.95**	**100**

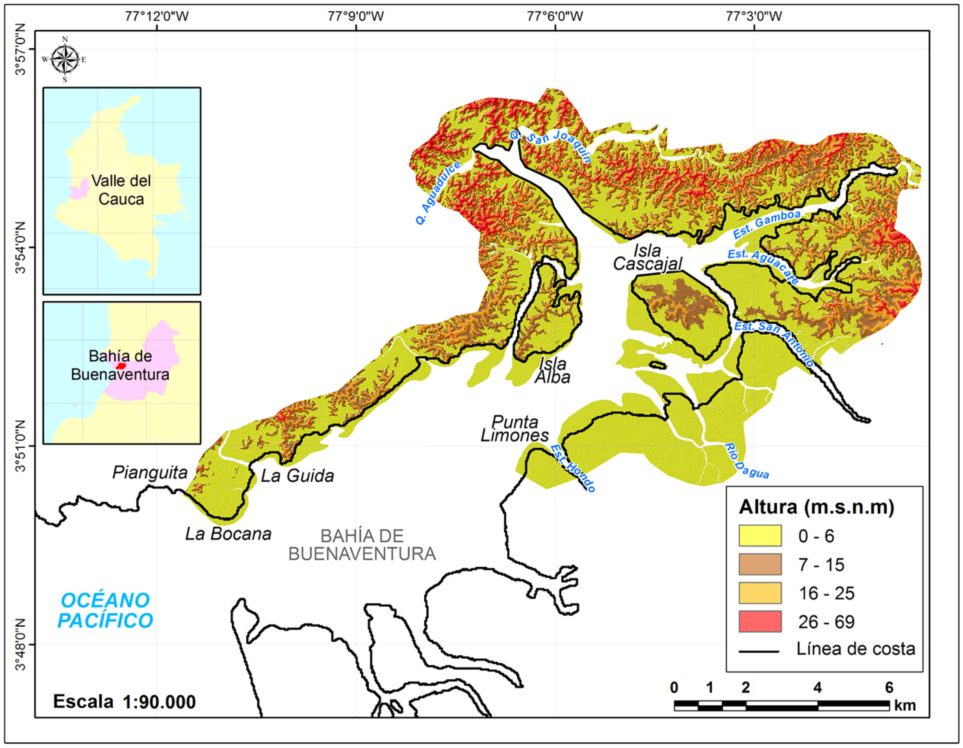

Figure 4. Model of land elevation on the coast of the Bay of Buenaventura, Valle del Cauca.

Geomorphological features

. Cliffs. Cliffs are observed towards the sector of La Bocana, on the rocky ledge that separates La Bocana from Piangüita (approximate height of 25 m). There are also cliffs on the edges of the hills and hills of the bay. In some areas they are not visible because they are so low (0.5 to 1 m) and are covered when there is high tide or covered by vegetated intertidal areas with mangroves.

. Boulders. These accumulations of debris are observed at the base of the Bocana cliff, as rock bodies with diameters greater than 50 cm, as a result of the destabilization of the escarpment of the rocky outcrop.

. Vegetation Coverages. 12 vegetation coverings were identified (Figure 5) in a total area of 8212.64 ha (Table 2), the largest area being that of the high dense forest of firm ground coverage (3690.47 ha equivalent to 44.94 %) and to a lesser extent, the herbaceous coverage of the beach (0.90 ha equivalent to 0.01 %).

. High dense forest of firm ground. The percentage of area occupied by this coverage in the study area is 44.94 %.

. Mangrove swamp. The percentage of area occupied by this coverage in the study area is 37.65 %. Some of the species found were: *Rhizophora mangle, Avicennia geminans, Laguncularia racemosa* and *Rhizophora harrisoni.*

. Fragmented forest with secondary vegetation. The percentage of area occupied by this coverage in the study area is 10.13 %.

. Non-flooded ferny. This coverage is characterized by being mainly dominated by ferns. They grow on firm land or hills that have been intervened to create paddocks, and that have been abandoned, and are consequently populated with different species of ferns. The percentage of area occupied by this coverage in the study area is 2.46 %.

Table 2. . Areas of vegetation found in the study area.

Vegetable Cover	ha	%
High dense forest of firm ground	3690.47	44.94
Mangrove swamp	3092.54	37.65
Fragmented forest with secondary vegetation	831.98	10.13
Not flooded swamp	201.77	2.46
Urban green areas	145.47	1.77
Palm grove	140.97	1.72
Naked and degraded lands	58.50	0.71
Trees in urban areas	23.70	0.29
Fragmented forest with pastures and crops	18.24	0.22
Ferny	7.01	0.09
Shrubs	1.01	0.01
Herbaceous beach plants	0.90	0.01
Total	**8212.64**	**100**

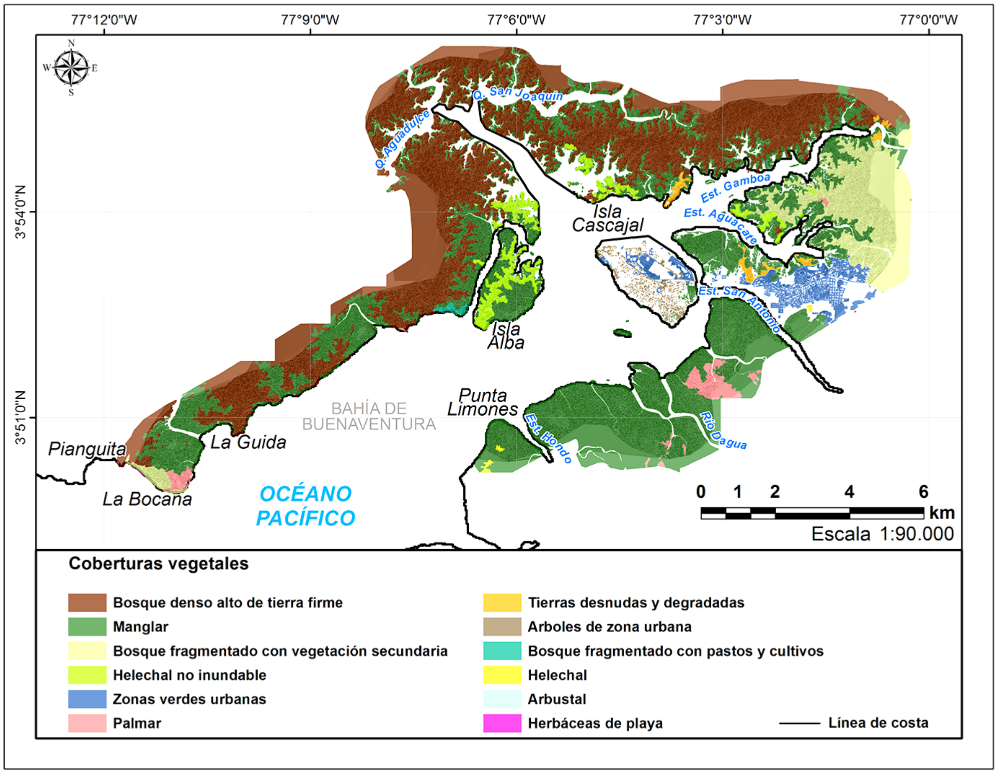

Figure 5. Map of the vegetation covering of the Bay of Buenaventura, Valle del Cauca.

. Urban green areas. Corresponds to parks, home patios, vegetated areas bordering rivers and small relicts of forest, always associated with a discontinuous urban fabric. The percentage of area occupied by this coverage in the study area is 1.77 %.

. Palm groves. The percentage of area occupied by this coverage in the study area is 1.12 %.

. Naked and degraded lands. The percentage of area occupied by this coverage in the study area is 0.71 %.

. Urban area trees. These corresponds to ornamental, shady, fruit trees and other shrub type vegetation, which is found only in urban areas. The percentage of area occupied by this coverage in the study area is 0.29 %.

. Fragmented forest with pastures and crops. The percentage of area occupied by this coverage in the study area is 0.22 %.

. Ferns. The percentage of area occupied by this coverage in the study area is 0.09 %.

. Shrubs. In this type of cover species like the Cecropia spp and some high grasses like the Gynerium spp species and some Musaceas and Araceas are seen. The percentage of area occupied by this coverage in the study area is 0.01 %.

. Herbaceous beach plants. Corresponds to areas dominated by open herbaceous natural vegetation that cover between 30 and 70 % of the total area of the unit. In no case can arboreal elements be presented. They grow on areas of sandy soils that do not retain moisture. In general, this type of coverage appears in newly formed areas, such as spikes and coastal bars. In this type of terrain, species usually appear that are characterized by being nitrogen fixers, and usually alter the soils so that another type of cover appears, such as shrubs, and thus continue the ecological succession. The species that can be found are: *Cenchrus pauciflorus, Homolepsis aturensis, Ipomea pes-caprea, Ipomoea stolonifera, Cannavalia marítima, Pectis arenaria and Stenotaprum secundatum.* The percentage of area occupied by this coverage in the study area is 0.01 %.

Coastal geomorphology and its associated vegetation cover

Of the total area of the geomorphology described, 77.30 % is covered by vegetation. The geoform with the most vegetative cover is vegetated intertidal platforms (Figure 6) with 99.11 % and the least covered are the beaches with 51.11 % (Table 3).

For the geoform hills, a greater predominance of high dense forest of firm ground is observed (Figure 6) with 77.99 %; in the islands the non-flooded fern predominates with 79.97 %; in the floodplains the mangrove with 34.95 %; in the vegetated intertidal platforms the mangrove covers 95.15 %, and in the beaches the herbaceous beach with 64.49 %.

Discussion

The geomorphology of Buenaventura Bay is formed by two generic processes; endogenous and exogenous. Among the endogenous processes is the formation of lithotectonic units associated with a particular tectonic environment. The Bay of Buenaventura is part of the Tumaco basin, which has an extension from the fault system of Garrapatas (North), dextral movement, to the Buenaventura fault, dextral transpressive movement, on the Ecuadorian border (South) (Ortiz & Valencia, 2013; Mountney and Westbrook, 1997 in Cediel *et al.,* 2003). This basin represents an Forearc Basin associated with a system of tertiary subduction, by the collision and subduction of the Nazca oceanic plate and the South American continental plate, and which rocks that contain massive basaltic flows, pillow lavas, Komatiitica lava flows and a peridotite-gabbro complex, of Cretaceous Superior age that constitutes the basement and seem to represent an oceanic plateau; and sedimentary rocks dominated by shales, sandstones and turbidite conglomerates and limestones in smaller proportions, of the Cenozoic from the Eocene to the Pliocene, and formed in deep marine environments (Ortíz & Valencia, 2013, Etayo-Serna *et al.,* 1983). Structurally the knolls and hills of Buenaventura are part of a fold imbricated with W vergence that include scales of oceanic crust (Etayo-Serna *et al.,* 1983).

Table 3. Association between geomorphology and coastal vegetation coverage, showing the percentage of coverage.

Geomorphological unit	Total ha of geomorphological unit	ha covered by vegetation	% covered by vegetation	Vegetation coverage	ha vegetation	% vegetation
Hills	4819.80	4712.14	97.77	High dense forest of firm ground	3675.23	77.99
				Fragmented forest with secondary vegetation	770.72	16.36
				Non floodable fern	119.8	2.54
				Urban green zones	79.55	1.69
				Naked and degraded lands	49.58	1.05
				Fragmented forest with pastures and crops	10.67	0.23
				Urban area trees	4.39	0.09
				Palm grove	1.2	0.03
				Arbustal	1	0.02
Vegetated intertidal platforms	3194.49	3166.14	99.11	Mangrove	3012.74	95.15
				Palm grove	95.19	3.01
				Fragmented forest with secondary vegetation	27.93	0.88
				Naked and degraded lands	8.91	0.28
				Fragmented forest with pastures and crops	7.57	0.24
				Fern	7.01	0.22
				Urban green zones	6.79	0.21
Non-vegetated intertidal platforms	2190.54			None		
Floodplains	245.91	231.39	94.10	Mangrove	80.86	34.95
				Urban green zones	45.75	19.77
				Palm grove	44.52	19.24
				Fragmented forest with secondary vegetation	32.87	14.21
				High dense forest of firm ground	15.24	6.59
				Urban area trees	12.15	5.25
Islands	167.33	102.49	61.25	Non floodable fern	81.96	79.97
				Urban green zones	13.37	13.05
				Urban area trees	7.16	6.99
Coastal lagoons	3.92			None		
Beaches	2.70	1.38	51.11	Herbaceous beach plants	0.89	64.49
				Fragmented forest with secondary vegetation	0.44	31.88
				Palm grove	0.05	3.62

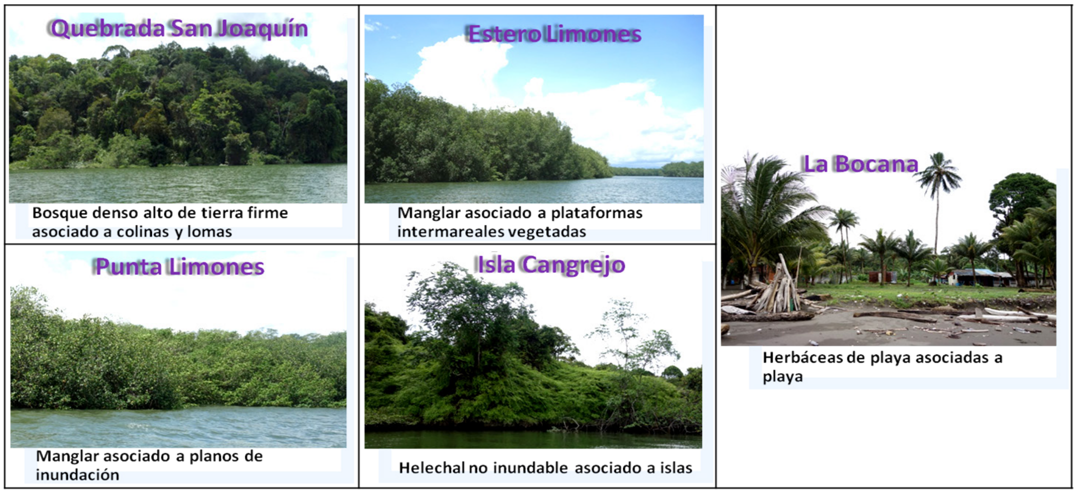

Figure 6. Predominant vegetation coverage in each geoform of the Bay of Buenaventura, Valle del Cauca.

At the same time, the exogenous processes are interacting with the surface, thus modeling the deformed crust. These exogenous processes are the product of the interaction of the crust with the atmosphere, hydrosphere and biosphere, producing weathering, erosion and sedimentation in the rocks that surface and in the soils.

In the bay, geomorphological units characteristic of high and low coasts were identified; which means the bay presents a type of composite coastline. The low coasts or passive deposits, have units with a marine and fluvial genesis, presenting soils with Quaternary deposits influenced by the daily tidal and fluvial fluctuation. Halophytic vegetation grows on this type of coast that supports brackish conditions. These coasts are also known as submerges, which are the result of floods due to sea level rise or sinking of the earth's crust (Johnson, 1919). The regions and geomorphological units found that characterize this type of coast are: deltaic plains, coastal plains, floodplains, vegetated and non-vegetated intertidal platforms, beaches and coastal lagoons. Of these units the ones with the greatest area are the vegetated intertidal platforms with 3194.49 ha., that are found mainly in the sectors known as Punta Limones, La Playita up to San Antonio estuary. It is to be expected that this unit is the one with the largest area in these zones, because generally in the predominantly low coasts, the topography is almost flat, therefore the tidal difference in the horizontal is very large.

The active or high erosion coasts are characterized by presenting geomorphological units that have a tectonic or eustatic genesis and are sedimentary rocks. Helophyte vegetation grows on these units. These coasts are also known as emergent coasts and their genesis is also due to the local elevation of the crust (Johnson, 1919). They are active because they are exposed on a daily basis to weathering and therefore to the erosion caused by some organisms that inhabit the rocky outcrops, the waves and the continuous flow of rivers. In the bay, the regions and geomorphological units that characterize these coasts are: the hills and rocky islands observed in La Bocana, Punta Bazan, Punta La Guida, from El Arrieral to the Aguacate estuary and the Alba and Cascajal islands. The units with the greater area are the hills, with a total area of 4819.80 ha. Unlike the low coasts, coasts that are predominantly high, with a steep topography, present a greater tidal difference in the vertical, which means, the tidal change is better observed in the height of the sea level, therefore, the units associated with low coasts such as beaches, vegetated intertidal and non-vegetated platforms have less area.

The dominant vegetation cover of the area was the high dense forest of firm ground, and this is because the coast of the Bay of Buenaventura is a high coast dominated by hills, which occupy almost half of the area's extension (44.04 %). In areas where coasts are low, such as the Tumaco zone (Bermúdez-Rivas *et al.,* 2014), the dominant coverage was characterized by vegetation associated with floodplains and vegetated intertidal platforms such as mangroves. In this area the intertidal platforms occupy a large portion of territory compared to the hills. Although in the Buenaventura area there is a greater dominance of the hills in the geomorphology of the landscape, the percentage of mangrove cover was high compared to the other coverings (*e.g.* fragmented forest with secondary vegetation), and this is because the floodplain geoforms have less diversity of coverage than the hills, since the plants that grow in these plains and floodplains need a high level of specialization to survive in these conditions (Bermúdez-Rivas *et al.,* 2014).

The association found between vegetation cover and geomorphology was not exclusive; some of the coverages found were present in more than one of the identified geoforms; however, the dominance of some of these coverages was high. An example of this was mangrove coverage in the floodplains, which had a total area of 34.95 % and which in turn occupied about 95.15 % of the vegetated intertidal platforms. In this type of geoforms that are directly influenced by the tide, dominance was marked by the mangroves that are characteristic of these spaces, due to the physiological and morphological adaptations that allow them to develop in unstable lands (Bird, 2008).

Conclusions

- The methodology used to combine several derived products in obtaining the identification of vegetation cover and geomorphologies, combined with remote sensing techniques and interpretation of satellite images, allowed low error levels in the verification process in the field; due to the high precision of LiDAR data and remote sensor images.
- There are no exclusive associations between vegetation cover and coastal geomorphology in this area of the Pacific. These results are consistent with other studies that have been done in other areas of the Pacific (Bermúdez-Rivas *et al.,* 2014).
- The Corine land Cover methodology for Colombia adapted well to this type of vegetation coverage approach and allowed the use of up to four levels of detail to identify and map plant cover.
- The hills are the most dominant and extensive geoforms in the area of the Bay of Buenaventura, have a high percentage of forest cover (95 % c.a.) compared with the other geoforms; in addition to this, they presented the greatest diversity of plant cover (79 % of the total).
- The evaluated area of the Bay of Buenaventura has a very low percentage of beaches (0.02 %) which in almost half are covered by herbaceous vegetation.
- The town center of Buenaventura is sitting on several of the evaluated geoforms (hills, vegetated intertidal platforms, floodplains and islands), in which the common denominator that was observed was the deforestation of the main vegetation coverings that were found as along the bay (mangroves, high dense forest of firm ground).
- •The most extensive vegetation coverings in Buenaventura Bay were wooded coverings such as high dense forest of firm ground and mangroves. The latter are unique to geoforms that are influenced by the tidal cycle.

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