Chapter 4
Environmental Analysis and Classification of Coastal Sandy Systems of the Dominican Republic

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Abstract The Dominican Republic is the most visited insular tourist destination in the Caribbean, being its beaches its main attractiveness. This tourism generates 37% of the total revenues of the country, concentrated in coastal regions. As a result of this pressure, the coastal ecosystems are threatened by the increasing tourist development. Parameters such as site and dune morphology, beach condition, surface character of the seaward 200 m of the dune, pressure of use and recent protection measures make good regional comparison of beach-dune systems. A checklist was developed to calculate Vulnerability Index (VI) and Management Measures (MM) in 99 beach-dune systems of Dominican Republic allowing to identify and prioritize the different pressures. This method of study, associated with Geographical Information Systems (GIS), give more visibility to beach-dunes conditions, and by this facilitate the necessary decisions in the context of a sustainable management of coastal areas. The results indicate that the risk of beach erosion and degradation is directly related to the pressure of use of the coastal area.

4.1 Introduction

Dominican Republic is located in the arch of the Antilles in the Caribbean Sea between the islands of Cuba and Puerto Rico. The island of Hispaniola is divided to Dominican Republic and Haiti (Fig. 4.1). Among the countries of the Greater Antilles, this is the second largest country, with 48,198 km^2 in extension. With

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C.M. Botero et al. (eds.), *Beach Management Tools - Concepts, Methodologies and Case Studies*, Coastal Research Library 24,
https://doi.org/10.1007/978-3-319-58304-4_4

Fig. 4.1 Physical setting and location of Dominican Republic

countless beaches as its main attraction, the Dominican Republic is the most popular Caribbean destination, receiving 6.3 millions of visitors in 2015 only, being its beaches its main attraction (http://www.godominicanrepublic.com).

In 2014, the tourism, mainly international, generated 7.7% of total country income. It is concentrated around coastal regions, where most of the resorts and hotels are located. Most of the activities are focused on sunbathing and other leisure time activities.

Tourists from these complexes spend most of their stay at the beach or using hotel facilities, being sun and beach activity their most usual activity. In recent decades, therefore, the country's coastline has been subjected to an important anthropogenic impact; two main reasons were the rapid increase of urban and touristic development centered on the coastline.

Although economically tourism is beneficial to a great extent, the important geo-environmental effects are not to be overlooked too. Past policies of the tourism development along the coast were not based on the understanding of the mechanisms of the coastal dynamic, such as the beach-dune interaction, the variability of the beach system, and the relationship between submerged and emerged system or the sedimentary balances (Roig-Munar et al. 2005). Such vulnerability of the coast needs to be assessed to establish proper management policies. This would help to conserve, maintain and restore the coastal resources as natural systems, where much of the country's economy gravitates.

One of the main obstacles for a better decision-making is the lack of information and understanding of the scope and value of the benefits provided by these ecosystems. Effective management strategy depends on the availability of objective information; the quality of decision making depends on the quality data collection systematically. These data should be organized in a better structured format, where problems are presented as generally complex and interrelated. Thus, a geo-environmental monitoring and the collection of sustainability indicators appear as an useful tool, since data can be incorporated into a management model (Roig-Munar et al. 2006).

The aim of this work is the geo-environmental evaluation of sandy coastal systems of the Dominican Republic, to determine their conservation status, their use and their management. The final result of this research is the development of a GIS, where vulnerability of the beach system will be exposed as the result of the management measures and the vulnerability index. In addition, the results of the analysis help to establish a starting point to establish the beach-dune systems in the country. Finally, it observes, argues and comments a general framework in decision making concerning coastal management.

4.1.1 Physical Setting

The Dominican Republic has the most notable relief of the West Antilles, with complex systems and rugged mountains, occupying two thirds of the territory, along valleys and wide plains (Moya 2004). The country extends along 1576 km of coastline, including islands, islets and cays, along 8950 km^2 of island shelf (Fig. 4.1). Among others, 27 dune systems can be found, 19 banks of coral reefs, 15 bays and inlets, 95 cays and islets (159.38 km^2), 781 km of rocky coast and cliffs (46.18%), 43 estuaries and 5 adjacent islands covering about 157 km^2. In addition there are 141 coastal lagoons, 125 km^2 of mangrove and 197 sandy beaches.

In the coast of the Dominican Republic we can distinguish basically three sectors:

Northern Coast. It stretches along 526 km (33%) and shows a continuous formation of cliffs and beaches, with presence of large estuaries and mangrove areas. The cliffs have a height of 80 m in average. The sandy beaches occupy 54% of this coast. They generally show an erosive character and can be defined as a coast with tectonic activity.

Eastern Coast. It stretches along 374 km (24%), and it is defined by lower reliefs and longer sandy beaches. Most of the coast is affected by tilting and erosive processes. The cliffs occupy 30.5%, beaches 56% and mangroves 12.8%.

Southern Coast. It stretches along 675 km (43%) and it has large areas of beaches, small cliffs and beaches of alluvial origin. There are wide areas of sand dunes. We highlight the presence of clastic sediments from the Yaque deltaic complex. The southern coast has 69.6% of beaches, 28.4% of cliffs and 2% of mangroves.

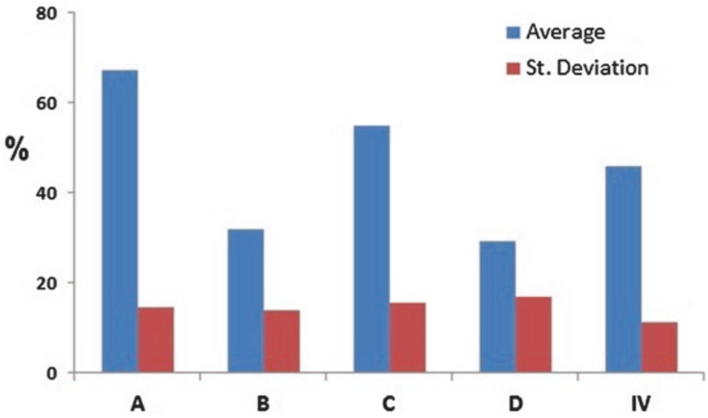

Fig. 4.2 Average and standard deviation for each category

Based on these three coastal regions, 99 beaches have been analyzed during three campaigns between September 2010 and March 2011 (Fig. 4.2).

4.1.2 Main Problems of the Coastal Zone

The diversity of the problems that take place in the Dominican coasts come mainly from the noncompliance of the Law 64–00 on the Environment and Natural Resources and the regulations, deriving from this. Besides, there is an institutional weakness and poor institutional cooperation among different agents. Among others, the problems are as follows:

1. Pollution in estuaries, coastal lagoons and the sea water with organic and inorganic waste from inland waters.
2. Mismanagement in privatized areas serving only economic criteria.
3. Development of marine and navigation channels in inappropriate places.
4. Dune and coastal vegetation destruction by vehicle circulation and park.
5. Dredging of the beach and coastal sands for various activities, including construction.
6. Removing and coral reef destruction for jewelry making and decoration.
7. Destruction of the areas of seagrass beds.
8. Marine dynamics interfering by misplaced breakwaters and jetties.

4.2 Methodology

Strategies for the coastline analysis must have clear objectives, clarity of information and a common goal (Barragán 2001). The systematic collection of data must be reliable, adequate, consistent and complete. These data should be organized in a logical frame, because the problems detected in the fragile and dynamic coastal environments are generally complex and interrelated. This fact often hinders an optimal beaches management.

Therefore, data collection must join the process of making strategic decisions in the coastal management at national level with a spatial and temporal analysis component. In this way, the collection of variables for formulating strategies adapted to each of the analyzed spaces will be essential. Alterations in the sandy coastal systems are generated by the interaction between objective and subjective variables that constitute the coastal environment. The former are measured accurately within the physical environment, such as fetch, width of the beach, etc., while the latter are established within socioeconomic and / or cultural factors. Those are more difficult to quantify, public access, system development, etc.

4.2.1 Checklist Methodology

The checklist is a semi quantitative method to identify vulnerability of the spatial and temporal variations both naturally and anthropic. It has been used and tested in numerous dune systems in Europe, both in the Atlantic and the Mediterranean area (García-Mora et al. 2001; Laranjeira et al. 1999; Martín-Prieto et al. 2008; Williams et al. 1998).

The checklist is a common method in many disciplines and is characterized by collecting data systematically. On the geo-environmental monitoring of beaches, collecting indicators is a useful tool. The repetition of this procedure and its analysis has been valuable for the evaluation of different management models (Curr et al. 2000; Leatherman 1997; Williams 1998). The approach and analysis through qualitative indicators, provides a simplified view of a complex phenomenon. The indicator is characterized by its easy measurement, easy observation and interpretability, making it easier to the manager to spot trends, simplifying a complex reality and geo-environmental dynamics, such as the beach-dune systems (Roig-Munar 2003; Williams et al. 1998).

The checklist applied in the Dominican Republic (Table 4.1) allows a systematic examination of the main parameters that summarize the condition of a coastal system or a sector of coast as an analysis unit. This list, modified from Curr et al. (1997), Garcia-Mora et al. (2001) and Williams et al. (1993), allows the systematic repetition of the main parameters that summarize the status of a beach-dune system, allowing knowing and understanding the causes that have led to its current state.

Table 4.1 Categories and parameters used for the checklist in the Dominican Republic

Category A: geomorphological aspects		0	1	2	3	4
1	Ortogonal fetch	Short		Medium		Long
2	Beach surface (m^2)	>100 mil	>75 mil	>50 mil	>25 mil	<25 mil
3	Coastline lengh (km)	>10 km	>5	>2	1_2	<1
4	Beach width (m)	>100 m	>75 m	50	15–50	<15
5	Reef present	Yes				No
6	Reef fragmentation	None		Small	3	Big
7	Dunar system	Yes				No
8	Dune heith	>3 m	2_3	1_2	1–0.5	<0.5
9	Tropical storm-Hurrican	None	1	2	3	4
10	Mangroove present	Yes				No
Category B: condition of the beach		0	1	2	3	4
1	Coastline setback (m)	<10		10_50		>50
2	Submerged terraces	Yes				No
3	Beach outcrops	No		Scarce		Big
4	Beach vegetation	Much		Scarce		None
5	Beach cliff	None		Medium		v. h
6	Presence of marine grasses	Very high		Moderate		Few
7	Emerged artificial structures	0		1_10		>10
8	Submerged artificial structures	1		1_10		>10
9	Presence of broken corals	0		Some		High
10	Sediment Compactation	1		Some		High
Category C: littoral fringe		0	1	2	3	4
1	Hesp Morfoec. classif (1988)	Est. 1	Est. 2	Est. 3	Est. 4	Est. 5
2	Vegetated surface (backshore)	>75	>40	>20	>10	<10
3	Pluvials	0		1_10		>10
4	Sand blown inland	Very low	Low	Moderate	High	v. h
5	Public acces	Restristed		Half		None
6	Neomorph. Along seaward edge	High		Medium		None
7	Coastline privatization	High		Medium		None
8	Housing	No				Yes
9	Urban area: Concentr.-disp.	0–30%		30–60%		>60%
10	Blowouts	0		Few		Much
Category D: pressure of use		0	1	2	3	4
1	Visitor pressure	Very low	Low	Moderate	Low	Very high

(continued)

Table 4.1 (continued)

2	Road acces	None		Some		Much
3	Dificuly to get the beach	High		Moderate		None
4	Traffic of vehicles	None		Some		Much
5	Horse riding	None		Some		Much
6	Presence of boats	Very low		Medium		High
7	Beach mechanical cleaning	No		Moderate		Yes
8	Presence of animals	Few		Some		Much
9	Vicinity tourist areas (km)	>1		0,5–1		0
10	Temporal buildings	None		1_5		>5
11	Permanent buildings	None		1_5		>5
12	Sand dregging	No				Si
13	Quads	None		Some		Much
Category E: management measures		0	1	2	3	4
1	Users restriction	No		Some		Much
2	Controlled parking	None		Some		All
3	Reefballs	No				Yes
4	On-dune driving controlled	None		Some		All
5	Sand traps	No				Yes
6	Planting on movile areas	No		Some		Much
7	Information boards	0				Yes
8	Artificial beach regeneration	si				No
9	Manual beach cleaning	No				Yes
10	Surveillance and maintenance	None		Some		All

Modified from Curr et al. (1997), García-Mora et al. (2001) and Williams et al. (1998)

To determine the relevant alterations affecting beaches, both geomorphology (Hesp, 2002; Martinez and Psuty 2004) and use and management (Laranjeira et al. 1999; Leatherman 1997; Roig-Munar 2003; Roig-Munar and Comas 2005) must be considered. This allows a systematic examination of the main parameters that summarize the status of a sandy coastal system. Given a particular environment (Fig. 4.1), the appreciation and interpretation of the parameters is essential to formulate strategies adapted to each of the analyzed areas (Roig-Munar 2003).

The objective of this geo-environmental classification of beaches is based on the assessment of the vulnerability of the sandy shoreline of 99 coastal systems (Fig. 4.3), using as categories of analysis the following ones (Table 4.1):

A: Geomorphological aspects (10 parameters).
B: Beach conditions (10 parameters).
C: State of the coastline (200 m from the shore) (10 parameters).
D: Pressure of uses (13 parameters).
E: Management measures (10 parameters).

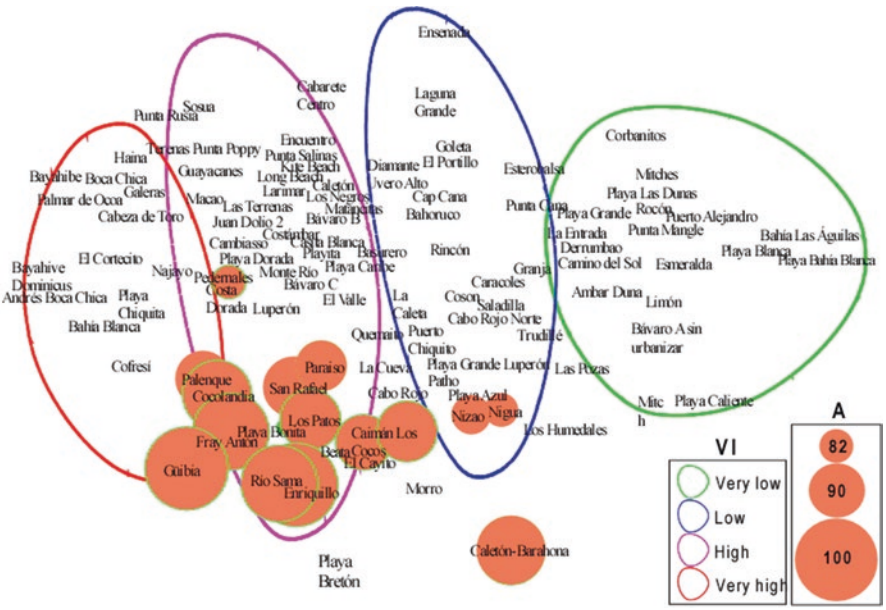

Fig. 4.3 Multidimensional analysis of the Vulnerability Index (VI). *Red circles* show the category A with a value higher than 80%

Table 4.2 Example of checklist applied to Punta Cana

Cat. A	Sc.	Cat. B	Sc.	Cat. C	Sc.	Cat D	Sc.	Total sc.	Cat E	Sc.	Total sc.
A1	0	B1	0	C1	2	D1	1		E1	4	
A2	3	B2	0	C2	2	D2	0		E2	4	
A3	3	B3	2	C3	2	D3	0		E3	0	
A4	3	B4	2	C4	2	D4	1		E4	4	
A5	0	B5	2	C5	0	D5	0		E5	0	
A6	0	B6	2	C6	2	D6	0		E6	2	
A7	0	B7	2	C7	0	D7	4		E7	0	
A8	3	B8	0	C8	4	D8	0		E8	0	
A9	4	B9	0	C9	0	D9	0		E9	2	
A10	4	B10	2	C10	0	D10	2		E10	2	
						D11	2				
						D12	4				
						D13	0				
Sum.	20		12		14		14	60		18	18
%	50		30		35		25	35		45	45

VI (=the % of sum. Cat. A-D) = 35%; MM (Cat. E) = 45%. MM/VI = 1.3

The use of the checklist in the classification analysis and proposals for geo-environmental management of the beaches of the Dominican Republic was carried out by 53 parameters. They were taken into consideration independently, with values ranging between 0 and 4, being the first the most positive value and the latter the most negative. Later, the percentage of each category has been calculated, and the sum of the percentage calculation for 53 parameters gives us four categories (A, B, C and D), which determines the Vulnerability Index (VI). Finally, the calculation of the percentage of the 10 parameters of the E category is performed and it constitutes the Management Measures Index applied to each studied unit (MM).

In the Table 4.2 we can see an example of Checklist applied to Punta Cana, where category A has a sum of 20 points, resulting in a percentage of 50% of the total. The result of the Vulnerability Index (VI) is a 35%. It was obtained from calculating the result of adding the percentages of categories A, B, C and D and divided by four. Category E has a sum of 18 points, equivalent to 45% of the total, which is the Management Measures Index (MM). The MM/VI ratio indicates the balance between vulnerability and protective measures and/or management of a particular sector of the coast (the example of Punta Cana is 1.3). This should not be interpreted as a good or bad management, as other factors in the system have to be taken into the account. Low values of category E does not always mean an inappropriate management. For instance, in natural beaches where accessibility is very difficult and pressure users is low, protective measures are not necessary, because the system regulates itself naturally by the lack of interference of anthropogenic type (Roig-Munar et al. 2006).

An advantage of the checklist is that through a repeated application of the same methodology throughout the time in the same units, allows a spatial and temporal comparisons. It shows and detects possible changes, either negative or positive, especially if management measures have been applied. It shows the tendencies throughout the time. One of the first results obtained from the Vulnerability Index is how much geomorphology and ecological diversity have been lost by each unit. This methodology detects variations in the space-temporary analysis of each analyzed unit and thus becomes a useful technique for the management of the beach-dune system and for the work of the territorial planners.

In this study we understand vulnerability as the "loss of capacity of a beach to return to their original state after a displacement or an alteration of the system". In this sense a high vulnerability implies that the system loses temper so intense and widely that it will be difficult to return to its original dynamics. It means that for a very vulnerable place its resilience is very low.

After all the items that form the four categories examined, the level of association between different units was checked. This analysis is presented by using multivariate analysis.

4.2.2 Goals

The main objective of this study is triple:

1. to determine the vulnerability of the sandy coast as consequence of both natural or antropogenic aspects along the coast of the Dominican Republic.

2. to evaluate the state of conservation of these spaces defined by analysis units.
3. to incorporate the information in a general mark to facilitate the administration a better knowledge for a better management and conservation of the sandy coasts.

4.3 Results and Discussion

The results of the three campaigns in 99 coastal units distributed along the coast of the Dominican Republic (Fig. 4.2) define the Vulnerability Index (later in the text: VI) and Management Measures (later in the text: MM) for each beach-dune system.

4.3.1 Vulnerability Index

The VI is obtained from the analysis of the first four categories applied to the beaches of the Dominican Republic (Fig. 4.2). These four categories are: the physical aspects of the system (A), the condition of the beach (B), the coastal strip (200 m landward from the coastline (C) and the pressure of use (D). Fig. 4.2 shows the results of the mean values of the four categories. The higher the numbers (value closer to 100), the greater is the vulnerability.

Category A (morphological aspects of the system) represents the highest percentage of all categories. It shows a high vulnerability associated with the physical aspects of each unit. The cause in most cases is in the existence of a long fetch in most of the beaches, a small surface of the beach, the absence of a dune system in many beaches and some fragmentation of the reef barrier. Another important aspect to consider is the impact of tropical storms and hurricanes that affect the littoral system.

Category B (beach state) shows a 40% of the coastline in a receding dynamic. This data is associated with a high presence of erosional scarps and of coral fragments. Another negative aspect is the high sediment compaction associated with an inaccurate management.

Category C (state of the coastline) shows results quite similar to the category A. These data is related with the morfo-ecological beach-dune classification of Hesp (2002). Most negative values (stages 4 and 5) are present in the 75% of all beaches. This percentage matches with the vegetated dune surface. The loss of sediment is also important, joined with the high level of urbanization of many beach-dune systems.

Category D (pressure of uses) shows intermediate values. They are related to the very different pressure visitors. Some beaches are totally isolated and not easily accessible, meanwhile other beaches undergo high pressure from the visitors (urban beaches).

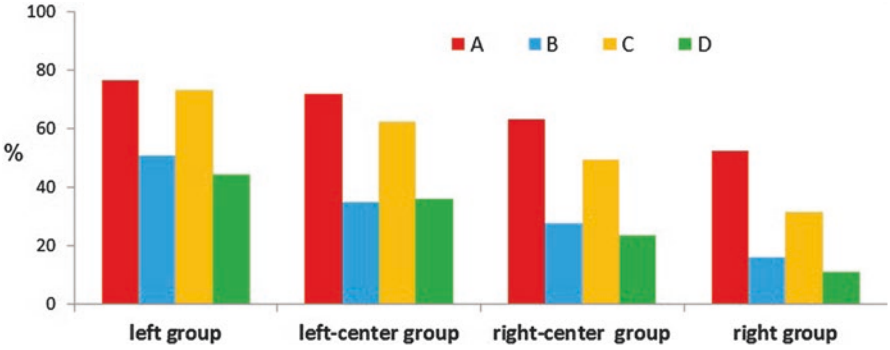

Fig. 4.4 Results for each group and category

The level of association between the different units trough a multivariate analysis results in four main groups of beaches. This analysis was performed both to achieve the maximum homogeneity inside each group as well as enhancing the differences between the groups. The resulting plot is a multidimensional diagram of the beaches. In Fig. 4.4, can be seen how the beaches are grouped.

The group on the right (*green circle* in Fig. 4.4) is formed by those beaches with the lower Vulnerability Index. They are formed by isolated beaches, with challenging accessibility and low or zero urbanization. The rates in all the values of the four categories are below the average: mainly in the categories B and C, but especially in the category D. It means a very low or even zero pressure of use.

On the contrary, the group on the left side (*red circle* in Fig. 4.4) consists of the beaches with the higher Vulnerability Index across the country. Their main common characteristic is that of all the values of all categories are above the average, especially in categories B, C and D (Fig. 4.5). This reveals a lack of naturalness of the beach-dune system and corresponds to urban or semi-urban beaches with an intensive use, mainly by local population.

The group located in the right center (*blue circle* in Fig. 4.4), is characterized by values slightly below the average. It is formed by a beach type where the vulnerability and the naturalness maintain certain balance. The management of this type of beaches should be a decisive factor to keep in mind to avoid its degradation. These are beaches of semi-urban character, some of them even quite isolated. Users are a mixture of local and international visitors.

Finally, the group located in the center left (*pink circle* in Fig. 4.4), shows all their axes overcoming slightly above the average, especially category A. It means that the physical aspects are overcoming the 70% (Fig. 4.5), some reaching the 100%. Most of these beaches is eminently urban of intensive use, both for local users or linked to big resorts.

Finally, there are beaches completely isolated from the groups above. They can be considered outliers, holding different characteristics as the rest, with very high values in the first three categories and zero in category D (Fig. 4.4).

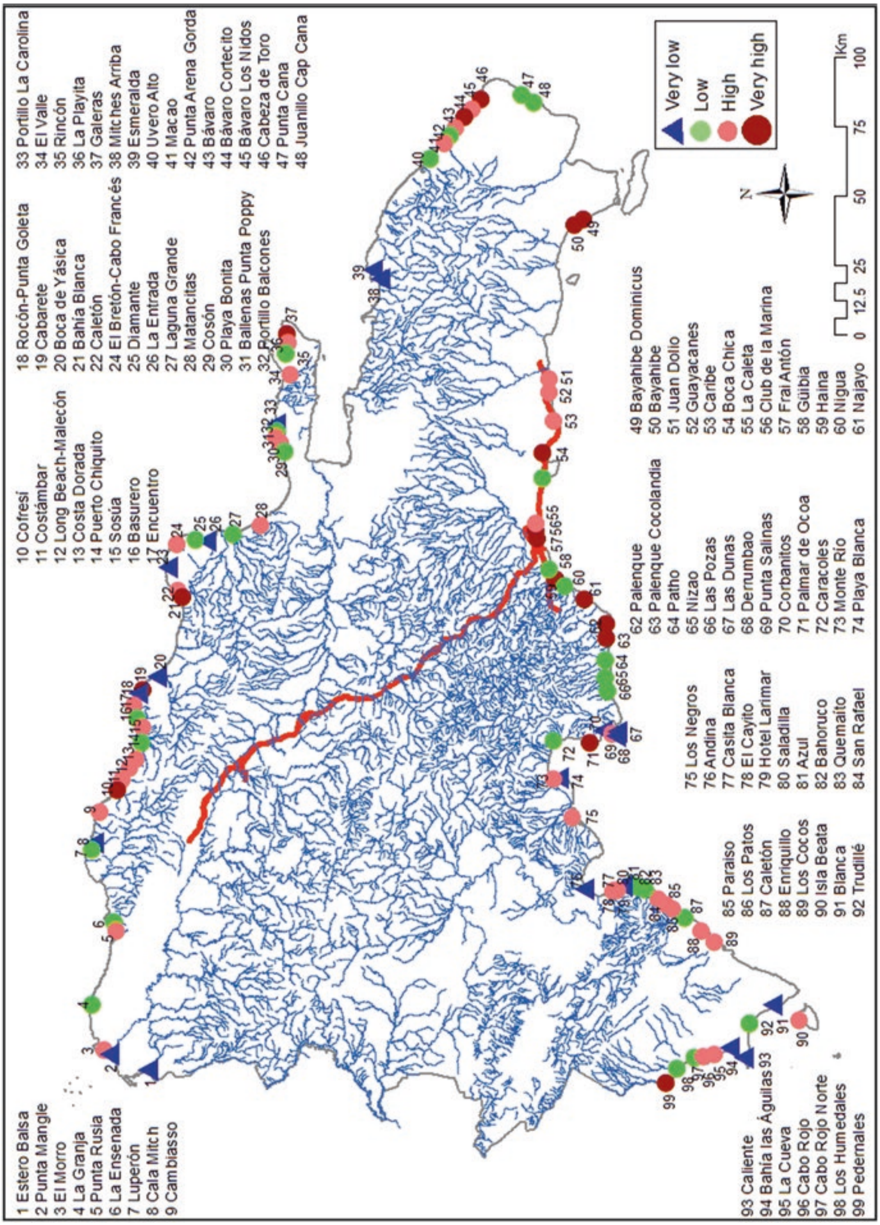

Fig. 4.5 Location of the beaches and their Vulnerability Index (VI)

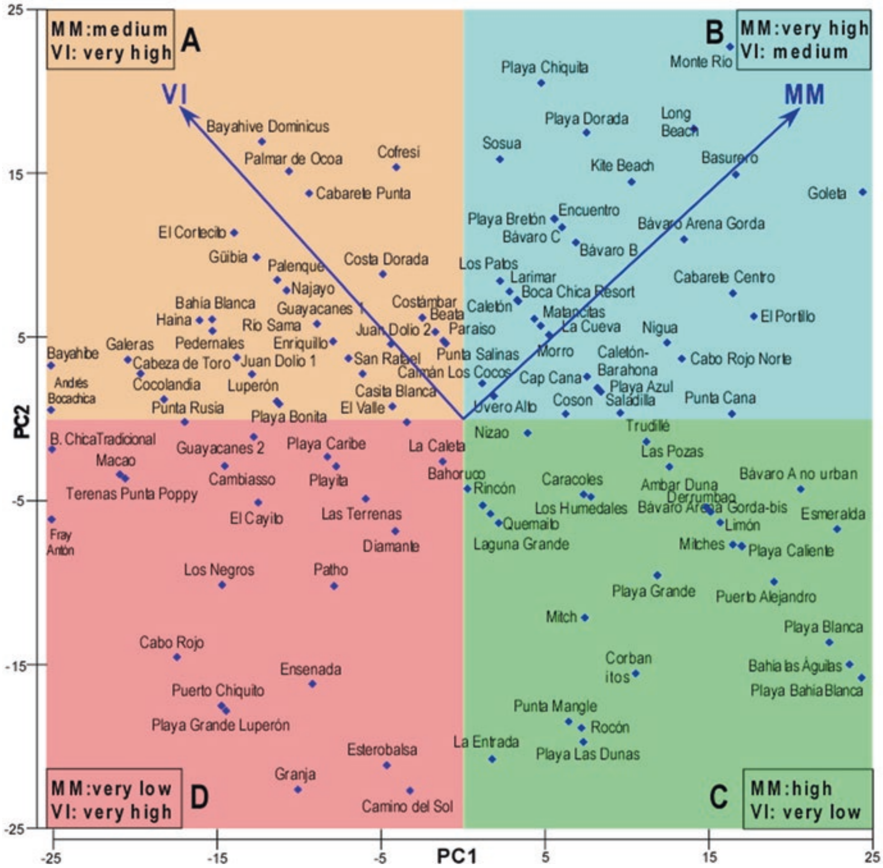

Fig. 4.6 Principal component analysis for beaches analyzed by the index MM/VI

From the all the obtained data, a GIS has been developed. Figure 4.6 shows the location of all the beaches and their Vulnerability Index (VI).

4.3.2 Management Measures (MM) and Vulnerability Index Ratio (MM/VI)

The values obtained for Management Measures (MM) reach an average of 40.7% (the optimum would be 100%). On the other hand, the Vulnerability Index (VI) shows an average of 46% (the values close to zero represent a better management). However, there are some of the beaches, reaching optimal values (close to zero) because of a limited users' pressure.

As a natural system exposed to the pressures of the anthropic type, the balance between Management Measures and Vulnerability Index (MM/VI) shows the circumstances of a certain beach, both from the management and vulnerability perspective. To analyze this relationship a Principal Component Analysis has been made from the data including all the beaches (Fig. 4.6). The results allow a classification into four main groups according to the value of MM, as well as the VI.

Statistical analysis grouped 99 beaches into four quadrants (Fig. 4.6): B quadrant clusters beaches with higher MM and vice versa in quadrant D, with the lower MM. For the purposes of the Vulnerability Index, the analysis collects the most vulnerable beaches in the quadrant A and vice versa, the lower vulnerable beaches in quadrant C.

The quadrant A is characterized by values of MM situated on the average and on the contrary, values of VI are very high as we move away from the center, especially in the case of beaches that overcome 60% of IV. In general these are beaches with high pressure, most of which coincide with the red circles of category A in Fig. 4.4.

The quadrant B clusters beaches characterized by higher values of MM and intermediate values for VI as we move away from the center. As we move toward a lower position, the values of MM and VI decrease. These are the beaches characterized by high pressure of users.

The quadrant C main characteristic is the high values of MM and very low values for VI. These are isolated beaches far away from urban areas with poor frequency, which coincides with the green circle in Fig. 4.4.

Finally, the quadrant D represents the group of beaches with the lowest score in both VI and MM, as we move away from the center.

Beaches located around the center of the figure represent the mean values both of MM as IV.

4.4 Conclusions

Ninety nine beaches of the Dominican Republic have been analyzed along three campaigns. A checklist has been used as a tool, with a total of 53 parameters divided into five categories, to assess the vulnerability of the Dominican sandy shoreline and analyzing disturbances, both natural and anthropogenic. These categories are: A: the geomorphology of the beach; B: the condition of the beach; C: the state of the coastline; and D: the pressure of use. These four categories form a Vulnerability Index (VI) presented by a percentage. The higher value means more vulnerability. The Management Measures (MM) was evaluated by an additional category E. The ratio MM/VI shows the balance between the vulnerability and management in the Dominican coast.

The main conclusions are:

1. Ckecklist is a useful tool for analysis and management of the beach-dune systems. The 53 items used are the starting point aiming to develop a management plan.
2. Beaches are not well understood as natural systems, because they are mainly subjected to the human exploitation. This focuses on the beach and dune front, although erosion processes extend beyond, such as mangroves and reefs.
3. In general, the management measures of the beaches cannot be considered as a management, i.e., cannot be considered measures "taken or made by a manager" for purposes of geo-environmental recovery.
4. The beaches with less vulnerability and greater naturalness are those isolated, accessible by foot or boat only or/and are far from urban or tourist centers.
5. On the contrary, the most vulnerable and entropized beaches are those located in urban areas or very close to them.
6. The beaches with the higher Vulnerability Index (VI) across the country share a common characteristic: the values of all categories are above average, but especially in the categories B, C and D.
7. There are some beaches that have some degree of naturalness, which shows the potential for system for recuperation without human intervention.
8. In 53% of the beaches, the balance MM/VI is above average, what could be considered well-balanced or "well-managed". However, this result could be improved in many beaches applying one of the items of the Management Measures (MM).
9. From the perspective of the physical aspects of the system, there are 13 beaches with a VI percentage higher than 85% and some reaching 100%.
10. As for the condition of the beach, there are 19 beaches that have poor or very bad condition. At the same time, the same number of beaches shows to be in a good condition.
11. With regard to the coastal strip, a total of 16 beaches could be considered in worrying conditions, but 22 beaches are in a very good shape.
12. As for the pressure of the use of the beach, 16 beaches have high or very high pressure. On the contrary 28 beaches have been reported by minimum or zero pressure.
13. Under the above figures, the highest Vulnerability Index (VI) corresponds to 21 beaches. Meanwhile the lowest VI corresponds to a total of 20 beaches.
14. For Management Measures, 20 beaches have high percentages, which represent good management procedures. Conversely, there are 14 beaches with a poor or very poor management.
15. Finally, the balance between Management Measures and Vulnerability Index (MM/VI) shows a total of 18 beaches with a proper management. The number of beaches that have inadequate or very inadequate is 21 in total.

Acknowledgments Contract Análisis, clasificación y propuestas de gestión geoambiental de las playas de República Dominicana. Contrato no. 360 2010, realizado por QU4TRE, consultoría ambiental of the Dept Planeación y Proyectos Ministerio de Turismo of the Government Republica Dominicana.

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