Hydric erosion in touristic beaches influenced by extreme rainfall events: case contribution of the pluvial drainage of the Ancon Hotel, Cuba

Technological Disruptions Triggered by Natural Events: Identification, Characterization, and Management

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Contents

Abstract

These proceedings are the outcome of the 61st ESReDA seminar “Technological Distruptions Triggered by Natural Events: Identification, Characterization, and Management” that took place at Politecnico di Torino, Italy, 22-23 September 2022. The seminar attracted a good mix of academic and industrial participants from many countries, and provided a platform for stimulating discussion on the state of the art and on-going developments in the NaTech risk assessment techniques and methodologies.

The editorial work for this volume was supported by the Joint Research Centre of the European Commission in the frame of JRC support to ESReDA activities.

Foreword

European Safety, Reliability & Data Association (ESReDA) is a European Association established in 1992 to promote research, application and training in Reliability, Availability, Maintainability and Safety (RAMS). The Association provides a forum for the exchange of information, data and current research in Safety and Reliability.

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1 Introduction

These proceedings are the outcome of the 61st ESReDa Seminar Hosted by Politecnico di Torino, in its Lingotto site on 22-23 September 2022.

We would like to thank the participants for attending and contributing to the seminar dedicated to “Technological disruptions triggered by natural events" and its multidisciplinary dimension.

As expected, the seminar provided a stage for stimulating discussion and debate and that participants were able to take the opportunity to form new, collaborative links and share their knowledge, also in relation to the impact of climate change.

We would like to thank the local organising committee in Turin, with the collaboration of PhD students from the SAfeR research group of the Department of Applied Science and Technology of Politecnico di Torino.

The seminar saw the presentation of 13 contributions, 3 of which were Key Notes: from Marcelo Masera, former Head of Unit "Energy Security, Distribution and Markets", Joint Research Center, The Netherlands, Valerio Cozzani, Full Professor at Bologna University and George Boustras, CERIDES Director, Professor at the European University, Cyprus.

These proceedings contain 8 full papers and 1 extended abstract and several presentations, with authors representing several domains. The seminar attracted a good mix of academic and industrial participants from many European countries.

We wish to thank the Technical Programme Committee for their efforts during the review process of the contributions, and all the authors during the presentations and the final stages of paper preparation. We look forward to future opportunities for collaboration and hope to see you at future events.

The editorial work for this report was supported by the Joint Research Centre of the European Commission in the frame of JRC support to ESReDA activities.

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Hydric erosion in touristic beaches influenced by extreme rainfall events: case contribution of the pluvial drainage of the Ancon Hotel, Cuba.

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Abstract

In some areas of the world, due to climate change, some natural hazards have expected return periods shorter than those considered to build single infrastructures long decades ago. The delays in adopting corrective actions join this issue, increasing the number of disrupting events triggered by natural hazards. Specifically, the tourism and entertainment industry disruptions induced by natural events may cause severe environmental, economic, and service functionality losses. In Cuba, 89 % of the beaches show signs of erosion; therefore, this problem represents a national priority established in the Cuban State Plan to Confront Climate Change. This plan sets the identification of existing vulnerability and the undertaking of actions to reduce it, as well as the recovery of beaches, prioritizing those for tourist use. The goal was to evaluate the contribution of one hotel's storm drainage system to the hydric erosion in the hotel's beach sector and its mitigation. The Ancon Hotel, located in Trinidad, Cuba, was used as a study case. The hydrologic calculations of the design rainstorm used the isoyetic map of maximum daily rainfall for 1 % probability and the calculation nomogram for different probabilities and time duration in the Republic of Cuba. Two scenarios were performed: Scenario 1: A 20 % probability of rainfall with a duration time of 10 minutes, a rain intensity of 1.83 mm/min was taken. Scenario 2: A 5 % probability of rainfall with a duration time of 5 minutes, established according to the degree of protection to be provided to the installation, considering the category of the work and the ecological damage it may cause, a rain intensity of 3.1 mm/min was taken. It was shown that erosion is predominantly of hydric origin, with gully-type erosion manifestations evaluated as critical and intense, limiting the tourist use of the beach. The rainfall erosivity, enhanced by technical and organizational deficiencies in the hotel's storm drainage system, the erodability of soil, and the presence of built elements, lead to increased flows towards the beach berm and influence changes in flow velocities. A corrective measures plan was designed to mitigate erosion based on minimizing the stormwater runoff to the beach and good beach management practices. The radical solutions contemplated eliminating the built environment and evacuating rainwater from the roofs for reuse to irrigate green areas. Implementing the proposed measures by beach operators enabled the Ancon Hotel's requalification, reducing the risk caused by natural events, building resilience against natural events, and contributing to the sustainability of tourism in Cuba.

Keywords: *beach, drainage, hydric erosion, runoff, vulnerability.*

1 Introduction

In 2015 United Nations Agenda presented an expansive vision of sustainability focused on the three pillars of sustainable development, which were settled in Sustainable Development Goals (SDGs). Precisely, SDG 11 focus on the necessity of making cities and human settlements inclusive, safe, resilient, and sustainable, including substantially increasing resource efficiency, mitigation and adaptation to climate change, resilience to disasters, and development and implementation of holistic disaster risk management at all levels. Likewise, one goal target of SDG 13 states the strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries [1].

Moreover, the Sendai Framework for Disaster Risk Reduction 2015-2030 outlines seven clear targets and four priorities for action to prevent new and reduce existing disaster risks: (i) Understanding disaster risk; (ii) Strengthening disaster risk governance to manage disaster risk; (iii) Investing in disaster reduction for resilience; and (iv) Enhancing disaster preparedness for effective response, and to "Build Back Better" in recovery, rehabilitation, and reconstruction. It aims to substantially reduce disaster risk and losses in lives, livelihoods and health and the economic, physical, social, cultural, and environmental assets of persons, businesses, communities, and countries [2].

Natural events triggering technological scenarios (Natech events) are generated considerable recent research interest for regulatory authorities and industry, particularly in areas prone to natural disasters. Meteorological events, such as storms, extreme temperatures, and lightning, were the main trigger of Natech scenarios [3]. Among all the typologies of natural disasters, in recent years, the number of hydro-meteorological events is featuring a significant increase and their frequency and severity are expected to grow further due to climate change [4]. Significantly, the number of studies on the topic of hydrological/weather triggered Natech events has been continually growing, a trend that might be attributed, according to experts, to the increasing number of extreme weather phenomena due to climate change [5].

On the other hand, the World Tourism Organization (UNWTO) [6] recognize the necessity of be aware of the current and future economic, social, and environmental impacts, addressing the needs of visitors, the industry, the environment, and the hosting communities, to achieve sustainable tourism. Thus, it should make optimal use of environmental resources that constitute a crucial element in its development, maintaining essential ecological processes and helping to conserve natural heritage and biodiversity. From this, UNWTO recalls the Sendai Framework for Disaster Risk Reduction 2015–2030 to set up the need to promote and integrate disaster risk management approaches throughout the tourism industry, given the often-heavy reliance on tourism as a critical economic driver. Likewise, it underlines the need to foster resilient tourism development, considering the sector's vulnerabilities the emergencies, and to develop strategies for rehabilitation [7].

Due to their location, a large proportion of the global tourism installations are highly exposed and vulnerable to environmental hazards. Tourism involves the interactions of organizations, infrastructure, people, and events in various subsystems. The complexity of this interconnected system and the relatively early stage of tourism disaster studies suggests that a dialogue between tourism and the disaster risk research community could be beneficial to share knowledge and define gaps regarding disruptions affecting the tourism industry [8]. State of the art regarding disasters, tourism, and infrastructure (hotels), has increased over the last 20 years. However, the hotels and sector's disaster preparedness improvements still appear to not be on the same line [9].

The small Island Developing States represent unique destinations where the visitors can enjoy their natural and cultural heritage richness. Nevertheless, many of these islands confront several challenges and vulnerabilities which have increased due to the impacts of climate change - from devastating storms to the threat of sea level rise [10-11]. Expressly, in the Caribbean Island States, beaches represent the primary natural resource the tourism industry uses. Unfortunately, climate change inducing beach erosion is one of the coastal systems' most severe impacts. In addition to marine dynamics, precipitation, and river flow can significantly alter beach erosion/accretion patterns [12].

In Cuba, over 89 % of the beaches show signs of erosion [13-15]. Numerous research in recent years has found the beaches in Cuba needed to counteract erosion processes and past human responses to prevent/slow down erosion processes. Moreover, beach erosion causes degradation and the emplacement of rigid, disorganized protection structures. In this sense, coastal structure dismantlement and beach nourishment represent proactive responses and have been carried out with good results in several areas devoted to local and national visitors [16-19]. Since this problem represents a national priority established in the Cuban State Plan to Confront Climate Change [20], the identification of existing vulnerability and the undertaking of actions to reduce it, represent an explicit national necessity, as well as the recovery of beaches.

Given all above, this paper focused on the hydric erosion in touristic beaches influenced by extreme rainfall events. Specifically, in this report is presented the contribution of one hotel's storm drainage system to the hydric erosion in the hotel's beach sector and its mitigation. The study case corresponds to the Ancon Hotel located in the Ancon Peninsula, which is one of Cuba's main poles of sun and beach tourism. It is a narrow projection of land on the south marine platform of the city of Trinidad and is formed by deposits of biogenic sands that make up about 3 900 linear meters of the beach with the same name. Owing to its geographical location and geological and hydrometeorological characteristics, it is a region prone and vulnerable to natural adverse events.

2 Material and Method

The procedure for the eight-step in solving a problem [21] was partially used. It consists of a methodology, inspired by the PDCA (plan-do-check-act) cycle, adapted to the hydric erosion in the hotel's beach sector as described below:

Step 1: Selecting and characterizing a problem (Planning Stage)

— Hydrographic characterization

A preliminary study of the hydrography of the study area was carried out through desk and fieldwork. The criteria established by González and Suárez [22] will be used, which include physical-geographical and anthropic characteristics: location and shape; geological formations, soil types and vegetation cover; buildings and hydraulic works; and morphometric parameters.

— Background studies of engineering research

A documentary review of the engineering studies carried out on the Ancon Peninsula was carried out.

— Study and survey of relief, soil, and vegetation information.

Six strata were defined according to the homogeneity of relief, soils, vegetation, and cover. The topographic map scale 1:25000 was used to study the relief and geomorphological characteristics of the area of interest. A topographic survey was also carried out on a scale of 1:500. The soils of the green areas were studied by visual examination and the execution of simple manual tests according to the Cuban technical standard NC 61:2000 [23]. The soil infiltration rate was determined according to RC-9005:2001 [24]. Likewise, the criteria established by González and Suárez [22] and the Cuban technical standard NC 700:2010 [25] were used to estimate soil erodability according to the relief, the kind of vegetation, and the soil type and permeability. The vegetation was surveyed according to González and Suárez [22], including trees, herbaceous species, and the level of soil cover.

— Assessment of erosion evidence in the emerged beach area.

The erosive evidence was identified during the rainy season using the qualitative method, recommended for preliminary and diagnosis studies [26-27]. During the identification processes, some characteristics as geographic coordinates, photographs, and dimensions (length, depths, and maximum widths) were taken. In cases of hydric clues, the classification was done according to established criteria [28-29], that implemented an ordinal scale with four categories: mild, medium, intense, and critical.

— Identification and description of the existing storm water collection, evacuation, and disposal system (SWCEDS).

Topographic maps with contour lines were interpreted to identify the drainage network, landforms, and relief designations. Due to the limited technical information on projects and plans of the hotel, the identification and description of the SWCEDS were made during the fieldwork, defining four subsystems: A, B, C and D.

— Review of SWCEDS status, functionality, operating conditions, and maintenance.

The requirements established in regulations and technical manuals were analyzed. Likewise, Cuban technical standards related to the design of storm drainage systems were used: NC 600:2008 [30], NC 683:2009 [31], NC 770:2010 [25], NC 775-13:2020 [32]. Moreover, the infiltration rate of wells was determined according to RC-9005:2001 [24] and diagnosed according to the criteria proposed in MINVU [33]. Finally, the existing maintenance conditions of the system were inspected.

— Definition of drainage sectors and hydrological calculations

The erodability of rainfall depends on the magnitude or sheet of water, intensity, and frequency [22].

The natural drainage network was divided by exhaustive sections of runoff, given by the topography characteristics, and confirmed from direct observation in the presence of rainfall events. Furthermore, the runoff contribution areas were measured in fieldwork.

The Rational Method was implemented for the hydrological calculation as described by the Cuban technical standard NC 770:2010 [25] and González and Suárez [22].

Subsequently, the rainfall intensity was estimated using the isoyetic map of maximum daily rainfall for 1 % probability and the calculation nomogram for different probabilities and duration times of the Cuban Republic. The following scenarios were studied in accordance with recomendations in the established regulations:

- Scenario 1: A 20 % probability of rainfall (5-year return period), and duration time of 10 minutes, according to the Cuban technical standard NC 775-13: 2020 [32]. A rainfall intensity of 1.83 mm/min was estimated.

- Scenario 2: A 5 % probability of rainfall (20-year return period), and duration time of 5 minutes, established according to the degree of protection to be provided to the facility, considering the category of the work and the ecological damage to which it may give rise, according to NC 600:2008 [30]. A rainfall intensity of 3.1 mm/min was estimated.

The runoff coefficient (C) is a dimensionless value that establishes the fixed relationship between the rainfall rate for the drainage inter basin and the surface and subsurface runoff. It was estimated according to the criteria established by the Cuban technical standards NC 600:2008 [30], NC 770:2010 [25], NC 775-13:2020 [32], and González and Suárez [22].

Some of the techniques and tools used were: direct observation, interviews, and a checklist. Global Mapper 11.02, Autodesk AutoCAD 2016, Google Earth Pro 7.1, and MapInfo Pro 16.0 software were used, ArcGIS Pro.

2.1 Step 2: Search for all possible causes (Plan Stage)

For the determination of water erosion causes in the emerged area of the beach sector, qualitative and quantitative criteria from the background of engineering research mentioned in Step 1 were considered.

The cause-effect diagram was used as a graphic method that relates the problem with the factors which possibly generate it [21].

2.2 Step 3: Investigate which causes are most important (Plan Stage)

The selection was based on qualitative and quantitative criteria according with the above-mentioned background of engineering research. The Failure Mode and Effect Analysis (FMEA) described by Gutiérrez and De La Vara [21] was used.

2.3 Step 4: Elaborate a plan of measures focused on remedying the most important causes (Plan Stage)

Then, a corrective action plan was developed, with a scope of conceptual ideas to mitigate the hydric erosion caused by extreme rainy events, detailed according to the proposal of Gutiérrez and De La Vara [21]. The validity of the measures was corroborated from the simulations of the rainfall scenarios defined in Step 1, where the mitigation of rainwater load was considered.

2.4 Steps 5, 6, 7 y 8: Implementation of the countermeasures (Do Stage), Check the obtained results (Check Stage), Prevent recurrence, and conclude (Act Stage).

Steps 5, 6, 7 and 8 (Execute remedial measures; Review results obtained; Prevent recurrence; and Conclude) were proposed to the decision makers of the hotel owner and operator.

3 Results and discussion

3.1 Step 1: Selecting and characterizing a problem

— Hydrographic characterization

The study confirmed that the natural hydrography of the study area was considerably modified by the construction of the hotel and access roads.

— Background studies of engineering research

As far as it concerns, the lithological characterization of the natural soils before the intervention on the plot for the hotel's construction showed an upper stratum of medium-grained calcareous sand, varying from 2.20 to 3.60 meters. Likewise, the studies confirmed the anthropic modifications to which the field was subjected, with the gravelly-sandy fill material, compact and of variable thickness used in the terrace.

— Study and survey of relief, soil, and vegetation information

The satellite image of the study area (Figure 1) shows the proximity of the hotel buildings to the emerged area of the beach (berm), separated only by a longitudinal strip of green areas with small squares and stairs for access to the beach. The six strata into which the study area was divided can also be appreciated.

Figure 1. Ancon Hotel and beach sector. Representation of the defined strata.

Source: Own source.

First, the relief of strata 1, 2 and 3 were classified as hilly and undulating. Moreover, the average slopes were between 5 % and 15 %, reaching 25 % in stratum 1. The rest of the strata were classified as flat, with less than 5 % slopes.

Second, high variability of grass cover for each stratum was constated. For instance, the stratum 2 constituted less than 10 % of the surface, while the rest of the strata have covered between 50 % and 90 %. In general, the type of existing turf is inadequate and lacks an artificial irrigation system, which is aggravated by poor maintenance practices.

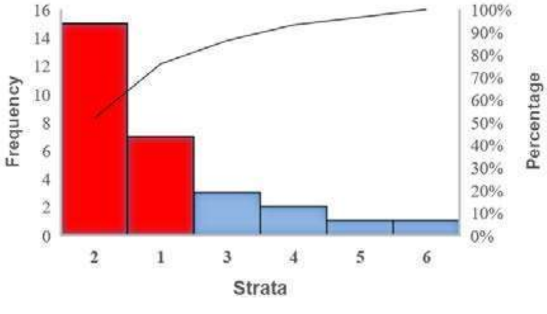
On the other hand, the soil characteristics are according with the characteristics of the borrowed materials used in the hotel's infill terrace. Therefore, it was not very permeable, its softness, compactness and slightly plasticity, restricting the infiltration capacity.

Finally, the results of the infiltration tests show that the soil has a relative absorption average (infiltration index of 12.08 min), comparable with soils of the fine-grained sand, silt, sand, silt and clay mixture and stratified clay types.

— Assessment of erosion evidence in the emerged beach area.

In the Ancon Hotel beach emerged area (berm) considerable predominates the hydric erosion, in correspondence with the characteristics and factors reported in the literature [26-29]. The Pareto diagram in Figure 2 illustrates the absolute frequency of the erosive evidence recorded in each stratum (left vertical axis) and the accumulated percentage concerning the factual evidence that appeared in all the strata (line above the bars). As could be appreciated, over the 75 % erosion evidence was concentrated in strata 1 and 2 (southwest sector of the main building). In these strata, the presence of several rigid build elements was observed, such as the extra hotel point of sale, hotel platforms, terraces, stairs, concrete walkways in the green area of the hotel, concrete slabs, hoses, and surface pipes in the emerged area of the beach, as well as the longitudinal retaining wall contiguous to the green area of the hotel and the emerged area of the beach.

Figure 2. Pareto diagram for erosional evidence. Analysis by strata.



Source: Own source.

As far as it concerns with what has been discussed, strata 1 and 2 coincide with a rugged relief, a woodland with a superficial root system and poor vegetation. Figure 3 shows some of the evidence detected.

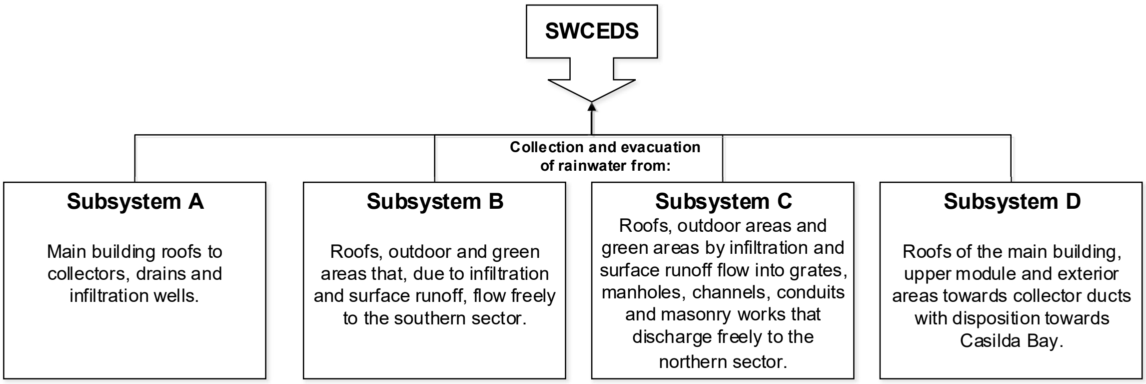
Figure 3. Sample of hydric erosion evidence in the berm, and green areas adjacent to strata 1 and 2.

Source: Own source.

— Identification and description of the storm water collection, evacuation, and disposal system (SWCEDS).

The rainwater collection, evacuation, and final disposal system at Ancon Hotel is of the conventional separate type, with four basic subsystems consisting of natural drainage elements and collection, evacuation, and infiltration works. There is no segregation and reuse of this water. Figure 4 shows its main subsystems.

Figure 4. Schematic representation of the storm drainage system of Ancon Hotel.



Source: Own source.

— Review of SWCEDS status, functionality, operating conditions, and maintenance

Numerous shortcomings were detected in the design, operation, and maintenance of the SWCEDS. In addition, inadequate practices were observed that affect the poor functioning and operation of the system, which have repercussions on the intensification of erosive processes. A crucial issue detected was that the effective infiltration areas of the four wells in subsystem A, were significantly lower than those required for the operating conditions evaluated and do not meet the recommended design requirements [33].

With a glace to the Figure 5, could be appreciated that filter beds were silted and filled with trash, soil, and sediment carried away by runoff from outside or covered areas. Regarding these issues, joint to the fact of plant rooting inside the filter beds the infiltration capacity of the wells was sensibly decreased with slow relative absorption (infiltration rate of 3.21 min).

Figure 5. Evidence of technical and maintenance deficiencies in the infiltration works.

Source: Own source

— Definition of drainage sectors and hydrological calculations

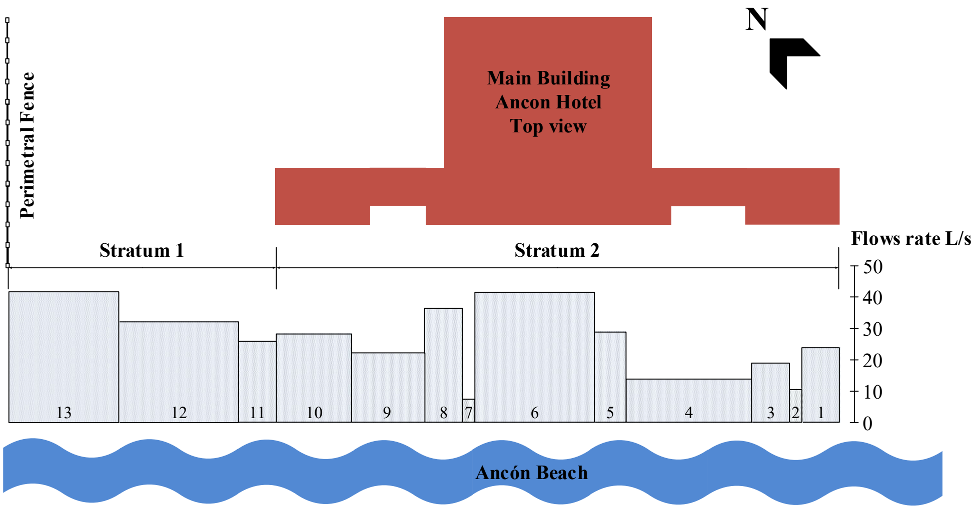
Thirteen runoff sections were identified in the natural drainage network for strata 1 and 2. Figure 6 shows a sketch of these strata, including the main building Ancon Hotel top view, as well as the surface runoff flows rate that reach the berm in each runoff section. This flow rates, were estimated for the rainfall scenario 2 (defined as the most critical) and were plotted proportionally to the length of each runoff section on the ground.

From the analysis of the figure can be realized the high flows that reach the emerged area of the beach in the strata 1 and 2, which are also the most damaged. In this sense, the Table 1 offered the association of the erosive evidence to the runoff sections, the gullies in each section and their categories. As c

It is important to highlight that critical gullies were identified in all sections except sections 11 and 13. The sections that showed larger numbers of gullies was corresponding to the ones with the highest flows rates (approximately the 54 % of the total reaching the emerged beach area). On the other hand, the section 7 offered results due to having the lowest flow, it was associated with two critical gullies. In this case were found the flow changed the natural patron increasing the velocity because of the effect of constructed elements.

Moreover, resulted evident the association among the number and categories of gullies, the runoff flow rates and other factors such as relief, grass cover, soil infiltration and build elements. The combination of the above factors and the high flow rates modify the laminar flow patterns, creating interceptions and turbulence effects that favor the increase in runoff velocity and the appearance of the phenomenon of water erosion.

Figure 6. Sketch of the southwest sector of the Ancon Hotel (strata 1 and 2). Estimated flows reaching the beach berm in the 13 runoff sections for rainfall scenario 2.



Source: Own source.

The figure shows the high flows that reach the emerged area of the beach (berm) in strata 1 and 2, which are also the most eroded. In this sense, it was convenient to associate their erosive evidence to the runoff sections represented in the previous figure. Table 1 shows the existing gullies in each section and the categories into which they were classified.

Table 1. Classification of erosional evidence associated with runoff sections.

Sections / Categories	13	12	11	10	9	8	7	6	5	4	3	2	1	Total
Slight	1	1	1											3
Medium	1	1												2
Intense	1													1
Critic		1		1	1	2	2	3	2	1	1	1	1	16
Total	3	3	1	1	1	2	2	3	2	1	1	1	1	22

Source: Own elaboration.

In summary, the relief of sections 13 to 11 is rugged, with slopes of up to 26 %. There is little grass cover in sections 10 to 1 (less than 10 % of the surface), and the trees present have superficial rooting. As previously discussed, the soil had a medium infiltration capacity, with the presence of constructed elements such as small squares, stairs, sidewalks, walls, and surface pipes.

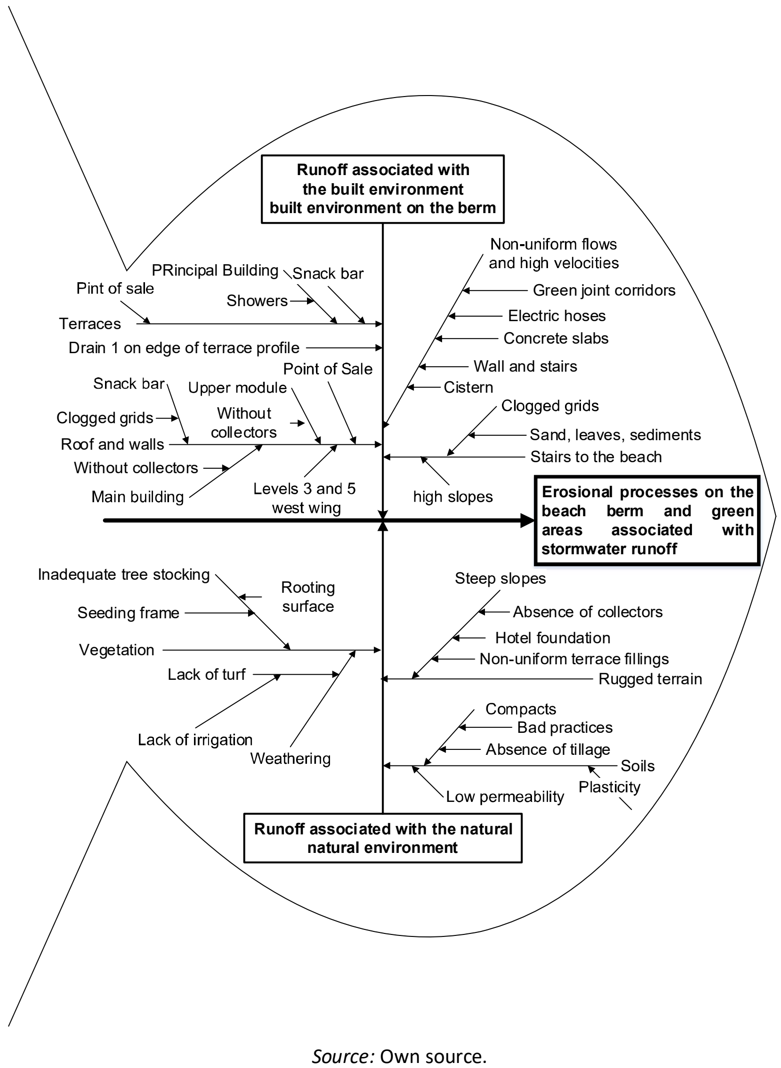
Regarding the estimated flows that reach the berm, it can be added that the hotel does not reuse rainwater and there is potential for rainwater harvesting in the order of 13 523.10 m^3/year. It is important to remark that the previous value resulted higher than the estimated water demand for irrigation of the hotel's green areas (11 679.00 m^3/year). Therefore, the reuse alternative represents an equivalent saving of potable water currently used to irrigate the gardens.

Furthermore, the water reusing represented that the hotel would no longer incur an economic expense of USD$18 102.45/year for water supply and services. This is a viable alternative, considering the presence of a water storage tank for reuse, distribution networks, and irrigation system accessories, although they are no longer in use.

3.2 Step 2: Search for all possible causes

This analysis contributed to characterize causes up to the sixth order in the SWCEDS subsystems, responsible for the erosive processes characterized in all strata. Figure 7 illustrated the causes identified for subsystem B, which was one of the most critical and representative.

Figure 7. Identification of the causes that aggravate erosive processes of water origin, Subsystem B.



Source: Own source.

3.3 Step 3: Investigate which causes are most important

The risk priority level obtained from the FMEA allowed to prioritize the list of possible causes detected in the previous point. In consequence, deficiencies in the design, operation, and maintenance of the Ancon Hotel SWCEDS; together with the state of the relief, soil, vegetation, and the presence of constructed elements were the main causes.

3.4 Step 4: Elaborate a plan of measures focused on remedying the most important causes

A corrective measures plan was proposed with 69 solutions, classified as palliative or radical (33 and 36 measures respectively). They were based on prevent or mitigate the stormwater runoff to the berm; and on applying good management practices and exploiting the hotel's stormwater drainage system and the emergent area of the beach [34].

The radical solutions firstly included the elimination of the elements built in the southwest sector of the Ancon Hotel. Secondly, involved the use hanging collectors to evacuate the rainwater from the roofs to a cistern for the reuse in the irrigation system of green areas. Finally, considered the beach profile rehabilitation and the protection zone in the hotel southwest sector.

Palliative solutions consist of relief leveling, soil tillage, turf improvement, technological improvements in the infiltration wells and the construction of infiltration ditches, and collectors. The infiltration trenches were also considered as a palliative solution according with its application in similar study case [35].

The validity of the measures was corroborated from the simulation of the rainfall scenarios defined in Step 1, where the prevention or mitigation of rainwater input was considered. Then, it was corroborated that runoff can be reduced to only the rainfall inputs on the beach profile if the remedial action plan were implemented. Therefore, the comprehensive package implementation contributes to enhance the preparedness and resilience, even facing an extreme event as intense rains and hurricanes, which are undergoing an increase due to climate change effects [36].

4 Conclusions

First, the procedure constitutes a valuable methodological instrument which can be generalized for diagnosing storm drainage systems and, especially, to evaluate how they contribute to erosive processes on beaches, coastal areas, and soils.

Second, it was confirmed that the Ancon Hotel and its beach sector, due to its geographic location and geological and hydrometeorological characteristics, are in a fragile ecosystem, highly vulnerable to natural phenomena such as heavy rains and hurricanes. The previous situation, combined with the deficiencies in the design and operation of the hotel's storm drainage system, increases the vulnerabilities in the berm of the beach caused by hydric phenomena, with negative impacts on the ecosystem, the hotel's image, and the tourism enjoyment, typifying disruption caused by natural events.

Third, it was demonstrated that the erosivity of the rain, intensified by the lack of water segregation, together with technical and organizational deficiencies in the rain drainage system, originate high runoff flows on the ground and the emerged area of the beach. Likewise, the erodibility of the terrain and the built elements increased flow velocities and favors the appearance of the phenomenon of hydric erosion.

Moreover, the solutions proposed were based on minimizing stormwater runoff to the berm; and on applying good management and operation practices for the hotel's stormwater drainage system and the emergent area of the beach. The simulation after implementing the package of solutions, showed a considerable runoff reduction. Consequently, the vulnerability of the Ancon Hotel beach facing extreme storm events was mitigated.

Finally, the implementation of the proposed measures by beach operators enabled the Ancon Hotel's requalification, reducing the risk caused by natural events, building resilience against natural events, and contributing to the sustainability of tourism in Cuba.

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