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Pollution Management Model for Coastal and Marine Systems in the Northern Region of the Dominican Republic

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Abstract
Blackground: Pollution of coastal and marine systems concerns the people, governments and businesses, due to the importance of coastal marine systems for economic activity (tourism, fishing, among others) and the conservation of natural resources and ecosystems. This study presents a model for the management of pollution on the beaches of the northern region of the Dominican Republic, specifically in Puerto Plata, one of the main tourist destinations of the country known for its sun and beaches.
Materials and Methods: The methodology for this research consisted of two parts. First, a literature review was conducted with the aim of analyzing scientific publications and reports of international agencies on pollution management in coastal and marine systems. This analysis served to understand the tools used to analyze pollution in other areas of the world. Secondly, field work was carried out to perform four elements: 1) Drone photographs were taken of coastal areas in order to see the vulnerable points; 2) coastal water pollution sampling was performed; 3) air pollution sampling was carried out in coastal areas; and 4) soil analysis sampling was conducted on beaches.
Results: As a result, a Pollution Management Model was proposed for coastal and marine systems in the northern region of the Dominican Republic. The model is proposed in four phases, as validated in this research.
Conclusion: The results promote the use of this model to analyze pollution on the beaches in the Dominican Republic.
Key Word: *pollution, pollution management, coastal systems, beach.*

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I. Introduction

In the 1970s, the first studies on coastal and marine pollution were carried out, with beaches being one of the best-known habitats where pollution usually accumulates[1,2]. Beaches occupy approximately 40% of the world's coasts at the land-ocean interface, being subjected to various human pressures for activities such as fishing, tourism, and recreation[3]. Pollution on beaches is a major environmental problem that impacts socio-economic activities (e.g. tourism and recreation), but also the provision of ecosystem goods and services for local society and wildlife[4].

Sandy beaches are highly dynamic environments, where local climate conditions, in particular winds, tides and waves, can strongly influence the abundance and distribution of pollution[5]. Identifying local factors that influence beach pollution is crucial to better inform stakeholders, coastal managers and society, as well as to provide adequate guidelines for effective monitoring and mitigation of potential loss of economic goods and ecosystem services[6]. The presence or absence of pollution also is a key parameter for defining the scenic value of a beach, that is, its attractiveness to tourists[7]. A polluted beach is usually avoided by beachgoers[8]. In general, pollution studies on beaches that provide practical tools to identify critical points of contamination and guide science-based management are still scarce[9].

This study presents a model for the management of pollution on the beaches of the northern region of the Dominican Republic, specifically in Puerto Plata, one of the main tourist destinations of the country known for its sun and beaches. Puerto Plata stands out as the second sun-and-beach destination in the Dominican Republic after Punta Cana, although demand has been decreasing in recent years[10].

II. Background

According to the World Health Organization (WHO), coastal pollution is defined as polluting activity by man that directly or indirectly introduces substances or energy into the marine environment, including estuaries, that produces or is likely to produce harmful effects such as damage to living resources and marine life, hazards to human health, an obstacle to marine activities, including fishing and other lethal activities. Human settlements, resource uses and interventions, such as infrastructure development and construction, agricultural operations, industrial developments, urbanization or tourism are sources of pollutant production and emission[11,12]. However, because the ocean appears to be common property, there is unrestricted access to coastal resources and services, putting significant pressure on marine ecosystems, mainly due to pollution. The ocean absorbs about 30% of the carbon dioxide created by human activities, and ocean acidification has increased by 26% since the beginning of the industrial revolution.

Coastal water pollution is divided into two categories depending on the source, as point sources and non-point sources, and occurs for a variety of reasons, including basin characteristics, human or land use activities[13]. Domestic wastewater and garbage, industrial effluents and waste discharges have been recognized as important point sources. In contrast, agricultural activities, mining operations, farms and urban runoff have been identified as primary non-point sources that eventually end up in the ocean[14].

Coastal and marine systems with pollution problems alter ecosystems, preventing natural processes such as coral growth, mangrove accretion and sediment contributions from coastal drifts from taking place. In this regard, the coastal and marine environmental structure of the Dominican Republic is composed of a coastline of 1,389 km, of which 166 km, or 11%, are coral reefs, accompanied by associated ecosystems such as mangroves, seagrass meadows and sandy beaches. The rest of the coasts are rocky cliffs or low terrestrial plains, in dry or swampy forests.

Mangrove ecosystems shelter and provide nesting areas to a significant number of resident and migratory, vulnerable or endangered bird species; protect the coasts from erosion and tidal waves caused by hurricanes; and trap sediment and litter in their roots and help to replenish and recover terrain. In the Dominican Republic there are four species of mangrove trees: Red mangrove (*Rhizophora mangle*), Black mangrove (*Avicenniagerminans*), Button mangrove (*Conocarpus erectus*) and White mangrove (*Lagunculariaracemosa*). In this regard, the United Nations Environment Programme[15] highlights the important role of mangroves in mitigating climate change, since this ecosystem stores five times more carbon than, for example, tropical forests. In addition, it significantly reduces the impact of tides, hurricanes, and in some cases, tsunamis.

In short, coastal and marine systems are spaces of opportunity for the development of tourism activities, the generation of ecosystems and the conservation of natural resources, although pollution is a threat that poses various negative impacts for marine and coastal systems.

III. Methodology

The methodology for this research consisted of two parts. First, a literature review was conducted with the aim of analyzing scientific publications and reports of international agencies on pollution management in coastal and marine systems. This analysis served to understand the tools used to analyze pollution in other areas of the world.

Secondly, field work was carried out to perform four elements: 1) Drone photographs were taken of coastal areas in order to see the vulnerable points; 2) coastal water pollution sampling was performed; 3) air pollution sampling was carried out in coastal areas; and 4) soil analysis sampling was conducted on beaches.

Once the literature and field work had been reviewed, the information was analyzed to design the proposed pollution management model for coastal and marine systems in the northern region of the Dominican Republic.

IV. Results: Model Proposal

The proposed model for the management of pollution of marine and coastal systems in the northern zone of Puerto Plata is presented in four phases:

- Phase 1. Planning.
- Phase 2. Characterization of the pollution.
- Phase 3. Action and correction plan.
- Phase 4. Final evaluation.

Phase 1. Planning

The planning phase aims to identify the resources needed to implement the model in the study area. The resources required are human, financial, physical and technological. In the case of human resources, a balanced group of actors must be created, ensuring participation of all parties, where researchers (biologists, chemists, economists, among others), political actors, residents and local associations are identified. Financial resources are necessary to be able to develop the actions to be implemented, such as travel, laboratory analysis, purchase of equipment, among others. The physical resources, on the other hand, will consist of laboratory equipment, office space, computer equipment, vehicles, among others. And finally, technological resources will include online measurement systems, camera systems, software for data analysis, among others.

Phase 2. Characterization of the pollution

The pollution characterization phase aims to define and analyze the existing pollution conditions in the study area. This phase should be analyzed using four variables:

- Characterization of the solid waste present in the marine and coastal zone.
- Characterization of water pollution at water entry points from water resources to the sea.
- Characterization of soil pollution on the beach.
- Characterization of air pollution in the marine and coastal zone.

For the characterization of solid waste present in the marine and coastal zone, it is proposed to carry out on-site field work, in order to create an inventory of solid waste, classifying them into four groups: ordinary (generated during routine population activities), biodegradable (those that can disintegrate or degrade quickly, such as food), inert (waste that is not easily decomposed, such as laboratory waste or other materials), and recyclable (those that can be subjected to a process to be reused, such as glass, some plastics, among others). In this characterization, it is necessary to investigate the source of entry of solid waste to the coast, and analyze the possible causes and effects of its arrival.

With regard to characterization of water contamination, after reviewing the scientific literature, it is recommended to carry out two analyses. The first one should be conducted in the water of the water resources that flow into the coast. It is proposed to use the version developed by the United States Health Foundation to obtain the Water Quality Index (WQI)[16-18]. The WQI of each river is calculated based on the 9 variables of water quality: pH, nitrates, fecal coliforms, biochemical oxygen demand, total phosphates, turbidity, water temperature, total dissolved solids, and dissolved oxygen. Analytical methods validated by the United States Environmental Protection Agency (EPA) are recommended for data collection. The equation designed by Brown et al.[16] is used: $\Sigma_{i=1}^{n}{}_{C_i P_i} / \Sigma_{i=1}^{n}{}_{P_i}$. In the equation, n is the total number of the selected parameters included in the study; C_i is the normalized value of parameter $_i$ and P_i is the weight of parameter $_i$. The minimum value of P_i was 1, as these values were used in previous publications[19]. This first analysis will tell us the quality of the water that is discharging into the ocean.

The second water analysis must be carried out in coastal waters, in areas near where there is entry of water bodies. For this calculation, it is recommended to use the Marine and Coastal Water Quality Index (MWQI), which is a tool validated by the José Benito Vives de Andréis Institute of Marine and Coastal Research (INVEMAR) of Colombia. The MWQI is a statistical information tool that allows evaluating changes in marine and coastal water quality, based on criteria or standards that allow quantifying the state of conservation or deterioration of water according to its characteristics and its use or destination in a specific place and time[20]. Analyses of the individual variables allow us to clearly visualize the quality of the water of the beach, for which we seek to generate a water quality indicator that serves as a basis to interpret the concentration levels of the physicochemical and microbiological parameters present in the medium[20]. The MWQI includes the analysis of 8 variables. These variables represent, according to their acceptance or rejection values, a water quality or condition based on the reference values of international standards considered suitable for protecting coastal and marine systems[21]. It is calculated based on 8 water quality variables: dissolved oxygen, nitrates, total suspended solids, thermotolerant coliforms, pH, dissolved and dispersed hydrocarbons, biochemical oxygen demand, and phosphates. Analytical methods validated by the United States Environmental Protection Agency (EPA) are recommended for data collection. To calculate the MWQI, the INVEMAR platform was used, adapted with software that applies the formula used to calculate the MWQI. The equation used is $MWQI = [(X_{DO})^{0.16} \text{ x } (X_{pH})^{0.12} \text{ x } (X_{TSS})^{0.13} \text{ x } (X_{BOD})^{0.13} \text{ x } (X_{TC})^{0.14} \text{ x } (X_{DDH})^{0.12} \text{ x } (X_{NO3-})^{0.09} \text{ x } (X_{PO_4{}^{3-}})^{0.13}]1/Wi$. In this equation, X_i is equal to the quality subscript of the variable i; and W_i refers to the weighting factor for each subscript *i*according to its importance within the MWQI, which is weighted between 0 and 1.

To characterize soil contamination on the beach, heavy metals present in the soil will be analyzed. The scientific literature recommends analyzing the following parameters: Cobalt, Cadmium, Copper, Chromium, Zinc, Lead and the compounds, Nickel, Iron and Manganese. Analytical methods validated by the United States Environmental Protection Agency (EPA) are recommended for data collection. These heavy metals are most frequent in the beach sediments of the world, and in several cases, their concentrations exceed the evaluation of the international guides[22]. Analyzing heavy metals is fundamental, since they can have a negative impact on tourism activities, the health of the population and the quality of ecosystems.

For the characterization of air pollution in the marine-coastal zone, it is recommended to use the Air Quality Index (AQI) of PM_{10} and $PM_{2.5}$. The WHO[23] states that the 24-hour average for $PM_{2.5}$ should not exceed

25 μg/m^3, and for PM_{10} 50 μg/m^3. It is recommended to use the formula used by the United States Environmental Protection Agency[24]: $\text{Si } j = 1,\ AQI = AQI_j \frac{C_m}{C_j}$ o $\text{Sí } j > 1,\ AQI = \frac{(AQI_j - AQI_{j-1})}{(C_j - C_{j-1})} X (C_m - C_{j-1}) + AQI_{j-1}$. The terms C_m refer to the monitored concentration of the pollutant; AQI_j and AQI_{j-1} refer to the indices corresponding to categories j and j-1, respectively; finally, C_j and C_{j-1} refer to the concentrations corresponding to the upper and lower limit of the j category. This index is currently one of the most used by governments and researchers[25].

Phase 3. Action and correction plan

The objective of this phase is to design an action and correction plan to reduce the impacts of pollution on marine and coastal systems. Programs, strategies and activities should be established to help reduce negative impacts. For example, to mitigate the arrival of solid waste in the marine-coastal zone, solid waste collection days can be established, where such waste is classified and processed depending on its characteristics (disposal, recycling, reuse, among others). In addition, the reason why solid waste reaches the coast, and its causes and effects for coastal-marine systems and society should be identified. This same process must be carried out for water, soil and air contamination. For this phase, each action, program, strategy or activity must have a specific objective, a date of completion, and a person responsible. Any stakeholders should be involved in this phase.

Phase 4. Final evaluation

The objective of this phase is to evaluate the efficiency and efficacy of the actions established and developed in phase 3. The action and correction plan must be followed up and its performance evaluated. During this phase, new conditions are identified to further mitigate the negative impacts of pollution on marine and coastal systems.

Figure no 1 shows an image with the summary of the proposed pollution management model for marine and coastal systems.

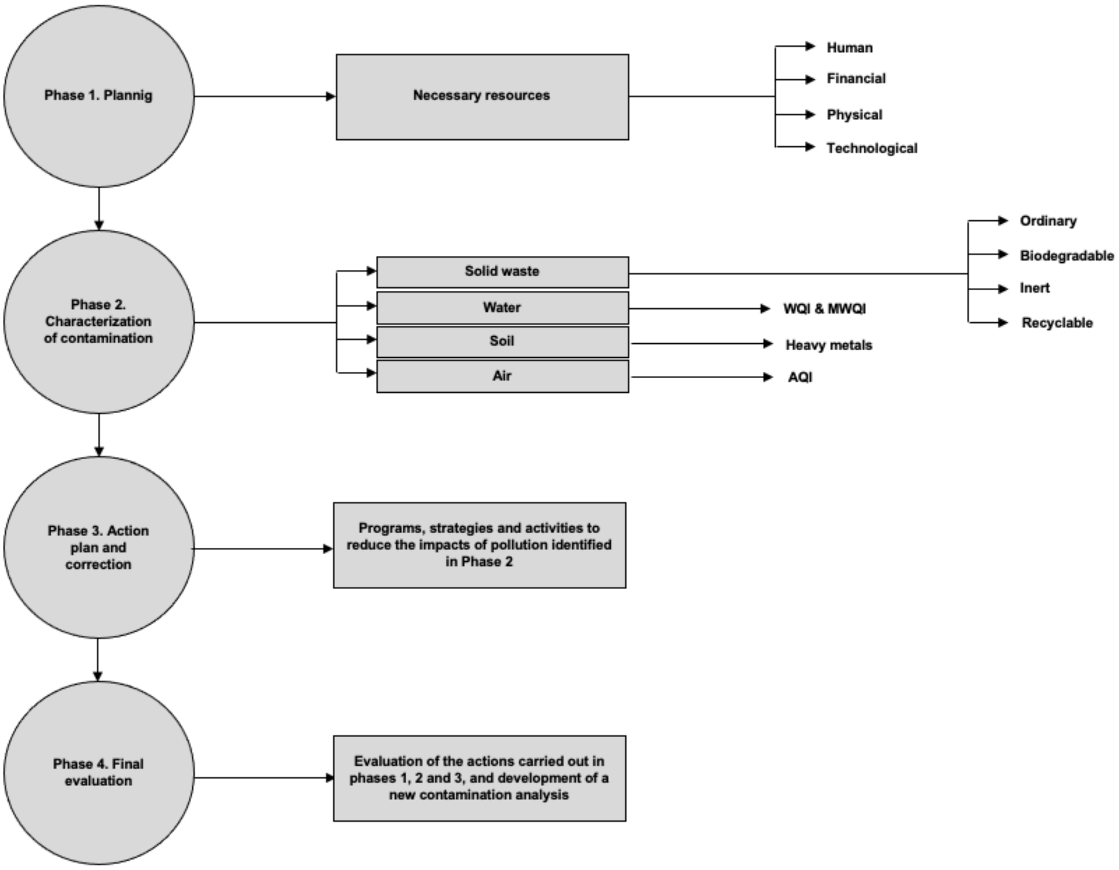

Figure no 1: Proposed pollution management model for marine and coastal systems.
Source: The authors.

V. Conclusions

Coastal and marine systems are crucial for a sustainable future, and should not be neglected at this significant time of global reboot and reconstruction. This fact is presented as a unique opportunity to enhance management tools to avoid deterioration of the coastal water quality on sandy beaches. While this paper is a small piece of a big puzzle, it is an important point to consider when thinking about beach management strategies that include new ecosystem-based strategies to maintain the ecosystem services of beaches and promote sustainable tourism in the long term.

This study has presented a model for the management of pollution on the beaches of the northern region of the Dominican Republic, specifically in Puerto Plata, one of the main tourist destinations of the country known for its sun and beaches. The proposed model is composed of four phases and takes into consideration all the actors available in the study area. It analyzes the available and necessary resources, characterizes solid waste, water, soil and air contamination, and proposes programs and activities to remedy the impacts of pollution. Finally, the model is evaluated. Once the four phases have been completed, the proposed model can be replicated after some time, in order to analyze the pollution levels of the marine and coastal systems of a specific site once again.

Although a model has been proposed for the management of pollution, more research is needed regarding the influence of the population and tourism on environmental performance and the formulation of strategies to minimize pollution of marine and coastal systems, as well as how to implement them on different beaches while respecting the laws and regulations in force in the corresponding countries or regions.

It is recommended to promote environmental education programs with scientists, NGOs and other local actors to raise awareness about the reduction of certain anthropogenic impacts (e.g., reduction of some pollutants, improvement of air quality, improvement of water quality, among others). These programs should include talks open to civil society to raise awareness about caring for coastal and marine systems.

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