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Review Article

Presence of microplastics: Impacts in a marine-coastal environment of the Colombian Caribbean

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Abstract

Part of the contamination of aquatic and terrestrial ecosystems is influenced by mass production, consumption habits, and improper disposal of plastics. Plastic degradation and fragmentation lead to the formation of Microplastics (MPs), small particles that easily infiltrate natural systems and pose ecological risks. These MPs are transported by atmospheric and water circulation dynamics, predominantly accumulating in soils and bodies of water, disrupting ecological processes in water, land, biosphere, and anthroposphere. This contamination adversely affects human productivity and disturbs fauna and flora in ecosystems. MPs can be consumed and bioaccumulated, potentially carrying pathogenic microorganisms and causing intoxication through constant contact.

Understanding the environmental impacts of microplastic presence is crucial to identifying and addressing contamination sources. It serves as a foundation for adopting clean and sustainable production practices, minimizing negative impacts, and maximizing positive effects on ecosystems. Environmental education and scientific research play vital roles in raising awareness and fostering societies' involvement in managing emission sources that disturb sensitive ecosystems.

Abbreviations

MPs: Microplastic; CGSM: Cienaga Grande de Santa Marta; INVEMAR: Instituto de Investigaciones Marinas y Costeras José Benito Vives de Andréis

Introduction

Over time, human activities have introduced various artificial elements into natural systems, with plastics serving as a notable example. The improper disposal of plastics has led to a significant pollution problem [1,2]. Microplastics (MPs) originate from plastic materials through processes of manufacturing, fragmentation, and/or degradation, resulting in plastic particles smaller than 5 millimeters [3]. These MPs can be classified based on their origin. Primary MPs are directly manufactured at sizes less than 5 mm [4], while secondary MPs are formed from the exposure of larger plastics to physical, biological, or chemical factors, leading to their fragmentation and subsequent redistribution into smaller particles.

The contamination by microplastics poses a risk to the ecological dynamics of natural systems, as they can be incorporated into even the most remote ecosystems worldwide. The abundance of MPs is closely linked to human activities in proximity to these ecosystems [4,5]. Even today, microplastic pollution affects agricultural activities, posing a risk to food security and resulting in detrimental consequences for soil, plants, and food production [6].

This study seeks to identify the impacts caused by the presence of MPs in the lagoon system, the largest and one of the most productive systems in the country due to its great abundance and variety of resources [3,7]. The lagoon system has a close (but disturbed) relationship with the Caribbean Sea [8] and receives flows from the Sierra Nevada de Santa

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Marta and the Magdalena River, bringing suspended solids and different pollutants [9]

The identification of the mostly negative impacts caused on the lagoon system of the CGSM by the presence of MPs allows us to rethink the activities that influence it and is born as a starting point to establish a set of corrective actions or management guidelines, seeking a resilient, sustainable, and interconnected ecosystem [10]. The proposal of corrective actions is focused on the reduction and regulation of the emitting sources of plastic and microplastic, given that in the region different economic activities are developed, which imply the direct and indirect use of plastic, this is present in fishing activities, agricultural production such as bananas, in commerce, tourism, or simply in the daily behavior of the population that inhabits the cienaga and its surroundings, and on the other hand, alternatives should be promoted to substitute the use of plastic for materials with less impact on the environment [11], hand in hand is the participation of communities and entities responsible for reducing waste production, and for example, the implementation of cleaner productions where the sustainable development of the CGSM would be guaranteed [12,13].

The presence of microplastics (MPs) in natural systems, exemplified by plastics, poses a significant pollution concern due to their non-degradable nature. MPs can infiltrate remote ecosystems and are directly linked to human activities. This study focuses on the Cienaga Grande de Santa Marta (CGSM) lagoon system in Colombia, aiming to assess the impacts of MPs on its ecological dynamics. The study's findings will guide corrective actions to reduce plastic emissions and promote sustainable practices. This research holds crucial importance for the scientific community as it provides insights into MP pollution's effects and offers a framework for preserving the CGSM ecosystem and other environments globally. The idea is to carry out a first analysis of the presence of microplastics in planetary systems and the disturbances that can occur at the biogeographic level and in the ecological processes of marine-coastal environments in the Caribbean.

Study area

The Cienaga Grande de Santa Marta (CGSM) is the largest lagoon complex in Colombia [3], located in the department of Magdalena in the north of the country, with an area of approximately 450 km2 extending west from the Magdalena River to the Sierra Nevada de Santa Marta to the east [8], it is also influenced by 14 municipalities and by the cities of Santa Marta and Barranquilla, capitals of the departments of Magdalena and Atlántico, respectively (Figure 1). The CGSM has presented a deterioration in its environmental conditions over the years, however, one of the main disturbing factors of the ecological processes was the construction of a road infrastructure that interrupted the natural exchange of fresh and saltwater from the Caribbean Sea [8], in addition to the increase in garbage

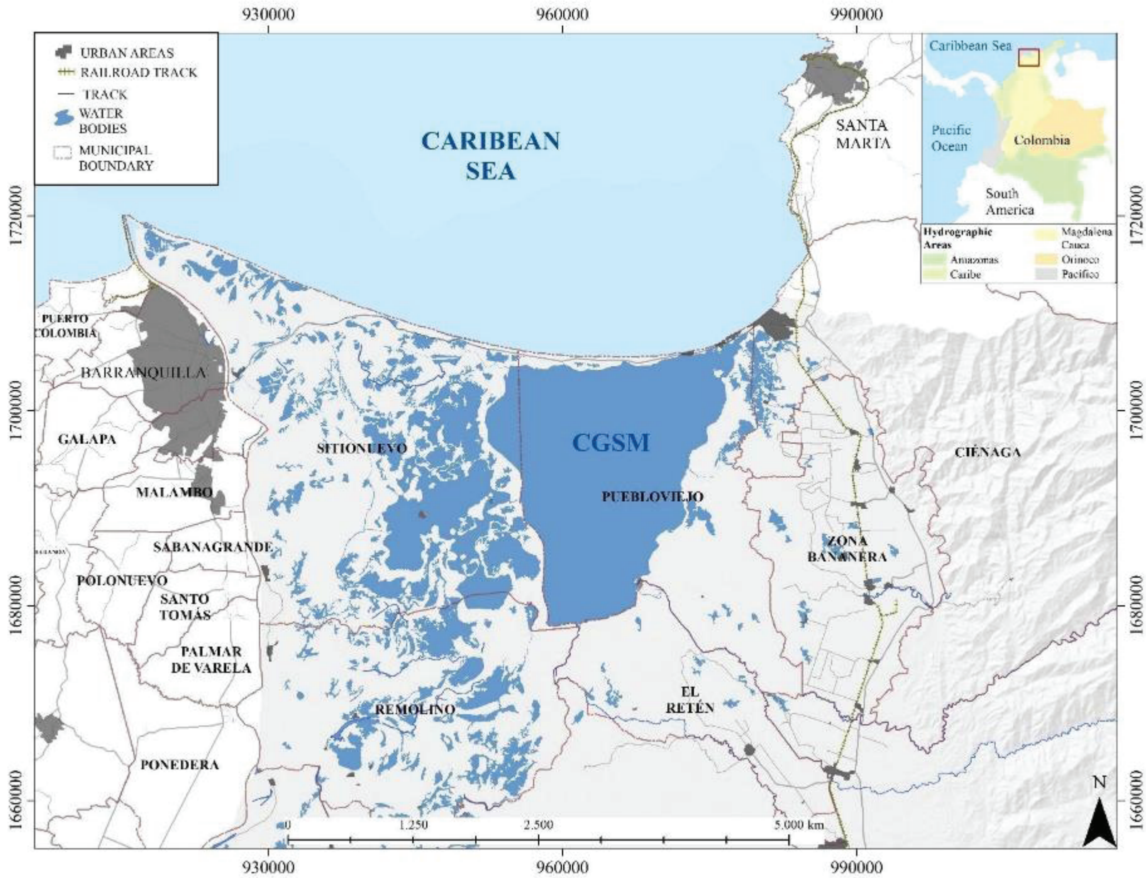

Figure 1: Study area, Cienaga Grande de Santa Marta (CGSM) Colombia.

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emissions as a result of the anthropic activity that takes place on it [14]. In this marine-coastal environment, the entry of nutrients, organic matter, suspended solids, and solid waste has been identified, generated mainly by domestic waste from the towns and stilt settlements located on the outskirts and inside the CGSM [8].

Methodology

In order to identify the environmental risks due to the presence of MPs in the CGSM, a mixed methodology was carried out.

Initially, the methodology proposed by Montoya-Rojas, et al. [15] was applied, where the elements of the landscape are divided into five planetary systems, allowing the analysis of the complexity of the relationships or flows between the elements that make up each system. These are the atmospheric, hydrospheric, geospheric, biospheric, and anthropospheric systems as found in [16-18]. By dividing the elements of the landscape into these five systems, it is possible to identify which of them there is potentially a greater impact due to the presence of MPs and, in addition, to propose corrective actions to mitigate the impact [19].

Now, the Conesa, et al. [20] methodology is employed for the identification and assessment of environmental impacts using an impact importance matrix. This matrix quantitatively determines the degree of impact manifestation in the environment, specifically caused by the presence of microplastics (MPs) in the lagoon system of the CGSM. The potential impacts are associated with the elements discussed in the next section (Planetary System), which are based on the literature review and, the rating ranges for impact evaluation, where values are assigned according to the qualitative characteristics determined for each impact (Table 1), are adapted from Conesa, et al. [20].

Table 1: Adapted for the study area from: Conesa, et al. [20]. The proposed rating ranges are presented for the evaluation of the impacts for each criterion, where the values are assigned according to the qualitative characteristics determined for each of the impacts.

Criteria	Description	Value
Character (CA)	Positive	1
	Negative	-1
Intensity (IN)	Low or minimal impact of the CGSM and its area of influence	1
	Average impact of the CGSM and its area of influence	2
	High impact of the CGSM and its area of influence	4
	Very high impact of the CGSM and its area of influence	8
	Critical impact of the CGSM and its area of influence	12
Extension (EX)	Punctual (25% of the area)	1
	Partial (50% of the area)	2
	Extensive (75% of the area)	4
	Total (100% of the area)	8
Moment (MO)	Long-term (> 5 years)	1
	Medium-term (1 - 5 years)	2
	Short-term or immediate (< 1 year)	4
Persistence (PE)	Fleeting	1
	Temporary (1 to 10 years)	2
	Long-term (> 10 years)	4
Reversibility (RV)	Short-term or immediate (< 1 year)	1
	Medium-term (1 - 5 years)	2
	Long-term (> 5 years)	4
Recoverability (RB)	Recoverable in the short term (1 year)	1
	Recoverable in the medium term (1 to 5 years)	2
	Partially recoverable (> 5 years)	4
	Irretrievable	8
Synergy (SI)	No synergism	1
	Moderate synergism	2
	Highly synergistic	8
Accumulation (AC)	Simple	1
	Cumulative	4
Effect (EF)	Direct	4
	Indirect	1
Periodicity (PR)	Discontinuous	1
	Periodical	2
	Constant	3

Planetary systems

In the atmospheric system, the meteorological variables were taken as elements, taking into account that MPs can generate bad odors and air pollution. Since precipitation contributes to the fall of MPs suspended in the air and at the same time, like solar radiation and temperature, at high values it helps to degrade plastic elements, converting them into MPs and even nanoparticles NP [21]. Finally, the direction of origin of the winds influences the displacement of MPs from one place to another [1].

Second, for the hydrospheric system, surface and groundwater were taken as elements that can be impacted by the presence of MPs. On the part of surface waters, are divided into marine and continental; authors state that the sea receives a large number of MPs transported by continental waters that flow into it [1,21,22], the presence of MPs in continental waters depends on their distance from the different anthropic dynamics, since, the closer they are, the greater the accumulation and deposition of MP particles in these water bodies [5,23]. For the groundwater in the study area, there is no specific documentation that mentions its contamination by MP, however, it is known that especially the plastic microfibers are capable of infiltrating and percolating the soil, contaminating the groundwater. This is why it is important to identify the recharge zones of the aquifers, preventing MPs from reaching the subterranean flows of the region.

Thirdly, in the geospheric system, the elements analyzed were the soil and the landscape, on the other hand, the soils, according to their characteristics, allow to a lesser or greater degree the accumulation of MPs, contaminating them, changing their physical and chemical properties, disturbing the edaphic biota and increase sedimentation [24-26]. Regarding the landscape, there is an alteration in the visual quality since it is there where the accumulation of MPs is evident [27,28].

Then, in the biospheric system, the terrestrial and aquatic ecosystems are taken into account, where the fauna and flora are analyzed, since MPs can cause intoxication or diseases of both animal species and plant cover, mortality of fauna, bioaccumulation and biomagnification of contaminants and the spread of potentially pathogenic microorganisms which

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can harm both aquatic species and humans [9,29-32]. On the other hand, the scenic quality of nature is disturbed by these plastic and microplastic materials [33,34].

Finally, in the anthropospheric system, the anthropic productive systems, the geographical and social environment where the human being lives, and the legal figures of conservation were considered as elements. Additionally, on the coasts there are fast-growing cities that put pressure on the natural dynamics of planetary systems [35], with greater impact on port-border cities [28,36] For this system, the presence of MPs could cause the reduction of the fishing resource, affectation of crops due to the alteration of soil properties, which would trigger the change in the traditional economic activities of the population that inhabits the area [9,25], in addition to the above, MPs can also affect human health causing the development of respiratory diseases, digestive and/or cutaneous [5,22].

Environmental impacts

Now, the concept of environmental impact refers to the effect produced on the environment and its processes due to human activities in each space and time, this effect can be favorable or unfavorable and is measured by an assessment scale that determines its level of importance [20,37].

Conesa, et al. [20] propose an impact importance matrix that allows relating the impacting actions, which in this case are the emission sources of MPs in the CGSM, and their impacts on the different environmental elements belonging to each planetary system [15] as observed in two field trips after collecting primary information in the study area, work with research scientist, have the input of experts, talked with the community and prior bibliographic review.

After the identification of the emission sources of MPs, the elements of the planetary systems, and the impacts, a cause-effect matrix was made where the interactions of the emission sources on the planetary systems were related. Subsequently, they were numerically qualified according to the values indicated in Table 1 according to the methodology of Conesa et al. (2010) taking into account the criteria listed below:

- Character (CA), positive or negative of the impact, which indicates that it is beneficial or harmful for the analyzed component.
- Intensity (IN), corresponds to the degree of incidence of the impact on the affected element.
- Extension (EX), refers to the area of influence of the impact in relation to the area of influence of the project.
- Moment (Mo), is the time in which the impact is manifested.
- Persistence (PE), is the effects associated with environmental impacts and how long they last in the environment.
- Reversibility (RV), is the ability of the medium to reverse the negative effects of an impact.
- Synergy (SI), corresponds to the possibility that the combined effect of two or more impacts is greater than the sum of all of them.
- Accumulation (AC), is the additive character at the time of impact.
- Effect (EF), refers to the possibility of accumulating secondary effects.
- Periodicity (PR), is the frequency with which the impact occurs.
- Recoverability (RB), corresponds to the capacity of the environment to recover from the impacts.

Then, each possible impact, identified from the detailed analysis of each of the elements involved in the study and grouped by planetary systems, was related to the PM emitting sources identified in the region, allowing a qualification to be given to each criterion mentioned in Table 1, these values were integrated into Equation 1, which yields the Impact Importance value, where the lowest possible value is 13, which corresponds to a minimum impact, and the highest value is 100, which would correspond to the maximum impact. It is important to highlight that the impacts that result with importance greater than -25, are considered compatible impacts, which present immediate recovery after the cessation of the activity of the emitting source.

Equation 1. Determination of the importance of the impacts, taken from: Conesa, et al. [20].

$$\text{Importance (I)} = CA\ (3IN+2EX+MO+PE+RV+SI+AC+EF+PR+RB)$$

Once the qualification of the importance of the impacts was obtained, an assessment was used for the different criteria that were grouped into ranges of importance (Table 2), it turns out that the values obtained as irrelevant, moderate, severe, and critical are for the case of the negative impacts and, not important or not very important, important, and very important correspond to the case of the positive ones.

Based on the results of the matrixes, the environmental elements on which critical and severe impacts occur are identified, and it is on these that the different management guidelines are proposed for their mitigation over time.

Results and Discussions

The emission sources of MPs identified were fishing, carried out by inhabitants near the Cienaga, and traditional tourism, which is related to activities that allow enjoyment and recreation in different places in the study area. The third source identified was commerce, in this case, it is considered as the sale of goods and services, whether formal or informal, since both plastic containers and packaging are mainly used. Another emitting source is the satellite dumps, which are open-air informal garbage accumulation areas in rural areas. These are generally located on the outskirts of settlements that

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do not have solid waste collection coverage and near canals and superficial water; the fifth source identified was that of waste from agricultural activities (in Table 3 agricultural waste), although it should be noted that, to a greater extent, the plastic elements observed in these activities were the bags used in the banana production process to protect each bunch from pests and insects.

A sixth emitting source of plastic (potential microplastic) recognized in the field was that of domestic waste from the populations that live on and around the CGSM, the poor sewage coverage causes both solid and liquid waste to be released directly into the medium. In addition, the waste associated with the management of the COVID-19 pandemic (In the COVID-19 waste table 3) was also considered, such as face masks and surgical gloves, which it was usual to find on the routes carried out even after their massive use. Finally, the transport of MP and plastic through channels and surface drainages was also contemplated (in Table 3 transport MPs), taking into account that the Cienaga receives water sources from the Magdalena River and also, the main rivers that pass through human settlements on the western foothills of the Sierra Nevada

Table 2: Classification of importance ranges. Taken from: Conesa, et al. [20]. The classification and ranges of importance used to assess the importance of the possible impacts due to the presence of MPs are observed.

	Negative Character	
Importance (I)= - CA (3IN+2EX+MO+PE+RV+SI+AC+EF+PR+RP)	Irrelevant or compatible	<-25
	Moderate	-25 A <-50
	Severe	-50 A -75
	Critical	>-75
	Positive Character	
Importance (I)= + CA (3IN+2EX+MO+PE+RV+SI+AC+EF+PR+RP)	Not important or not very important	<25
	Important	25 a 50
	Very important	>50

Table 3: Summary matrix of the importance of impact by the emitting and mitigating sources of MPs identified in the study area, the colors represent the range of importance based on Table 2.

Matrix

Systems	Environmental impact (on landscape elements)	Fishing	Tourism	Commerce	Satellite dumps	Agricultural waste	Household waste	In the Covid-19 waste	Transport MPs	Community initiatives	Research and academia
Atm.	Air pollution	-15	-37	-37	-56	-33	-40	-28	-25	46	47
	Generation of bad odors	-39	-30	-39	-58	-24	-46	-21	-30	52	44
Hydro.	Inland water pollution	-61	-49	-59	-57	-52	-63	-58	-63	44	65
	Marine water pollution	-65	-53	-63	-50	-36	-60	-58	-61	44	65
	Groundwater contamination	-33	-42	-42	-42	-35	-48	-38	-42	36	43
Geospheric	Soil pollution	-53	-50	-50	-77	-56	-67	-62	-46	52	47
	Change in the physical and chemical properties of the soil	-44	-44	-41	-75	-37	-50	-35	-43	38	46
	Disturbance of soil biota	-43	-47	-51	-63	-29	-45	-21	-48	41	46
	Changes in land use	-17	-49	-51	-57	-16	-34	-13	-16	37	47
	Increased sedimentation	-31	-27	-27	-37	-47	-57	-30	-59	41	46
	Changes in the visual quality of the landscape	-41	-57	-57	-71	-53	-57	-67	-53	52	53
	Accumulation of plastic in the landscape (potential MP)	-45	-55	-59	-73	-42	-59	-41	-49	52	53
Biospheric	Vegetation cover poisoning	-23	-33	-39	-54	-28	-54	-23	-24	40	46
	Diseases and/or mortality in fauna	-25	-40	-42	-54	-40	-42	-34	-33	47	53
	Afectación del bosque de manglar	-30	-33	-34	-37	-23	-42	-23	-38	46	64
	Diseases and/or mortality in fauna	-42	-42	-40	-39	-35	-43	-34	-55	47	65
	Involvement of benthic organisms	-39	-39	-34	-37	-46	-55	-32	-53	41	46
	Bioaccumulation and biomagnification of contaminants	-40	-40	-40	-37	-35	-45	-34	-57	41	53
	Spread of potentially pathogenic microorganisms	-39	-39	-34	-37	-33	-57	-38	-57	40	65
Anthropospheric	Reduction of fisheries resources	-39	-42	-42	-30	-32	-52	-22	-47	46	64
	Decrease in crop productivity	-13	-17	-17	-29	-35	-23	-16	-22	39	46
	Decrease in crop productivity	-33	-31	-37	-33	-32	-39	-25	-34	45	64
	Development of digestive diseases due to consumption of contaminated food	-39	-37	-37	-37	-35	-46	-29	-53	40	65
	Development of respiratory and/or skin diseases	-30	-39	-39	-51	-33	-40	-36	-40	39	65
	Alteration of natural heritage	-40	-54	-42	-69	-39	-56	-51	-41	50	65
	Recycling accumulation and collection	33	43	52	-	52	48	-	-	52	55
	Knowledge generation and transfer	-	-	-	-	-	-	39	-	47	68

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de Santa Marta, making the swamp a convergence zone for ecological flows in the region.

On the other hand, two mitigating sources are selected for the presence of MPs in the CGSM environment, these being Community Initiatives, Research, the institutional framework, and the academy, which allows for generating positive impact importance, since they seek to carry out a management of plastics with activities such as recycling, which are related to the practices or initiatives led by the community, foundations or some entities that are directed towards mitigation, reduction of said impacts and the transformation of industrial processes with cleaner productions. This, in the long term, will allow the environmental conditions of the swamp to be restored. Scientific research associated with plastics and microplastics in these marine-coastal areas in the country is relatively recent, which contributes to knowledge and cultural practices, an opportunity for change, and awareness, about the disturbances generated by these pollutants to the natural and human systems.

Once the identified sources of emission of MPs in the CGSM and its influence area qualified the importance of impact [20] for each environmental impact possible impact on values resulting from equation 1, values that are synthesized in Table 3.

Based on the results obtained, it is evident that there is one or another irrelevant or compatible impact, which is easily mitigated once the emitting source ceases its incorporation of MPs into the environment. In greater quantity, the emission sources generate a moderate impact on the selected environmental elements, and severe impacts on the visual quality of the landscape due to the contamination of continental, marine, and soil waters. Specifically, the transport of microplastics through channels and surface drainages on its way impacts most of the environmental elements, since it contributes to water pollution, increased sedimentation, visual quality of the landscape, development of digestive diseases, and damage to fauna and flora. The foregoing triggers a greater impact for aquatic fauna species due to consumption and contact with MPs, which also facilitate the presence, protection, and transport of potentially pathogenic microorganisms, making different specimens sick or killing them; The only severe impact identified is related to the existence of satellite dumps that contaminate the soil.

As for the positive impacts resulting from the interaction of mitigating sources, most of them have an important positive impact importance, but the very important ones stand out according to the scale, where community initiatives interact with generation mitigation of bad odors, soil contamination, changes in visual quality, accumulation of MPs in the landscape and recycling. Research and academia are an activity that favor in a positive way due to the awareness that is given to reduce water pollution, the quality of the landscape, the disturbance of flora and fauna, and the elements that make up the anthropospheric system.

In the impacts they are valued negatively, they are the ones that guide where it is necessary to apply the corrective actions or the management guidelines, which are proposed by each planetary system in the face of the problem due to the presence of MPs.

For the atmospheric system, it is necessary to adapt bins in public spaces for the collection of plastic materials, avoiding their disposal in unsuitable places where they are more exposed to atmospheric factors, causing the generation of particles and odors due to the chemosynthesis of plastics to MPs.

In the hydrospheric system, it is proposed to expand the coverage of the solid waste collection service in rural areas, avoiding the creation of satellites or isolated dumps in areas close to bodies of water. In addition, expanding the sewage service in the townships and urban areas of the municipalities that have a direct influence on the CGSM and the incorporation of wastewater treatment plants in areas of direct discharge to the Cienaga is proposed.

Regarding the geospheric system, it is necessary to clean up the critical points of the satellite dumps, expand the coverage of the solid waste collection service in rural areas, avoid the creation of new dumps, and supra-municipal coordination to establish common disposal and use areas of plastic waste.

For the biospheric system, it is necessary to inform the communities of the importance and benefits of conserving species. In addition, regulate the sources of plastic emissions in the CGSM and its tributaries, in order to also prevent the spread of potentially pathogenic microorganisms that are associated with the presence of MPs in the soil biota and waters. Thus, encourages inter-institutional work for the conservation of species in the CGSM at the level of micro, meso, and functional macro-organisms in the ecology of the region.

Finally, for the anthropospheric system, scientific dissemination of the impact of MP on the CGSM ecosystem is required, aimed at different social groups, the implementation of plastic recycling chains, and incentives for its replacement in each of the economic activities. Additionally, the coordination of the different planning instruments at the supra-municipal level for the proper management of plastic on various sectoral and cultural scales.

Considering all of the above, we understand that the presence of microplastics (MPs) in natural environments is a growing concern, and the text highlights several critical scientific discussions arising from their impact. Understanding the sources of MP emissions, such as fishing, tourism, or wastewater, is crucial for prioritizing mitigation efforts. Research on the ecological consequences of MPs can shed light on their effects on biodiversity, food webs, and ecosystem functioning. Additionally, investigating the potential human health risks associated with MPs is vital given their prevalence in water bodies and marine organisms. Furthermore, exploring the fate and transport of MPs will reveal their dispersion patterns and accumulation in different ecosystems. Effective mitigation strategies must be developed and assessed,

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considering the national environmental regulations applicable in the study area, social behaviors, and technological solutions.

Moreover, focusing on the impacts of MPs in specific ecosystems, as seen in the Cienaga Grande de Santa Marta, provides context-specific insights. Long-term effects and ecosystem recovery after implementing mitigation measures warrant examination. Global collaboration and knowledge exchange can further enrich our understanding of the global distribution and impact of microplastics, ultimately leading to better-informed approaches to address this pressing environmental issue.

Recently, with research associated with the Anthropocene, delving into the impacts of microplastics implies innovating in systemic analysis methodologies. This also helps to focus specific projects in the territory of analysis and seek synergies with local entities in coherence with regional and global environmental policies for the control of microplastic contamination and the impacts on ecosystem services, as well as on food chains. Over time, the litter is transformed into microplastic, which is incorporated into the trophic chains not only of the mangrove swamp but also of the surrounding ecosystems, the soil, and even the rocks of coastal sectors, which is known as "plasticrust" [38]. This plastic contamination, alters and impacts the trophic chains of sensitive ecosystems such as corals and mangroves, among others, that fulfill a regulatory function, supplying food, and that also offer carbon storage in marine-coastal areas.

Concluding remarks

The presence of MPs in any environment represents a mostly critical negative impact on its ecological processes, it alters the ecosystem services and the functions of the planetary systems that interact in the CGSM.

The MPs navigate in an interrelated way with all the planetary systems, where, for example, the dynamics of the atmospheric and hydrospheric systems contribute to the redistribution of the MPs, and the geospheric system influences the accumulation and sedimentation zones of these particles. For its part, the biospheric system contains the receiving organisms with greater affectation. The anthropospheric system has attributed the responsibility for the emissions of plastics and MPs, and in turn, is harmed by the existence of these materials that this same system generates. In the CGSM, the presence of MPs negatively disturbs the main productive activities in the region, such as the trade of fish and other aquatic species, which accumulate MPs that are in continental and marine waters and in the soil.

Most of the impacts on the CGSM and its area of influence are moderate, which, based on workshops with experts and scientists, can initiate a short-term and long-term recovery process, once the incorporation of MPs, but this possibility, due to cultural practices, will require many wills of cooperation and immediate actions, which would limit the proposal.

For the implementation of corrective measures, for those sources of severe and critical impact, it will be necessary to use measures to rehabilitate the ecosystem, much more expensive and that will be reflected in the long term in the ecosystem of the lagoon complex of the Cienaga Grande de Santa Marta.

This study presents innovative approaches to understanding the impact of microplastic pollution on the Cienaga Grande de Santa Marta (CGSM) lagoon system in Colombia. The study examines the ecological dynamics affected by microplastics and proposes corrective actions to mitigate their impact. What distinguishes this research is its comprehensive evaluation of the various environmental impacts caused by microplastics, encompassing a wide range of ecological disturbances. The study also emphasizes the importance of community participation and the implementation of sustainable practices to protect the CGSM ecosystem and promote global environmental stewardship. This comprehensive approach underscores the urgent need to address microplastic pollution and its far-reaching consequences in natural systems and human activities, demonstrating its applicability across ecosystems and scales.

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