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Plastic and microplastic pollution in Ecuador: Environmental evidence, human exposure, regulatory gaps, and circular economy responses

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A B S T R A C T

Plastic and microplastic pollution in Ecuador is a growing environmental and public health concern in a country where biodiverse continental and insular ecosystems coexist with weaknesses in waste management and recycling, tourism and fisheries pressure, and transboundary marine debris. This article presents a scoping review of the scientific evidence on this issue, complemented by a documentary analysis of legal, regulatory, and public policy instruments issued between 1976 and 2024. The review followed PRISMA-ScR procedures and included 109 studies, with the aim of mapping environmental occurrence, wildlife and human exposure, and the evolution of the national regulatory framework. Plastic pollution is not limited to coastal or insular areas: it is recorded on beaches, estuaries, wetlands, river systems, Amazonian sediments, high-altitude lakes, glacier snow, wildlife, foods, beverages, and drinking water. The clearest signs of wildlife exposure are ingestion and entanglement, followed by trophic transfer, particles in internal tissues and feces, and alterations in behavior and reproduction. Human exposure is mostly dietary, spanning seafood and canned tuna, milk, honey, and both bottled and drinking water, and extends to chemical migration from polymers and to intravenous solutions. No study included in this review assessed health outcomes in exposed populations or examined inhalation as an exposure route. Although Ecuador has expanded its regulatory framework, considerable gaps persist in source separation, recycling infrastructure, enforcement, and territorial coordination, while methodological heterogeneity limits comparison across studies. Addressing it requires source reduction, environmental monitoring, technological innovation, food-safety controls, inclusive recycling, and stronger governance supported by regional cooperation.

Keywords: Plastic pollution; Microplastics; Waste management; Food safety; Environmental policy.

Poluição por plásticos e microplásticos no Equador: evidências ambientais, exposição humana, lacunas regulatórias e respostas da economia circular

R E S U M O

A poluição por plásticos e microplásticos no Equador é uma preocupação ambiental e de saúde pública crescente em um país onde ecossistemas biodiversos convivem com fragilidades na gestão de resíduos e na reciclagem, pressão turística e pesqueira, e resíduos marinhos transfronteiriços. Apresenta-se uma revisão de escopo da evidência científica, complementada por uma análise documental de instrumentos normativos e de políticas públicas emitidos entre 1976 e 2024. Seguiu os procedimentos PRISMA-ScR e incluiu 109 estudos, para mapear a ocorrência ambiental, a exposição da fauna e de humanos, e a evolução do marco regulatório. A poluição não se limita a áreas costeiras ou insulares: é registrada em praias, estuários, áreas úmidas, sistemas fluviais, sedimentos amazônicos, lagos de altitude elevada e neve glacial. Na fauna predominam a ingestão e o emaranhamento, seguidos de transferência trófica, partículas em tecidos internos e fezes, e alterações comportamentais e reprodutivas. A exposição humana é principalmente alimentar: frutos do mar e atum enlatado, leite, mel e água engarrafada e de abastecimento, estendendo-se à migração química de polímeros e a soluções

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intravenosas. Nenhum estudo incluído nesta revisão avaliou desfechos de saúde em populações expostas nem examinou a inalação como rota de exposição. Embora o Equador tenha ampliado seu marco regulatório, persistem lacunas na separação na fonte, infraestrutura de reciclagem, fiscalização e coordenação territorial, enquanto a heterogeneidade metodológica limita a comparação entre estudos. Enfrentá-la exige redução na fonte, monitoramento ambiental, inovação tecnológica, segurança dos alimentos, reciclagem inclusiva e uma governança mais forte apoiada pela cooperação regional.

Palavras-Chave: Poluição plástica; Microplásticos; Gestão de resíduos; Segurança dos alimentos; Política ambiental.

Contaminación por plásticos y microplásticos en Ecuador: Evidencia ambiental, exposición humana, brechas normativas y respuestas desde la economía circular

R E S U M E N

La contaminación por plásticos y microplásticos en Ecuador es una preocupación ambiental y de salud pública creciente en un país donde ecosistemas biodiversos conviven con deficiencias en gestión de residuos y reciclaje, presión turística y pesquera, y desechos marinos transfronterizos. Se presenta una revisión de alcance de la evidencia científica, complementada con un análisis documental de instrumentos normativos y de política pública emitidos entre 1976 y 2024. Siguió los procedimientos PRISMA-ScR e incluyó 109 estudios, para mapear la ocurrencia ambiental, la exposición de fauna y humanos, y la evolución del marco normativo. La contaminación no se limita a zonas costeras o insulares: se registra en playas, estuarios, humedales, sistemas fluviales, sedimentos amazónicos, lagos altoandinos y nieve glaciar. En la fauna predominan la ingestión y el enredamiento, seguidos de transferencia trófica, partículas en tejidos internos y heces, y alteraciones conductuales y reproductivas. La exposición humana es principalmente alimentaria: productos marinos y atún enlatado, leche, miel y agua embotellada y de consumo, y se extiende a la migración química de polímeros y a soluciones intravenosas. Ningún estudio incluido en esta revisión evaluó desenlaces en salud en poblaciones expuestas ni examinó la inhalación como ruta de exposición. Aunque Ecuador ha ampliado su marco regulatorio, persisten brechas en separación en origen, infraestructura de reciclaje, fiscalización y coordinación territorial, mientras la heterogeneidad metodológica limita la comparación entre estudios. Enfrentarlo requiere reducción en la fuente, monitoreo ambiental, innovación tecnológica, inocuidad alimentaria, reciclaje inclusivo y una gobernanza más sólida apoyada en la cooperación regional.

Palabras clave: Contaminación plástica; Microplásticos; Gestión de residuos; Inocuidad alimentaria; Política ambiental.

1. Introduction

Plastics currently occupy a central place in everyday life and in many productive sectors. Their low cost, light weight, durability, versatility, and ease of processing have favored their widespread use in areas such as medicine, electronics, construction, agriculture, and the food industry (Andrady & Neal, 2009; Haba et al., 2025; Nikiema & Asiedu, 2022; Thompson et al., 2009). In the latter, for example, plastic packaging helps protect products, facilitates storage and distribution, and extends shelf life (Alamri et al., 2021; Ncube et al., 2020). However, the same properties that explain their usefulness also favor their persistence and accumulation in the environment when plastic waste is not properly managed. In these cases, plastics may end up in terrestrial, freshwater, coastal, and marine environments, where they persist as macroplastics or fragment into microplastics and nanoplastics capable of accumulating in water bodies, sediments, soils, organisms, food products, and remote ecosystems (Kamalasekaran & Sundramoorthy, 2026; Napper & Thompson, 2023).

The increase in global plastic production has not been accompanied by an equivalent capacity for recovery and recycling. In 2019, only about 15% of plastic waste was collected for recycling, and nearly 9% was effectively recycled after process losses (OECD, 2022). This gap shows that recycling alone has not been sufficient to address the problem. For this reason, current responses tend to incorporate circular economy strategies oriented toward reduction, redesign, reuse, extended producer responsibility, and waste prevention (United Nations Environment Programme, 2023).

Plastic and microplastic pollution raises both ecological and public health concerns. Aquatic and terrestrial organisms may be exposed through ingestion, entanglement, or contact with contaminated matrices, with potential physical, chemical, physiological, and ecological effects (Ghaffar et al., 2022; Samadi et al., 2022). At the same time, the presence of microplastics in food and drinking water has increased concern about human exposure pathways and the need to strengthen public-health and environmental monitoring (Das et al., 2024).

Different governments have responded with policies aimed at reducing plastic consumption, restricting single-use products, promoting recycling, and improving waste management systems (Diana et al., 2022; Knoblauch & Mederake, 2021). At the international level, this debate has reinforced the need to address plastic pollution throughout the entire life cycle of these materials, from production and design to consumption, waste management, and their release into the environment (Cowan & Tiller, 2021; Wang & Praetorius, 2022). However, this regulatory progress does not by itself guarantee effective mitigation unless it is accompanied by enforcement capacity, infrastructure, standardized monitoring, extended producer responsibility, and changes in consumption patterns.

Ecuador represents a relevant case for analyzing plastic and microplastic pollution because of the coexistence of highly biodiverse terrestrial, freshwater, coastal, marine, and insular ecosystems, together with major challenges in waste management, recycling, sanitation, tourism, fisheries activity, and transboundary marine pollution. In 2022, for example, the country generated more than 627,000 tons of plastic waste, of which only 7.7% was recycled (Ministerio del Ambiente Agua y Transición Ecológica, 2024a). In the Galapagos Islands, plastic pollution has been reported as a threat to endemic and vulnerable fauna through ingestion and entanglement, affecting species such as green sea turtles, marine iguanas, and Galapagos sea lions (Moreira-Mendieta et al., 2023; Muñoz-Pérez et al., 2023). Yet the problem is not confined to marine and insular ecosystems. Microplastics have also been reported in coastal wetlands, Andean rivers, Amazonian fluvial sediments, glacier snow, and high-altitude lakes, suggesting a broader distribution across the national territory and the possible involvement of atmospheric transport pathways (Cabrera et al., 2022; Donoso & Rios-Touma, 2020; López et al., 2023; Lucas-Solis et al., 2021; Ramos et al., 2026).

This evidence is further complemented by reports of contamination in environmental matrices, biota, food products, and drinking-water sources, extending the concern from ecosystems and wildlife to human exposure through diet and water consumption (Velez-Terreros et al., 2024; Villafuerte-Campi et al., 2026).

Research conducted in Ecuador has also explored polymer-related mitigation alternatives. These include recycling processes, energy recovery through pyrolysis, "bottle-to-bottle" polyethylene terephthalate (PET) recycling, the use of recycled plastics in construction and wastewater treatment, and the development of biopolymer alternatives (Chango et al., 2015; Hidalgo-Crespo et al., 2020; Lambré et al., 2022; Mancheno et al., 2016; Muñoz, Fuentes, et al., 2016; Riofrio et al., 2022; Sangucho Barros et al., 2023).

On the governance side, Ecuador has built an increasingly broad legal framework that includes fiscal instruments, local ordinances, single-use plastic regulations, circular economy provisions, extended producer responsibility mechanisms, and strategies aimed at reducing plastic waste (Ministerio de Ambiente y Energía, 2026).

Despite these advances, environmental, technological, health-related, and regulatory information on plastic and microplastic pollution in Ecuador remains dispersed, which makes it difficult to provide an integrated assessment of the problem and its possible responses. For this reason, this study presents a scoping review of plastic and microplastic pollution in Ecuador, developed according to PRISMA-ScR procedures and complemented by a documentary analysis of legal, regulatory, and public policy instruments. By relating environmental distribution, wildlife exposure, ecological impacts, human exposure pathways, regulatory evolution, implementation gaps, and circular economy responses, this review synthesizes the current state of knowledge and identifies priorities for research, monitoring, governance, and mitigation.

2. Material and Methods

2.1 Study design

This study was designed as a scoping review complemented by a documentary analysis of legal, regulatory, and policy instruments related to plastic pollution in Ecuador. The review mapped and synthesized scientific and technical evidence on the presence of plastics and microplastics across the national territory, considering environmental occurrence, wildlife exposure, potential ecological impacts, human exposure pathways, recycling processes, biopolymer alternatives, and other polymer-related mitigation strategies. The documentary analysis examined the evolution of Ecuador's legal, regulatory, and policy framework addressing plastic pollution, single-use plastics, recycling, circular economy, and extended producer responsibility.

The review was conducted and reported following PRISMA-ScR procedures, given the broad and heterogeneous nature of the evidence included. This approach was appropriate because the purpose of the study was not to estimate pooled effects or conduct a meta-analysis, but to organize, describe, and integrate the diverse evidence relevant to the Ecuadorian case.

2.2 Literature search strategy

The literature search was conducted on March 12, 2026, across four bibliographic databases: Scopus, Web of Science Core Collection, SciELO, and Redalyc. This combination was selected to cover both international and regional literature. The same core search equation was used across the four databases:

(plastic OR microplastic* OR "marine debris") AND (Ecuador OR Galapagos)*

Although the equation was deliberately broad and centered on plastic-related terms, the screening process allowed the inclusion of studies on recycling, biopolymers, plastic waste management, and circular economy, provided that they were directly related to plastic polymers in Ecuador.

The search was adapted to the interface of each database. In Scopus, the equation was applied to title, abstract, and keyword fields; in Web of Science Core Collection, it was entered through Smart Search; in SciELO, it was applied to all indexes; and in Redalyc, it was entered with document type set to "Articles". No restrictions were imposed on publication year or language during the database search; language eligibility was applied during screening (Table 1).

Table 1 - Complete search strategy used in each database.
Tabela 1 – Estratégia de busca completa utilizada em cada base de dados.

Database	Search date	Search equation	Search fields/search mode	Additional filters applied in the database	Initial records retrieved	Records retained for consolidation
Scopus	March 12, 2026	(plastic* OR microplastic* OR "marine debris") AND (Ecuador OR Galapagos)	Title, abstract, and keywords	No additional filters applied	366	366
Web of Science Core Collection	March 12, 2026	(plastic* OR microplastic* OR "marine debris") AND (Ecuador OR Galapagos)	Smart Search	No additional filters applied	375	375
SciELO	March 12,	(plastic* OR microplastic* OR	All indexes	No additional filters applied	33	33

	2026	"marine debris") AND (Ecuador OR Galapagos)				
Redalyc	March 12, 2026	(plastic* OR microplastic* OR "marine debris") AND (Ecuador OR Galapagos)	Platform search interface; document type: Articles	Discipline filters: Engineering; Multidisciplinary Sciences (Natural and Exact Sciences) [Multidisciplinaria (Ciencias Naturales y Exactas)]; Earth Sciences; Biology. Country filter: Ecuador. No year or language filters were applied.	4,298	300
				Total	**5,072**	**1,074**

Because Redalyc produced a substantially broader retrieval (4,298 records), two additional filters were applied only to this database to improve specificity: discipline, retaining Engineering, Multidisciplinary Sciences (Natural and Exact Sciences), Earth Sciences, and Biology; and country, retaining Ecuador. This refinement reduced the Redalyc set to 300 records. Across the four databases, the search retrieved 5,072 records, of which 1,074 were retained for consolidation: 366 from Scopus, 375 from Web of Science Core Collection, 33 from SciELO, and 300 from Redalyc. All records were exported to Mendeley for consolidation and duplicate removal. The complete database-specific search strategy is shown in Table 1.

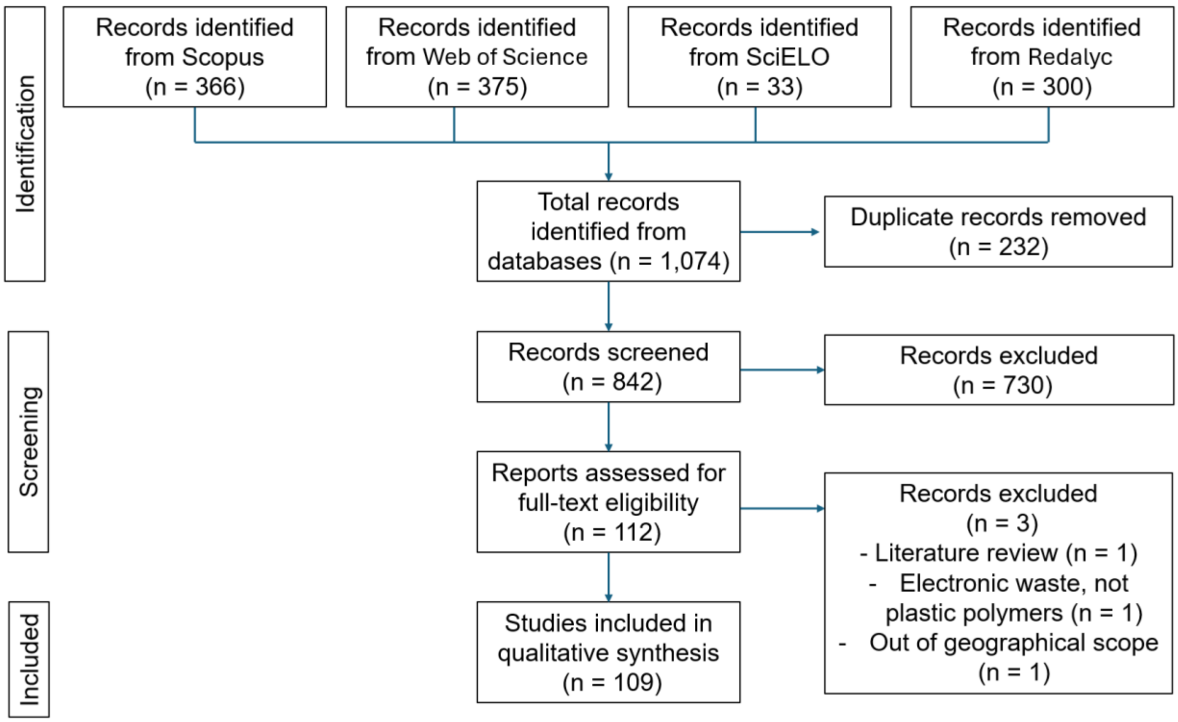
2.3 Eligibility criteria and study selection

For the scientific and technical review, records were included when they reported empirical data, quantitative or qualitative analyses, modelling results, technological applications, regulatory assessments, socioeconomic analyses, or evidence directly relevant to plastic pollution or polymer-related mitigation in Ecuador. Eligible topics included macroplastic, microplastic, or nanoplastic pollution; environmental or biological occurrence of plastic particles; plastic contamination in food, beverages, drinking water, or other exposure-related matrices; recycling, recovery, or valorization of plastic polymers; biopolymer or bio-based alternatives; plastic waste management; circular economy strategies; and regulatory, socioeconomic, or governance dimensions of plastic pollution. Studies were required to include Ecuador as a national, regional, local, continental, or insular focus and to be published in English or Spanish.

Records were excluded when they did not address plastic pollution, plastic waste, polymer contamination, recycling, circular economy, or plastic-related governance. Publications using the term “plastic” in unrelated contexts, such as mechanical deformation or phenotypic plasticity, were excluded. Review articles were excluded when they did not provide Ecuador-focused evidence synthesis or a direct analytical contribution to the national case. Book chapters, conference papers, and proceedings were retained when they provided relevant evidence, technical information, modelling results, policy analysis, or contextual synthesis related to plastic pollution or polymer management in Ecuador.

The study selection process is summarized in Figure 1. From the 1,074 records retained for consolidation, 232 duplicates were removed, and 842 were screened by title and abstract. During this stage, 730 records were excluded. The remaining 112 reports were assessed in full text, of which three were excluded: one literature review without sufficient Ecuador-focused contribution, one study focused on electronic waste without specific attention to plastic polymers, and one report outside the geographical scope. This process resulted in 109 studies included in the qualitative synthesis.

Figure 1 - PRISMA flow diagram of the study selection process
Figura 1 - Fluxograma PRISMA do processo de seleção dos estudos



Note: The initial Redalyc search retrieved 4,298 records, which were refined by discipline and country before consolidation, yielding 300 records. The "Records identified from databases" count (n = 1,074) therefore reflects the four databases after this database-level filtering. Across all databases, 5,072 records were initially retrieved.

Nota: A busca inicial no Redalyc recuperou 4.298 registros, refinados por disciplina e país antes da consolidação, resultando em 300 registros. O total de "registros identificados nas bases de dados" (n = 1.074) reflete, portanto, as quatro bases após essa filtragem em nível de base de dados. No conjunto, foram recuperados inicialmente 5.072 registros.

2.4 Data charting and synthesis

A standardized data-charting matrix was developed in Microsoft Excel to organize the information extracted from the included studies. The matrix included bibliographic data, source type, study location, Ecuadorian region, ecosystem type, environmental or exposure-related matrix, type of plastic pollution or polymer-related topic, target organism or product when applicable, and the main environmental, ecological, health-related, technological, or regulatory findings. Data extraction was performed by one author and independently verified by a second author. Disagreements or uncertainties were resolved through discussion and checked against the full text.

Given the heterogeneity of the included studies in terms of design, matrices, methods, ecosystems, organisms, products, and outcomes, a meta-analysis was not performed. Instead, the evidence was synthesized narratively and thematically. All 109 included studies were entered into the data-charting matrix and contributed to the thematic mapping of the evidence; in the narrative synthesis, representative studies are cited to illustrate each analytical dimension, while the full set underpins the overall mapping. Studies were organized into five analytical dimensions: environmental distribution of plastic and microplastic pollution; wildlife exposure and ecological impacts; human exposure pathways; technological and circular economy responses; and regulatory evolution, governance challenges, and implementation gaps. Quantitative findings, such as concentrations, abundance, prevalence values, and economic estimates, were summarized descriptively when available, but were not statistically pooled. Consistent with the scoping review approach, a formal risk-of-bias assessment was not conducted; the review focused instead on mapping the extent, range, and nature of the available evidence.

2.5 Documentary analysis of the legal framework

To complement the scientific and technical review, a documentary analysis was conducted to examine the evolution of Ecuador's legal, regulatory, and policy framework related to plastic pollution. Documents were identified through targeted searches in official government portals and national open-access legal repositories. Priority was given to sources issued or hosted by Ecuadorian public institutions, including the Ministry of Environment, Water and Ecological Transition, the National Assembly, the Official Registry, the Internal Revenue Service, the Presidency of the Republic, decentralized autonomous governments, and the Governing Council of the Special Regime of Galapagos.

The documentary search covered the period from 1976 to 2024. The starting point corresponds to the Pollution Control Law, the first national instrument to address the disposal of non-biodegradable waste, and the closing point to the most recent instrument incorporated into the corpus. The National Plan for the Reduction of Plastic Waste, presented in 2026 while this review was being completed, is discussed as contextual background but was not included in the documentary analysis. Eligible documents included national laws, executive decrees, ministerial agreements, technical regulations, fiscal instruments, local ordinances, circular economy regulations, extended producer responsibility instruments, national plans, and policy strategies explicitly related to plastic pollution, plastic waste management, single-use plastics, recycling, circular economy, or polymer-related mitigation.

The selected documents were examined qualitatively to identify their year of enactment or publication, issuing institution, territorial scope, regulatory purpose, target plastic products or waste streams, restrictions, fiscal or economic instruments, implementation mechanisms, enforcement provisions, circular economy principles, and links to plastic pollution mitigation. This information was organized chronologically to reconstruct Ecuador's regulatory evolution and to identify gaps between regulatory ambition, implementation capacity, and the environmental evidence synthesized in this review.

2.6 Development of conceptual figures

The conceptual figures (Figures 3 and 4) were created to visually synthesize the main ecological and human exposure pathways identified in the review. These figures were generated with the assistance of an AI-based image-generation tool, using author-designed prompts grounded in the reviewed literature. The authors then reviewed and refined the figures iteratively to ensure scientific accuracy, consistency with the manuscript, correct terminology and units, and faithful correspondence with the synthesized evidence.

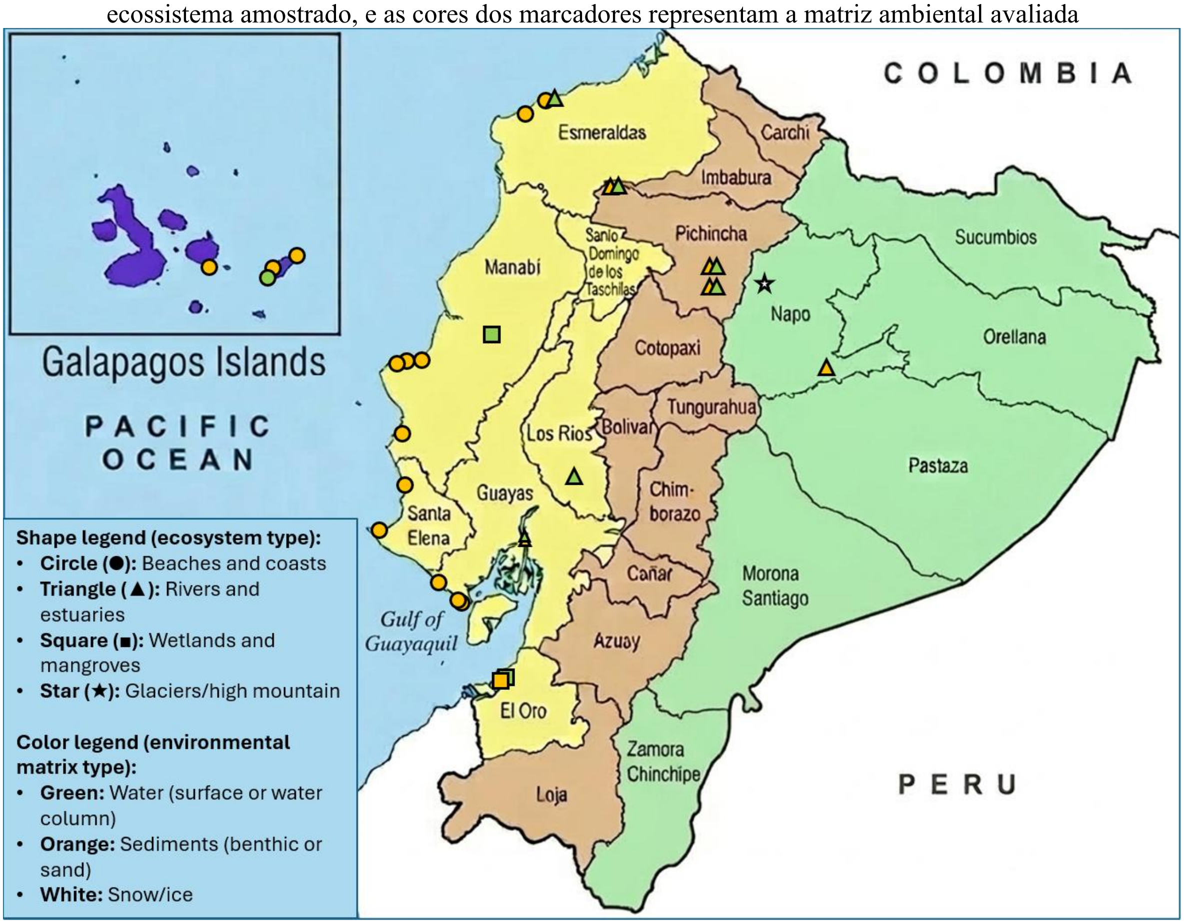
3. Results and Discussion

3.1 Environmental distribution of plastic pollution across Ecuadorian ecosystems

The 109 studies included in this scoping review show that plastic pollution has been documented across the four geographical regions of Ecuador: Coast, Highlands, Amazon, and the Insular region. As shown in Figure 2, macroplastics and microplastics have been reported in several environmental matrices, including surface and water-column samples, benthic sediments, beach sand, wetlands, river systems, Amazonian fluvial sediments, high-altitude lakes, and glacier snow. This pattern indicates that plastic pollution in Ecuador is not confined to coastal or insular environments, but is part of a broader and spatially distributed environmental problem.

Figure 2 - Spatial distribution of studies on plastic and microplastic pollution across the natural regions of Ecuador. Background colors delineate the continental regions: Coast (yellow), Highlands or Andes (brown), and Amazon (green), alongside the Galapagos Islands (inset). Marker shapes indicate the sampled ecosystem, and marker colors represent the evaluated environmental matrix

Figura 2 - Distribuição espacial dos estudos sobre poluição por plásticos e microplásticos nas regiões naturais do Equador. As cores de fundo delineiam as regiões continentais: Costa (amarelo), Serra ou Andes (marrom) e Amazônia (verde), juntamente com as Ilhas Galápagos (mapa inserido). Os formatos dos marcadores indicam o ecossistema amostrado, e as cores dos marcadores representam a matriz ambiental avaliada



Source: Prepared by the authors
Fonte: Elaborado pelos autores

The Galapagos Islands have received particular attention because of their ecological uniqueness and their exposure to both local and transboundary plastic inputs. Available evidence indicates that a substantial fraction of debris reaching the archipelago is transported by marine currents from continental coasts of South and Central America, while local waste leakage and fisheries-related debris also contribute to accumulation patterns (Benito-Kaesbach et al., 2024; Jones et al., 2021; van Sebille et al., 2019). Macroplastic debris and microplastics have been documented on Galapagos beaches and in coastal matrices (Alava et al., 2014; Jones et al., 2021). Direct filtration approaches have also reported high concentrations of small particles that may be underestimated by conventional plankton-net sampling (Deakin et al., 2024). Recent evidence further suggests that oceanographic variability, including El Niño events, may influence microplastic accumulation in sensitive habitats such as turtle nesting areas (Savage et al., 2026). These findings suggest that local conservation measures in Galapagos need to be complemented by regional and international actions addressing transboundary transport, fisheries-related debris, and the standardized monitoring of smaller particle fractions.

On the continental coast, plastic pollution has been reported across beaches, rocky reefs, coastal waters, estuaries, mangroves, and river-influenced systems. In Manabí, submerged marine debris in rocky reef ecosystems has been dominated by plastic items, many of them associated with fishing activities (Figueroa-Pico et al., 2016). Beach litter surveys across continental and insular sites have also identified plastics as the dominant fraction of anthropogenic debris, with high densities in areas influenced by the Guayas River (Gaibor et al., 2020). Coastal waters, estuarine systems, and mangrove environments, including Esmeraldas, the Gulf of Guayaquil, Estero Salado, and the Jambelí Archipelago, appear to function as both retention zones and transport pathways for plastic particles, especially fibers and fragments associated with urban discharges, riverine inputs, and coastal hydrodynamics (Arteaga et al., 2024; Capparelli et al., 2021; Quizhpe Asencio et al., 2025).

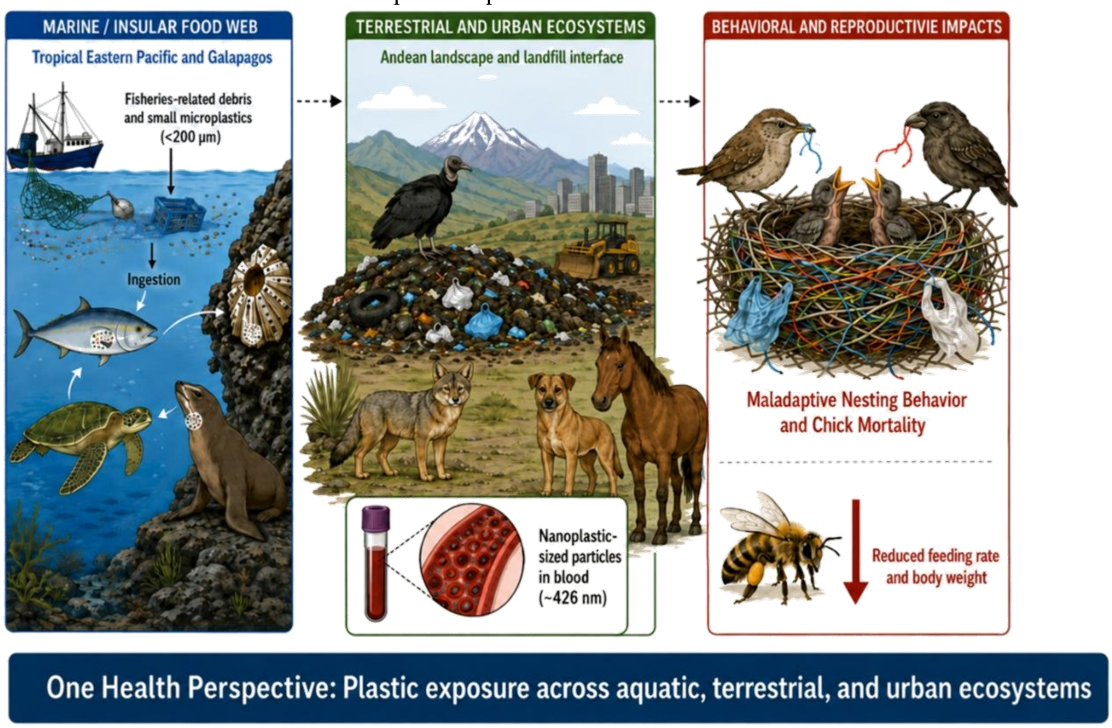
Freshwater and inland systems show another dimension of the problem, linked to urban sanitation, waste management, and hydrological connectivity. Microplastics have been reported in Andean rivers affected by untreated wastewater and urban discharges, in coastal wetlands such as La Segua, and in Amazonian fluvial sediments from Puerto Misahuallí, where contamination has been associated with inadequate solid waste management and downstream transport from populated areas (Donoso & Rios-Touma, 2020; López et al., 2023; Lucas-Solis et al., 2021). These findings suggest that rivers and wetlands should not be understood only as impacted ecosystems, but also as pathways that connect inland waste sources with coastal and marine contamination.

Recent studies also indicate that remote high-altitude ecosystems are not isolated from microplastic pollution. Microplastics have been detected in surface snow from the Antisana glacier and in sediments from Andean lakes above 3,800 m a.s.l., suggesting the possible contribution of atmospheric deposition and wind-driven transport (Cabrera et al., 2022; Ramos et al., 2026). The picture that emerges is of a systemic, multi-pathway problem: waste generated inland, carried downstream by rivers toward estuaries and the coast, redistributed at sea by ocean currents and supplemented by fisheries-related debris, and reaching high-altitude glaciers and lakes through atmospheric transport.

3.2 Wildlife exposure and ecological impacts of plastic pollution

Across the reviewed studies, plastic reaches Ecuadorian wildlife through multiple exposure routes, of which ingestion is only the most frequently reported. Alongside entanglement, studies also document particles moving through food webs, lodging in internal tissues, passing in feces, and altering behavior and reproduction across marine, terrestrial, insular, and urban settings (Figure 3). The species involved include invertebrates, fish, reptiles, birds, and mammals, several of them of ecological, conservation, or commercial importance.

Figure 3 - Conceptual synthesis of wildlife exposure pathways and ecological impacts of plastic pollution across marine, insular, terrestrial, and urban ecosystems in Ecuador. The figure summarizes documented interactions including ingestion, entanglement, trophic exposure and potential bioaccumulation-related pathways, fecal excretion, internal particle occurrence, nesting behavior alteration, and effects reported in selected Ecuadorian species
Figura 3 - Síntese conceitual das vias de exposição da vida selvagem e dos impactos ecológicos da poluição por plástico em ecossistemas marinhos, insulares, terrestres e urbanos no Equador. A figura resume as interações documentadas, incluindo ingestão, emaranhamento, exposição trófica e potenciais vias relacionadas à bioacumulação, excreção fecal, ocorrência interna de partículas, alteração no comportamento de nidificação e os efeitos relatados em espécies equatorianas selecionadas



Source: Prepared by the authors
Fonte: Elaborado pelos autores

In aquatic ecosystems, microplastic ingestion has been documented across different trophic levels. Studies from the Tropical Eastern Pacific and Ecuadorian coastal waters have reported microplastics in fish, mollusks, crustaceans, fiddler crabs, jumbo squid, and the Pacific fat sleeper, indicating exposure in both marine and freshwater-associated food webs (Cáceres-Farias et al., 2023; Isea-León et al., 2023; Rosas-Luis, 2016; Villegas et al., 2021). This issue is particularly relevant because direct filtration studies in Galapagos have shown that conventional plankton-net sampling may underestimate smaller and potentially more bioaccessible particles (Deakin et al., 2024). These findings suggest that wildlife exposure may be underestimated when smaller particle fractions are not adequately captured, with implications for food-web interactions and, potentially, for human dietary exposure.

In the Galapagos Marine Reserve, available evidence indicates that plastics are entering endemic and protected food webs. Microplastics have been detected in marine invertebrates, while Galapagos sea lions, giant tortoises, marine iguanas, green sea turtles, whale sharks, and other species have been identified as exposed or vulnerable through ingestion, fecal excretion, or entanglement (Jones et al., 2021; Moreira-Mendieta et al., 2023; Muñoz-Pérez et al., 2023; Ramon-Gomez et al., 2024). The higher occurrence of anthropogenic debris in giant tortoises from human-modified areas, compared with protected areas, further suggests that local land use and human activity influence exposure patterns (Ramon-Gomez et al., 2024). In this context, protected-area status does not fully prevent plastic exposure when local waste leakage, fisheries-related debris, and transboundary inputs interact within insular ecosystems.

Plastic exposure has also been documented in terrestrial wildlife and urban-associated fauna in continental Ecuador. Anthropogenic materials, mainly plastics, have been reported in regurgitated pellets from black vultures in Manabí, while plastic remains have been identified in fecal samples from Andean foxes in high-Andean ecosystems (Beltrán-Ortiz et al., 2017; Richard et al., 2021). In urban settings, domestic dogs have been proposed as bioindicators of shared environmental exposure, with microplastics reported in fecal samples (Martínez-Cepeda et al., 2026). These records support the relevance of a One Health perspective, since exposure in wildlife and companion animals may reflect broader contamination patterns in human-modified environments.

Evidence of internal exposure and behavioral alteration further broadens the ecological relevance of plastic pollution. Nanoplastic-sized particles have been reported in blood samples from horses in Guayas Province, suggesting systemic exposure in mammals and the need for further toxicological confirmation (Culcay-Troncozo et al., 2025). Plastic bags, synthetic fibers, and other anthropogenic materials have also been incorporated into bird nests, including those of house wrens and Darwin's finches, with reported cases of chick mortality associated with entanglement and ingestion in urban nests (Gutiérrez-Vannucchi & Sandoval, 2021; Harvey et al., 2021; León-E. et al., 2024). These cases suggest that the incorporation of plastics into nesting structures may represent a maladaptive response to human-altered environments, with potential consequences for reproductive success.

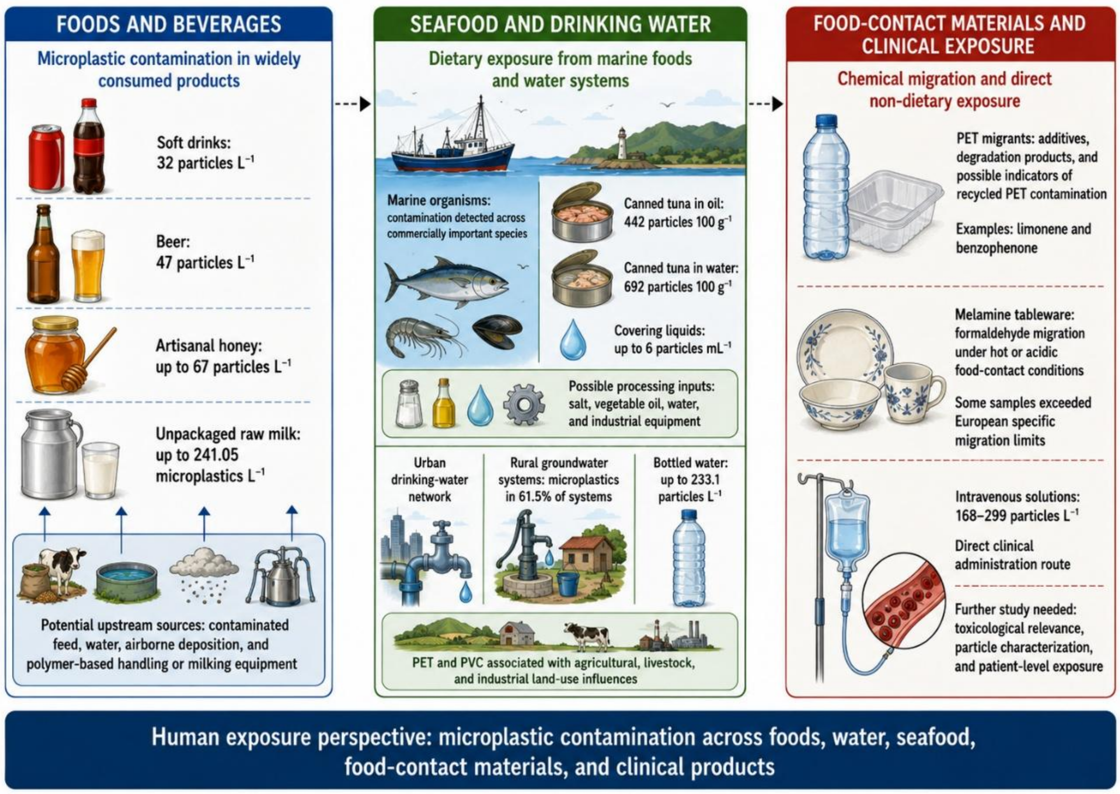
Taken as a whole, the evidence places wildlife exposure well beyond marine systems, reaching terrestrial, urban, and insular settings, even if its strength still varies from species to species, matrix to matrix, and study to study. Closing that gap will require monitoring that is both standardized and species-specific, and assessments that bring conservation biology, ecotoxicology, food safety, and One Health into a single frame.

3.3 Human exposure to microplastics through food, water, and clinical matrices

Evidence on human exposure to microplastics in Ecuador is considerably scarcer than the environmental and wildlife literature. The available studies nonetheless document plastic particles and polymer-derived chemicals along both dietary and non-dietary routes, ranging from everyday foods and drinking water to food-contact materials and intravenous solutions (Figure 4).

Figure 4 - Conceptual synthesis of human exposure pathways to microplastics and polymer-related contaminants in Ecuador. The figure summarizes documented contamination in foods and beverages, seafood, drinking water, bottled water, food-contact materials, and clinical matrices, including potential contributions from production chains, packaging degradation, processing inputs, chemical migration, and intravenous administration routes

Figura 4 - Síntese conceitual das vias de exposição humana a microplásticos e contaminantes relacionados a polímeros no Equador. A figura resume a contaminação documentada em alimentos e bebidas, frutos do mar, água potável, água engarrafada, materiais em contato com alimentos e matrizes clínicas, incluindo potenciais contribuições das cadeias de produção, degradação de embalagens, insumos de processamento, migração química e vias de administração intravenosa



Source: Prepared by the authors
Fonte: Elaborado pelos autores

In foods, beverages, seafood, and processed marine products, microplastic contamination has been reported in products of widespread consumption, including soft drinks, beer, honey, milk, commercially relevant marine organisms, and canned tuna. Diaz-Basantes et al. (2020) detected microplastics in Ecuadorian beverages and food products, while González-Puetate et al. (2025) reported microplastic particles in unpackaged raw milk. This suggests that contamination may occur before final packaging and may involve upstream sources such as feed, water, airborne deposition, or polymer-based equipment. In seafood and processed marine products, microplastics have been detected in commercially relevant marine organisms and canned tuna sold in Ecuador, indicating that exposure may be related both to environmental contamination of marine food webs and to contamination introduced during processing (Alfaro-Núñez et al., 2021; Diaz-Basantes et al., 2022).

Drinking water represents another relevant exposure pathway. Microplastics have been reported in urban drinking-water networks, rural community-managed groundwater systems, and commercial bottled water, with possible contributions from atmospheric deposition, glacier or snowmelt-related transport, agricultural and industrial land use, bottling processes, and packaging degradation (Arévalo Moscoso et al., 2024; Cobos et al., 2025; Paredes et al., 2019). These findings suggest that exposure through water is not limited to a single supply system, but may occur across municipal, rural, groundwater, and bottled-water sources.

Beyond particle ingestion, food-contact materials and intravenous solutions used in clinical settings raise additional concerns related to chemical migration and direct non-dietary exposure. Potential migrants have been identified in PET samples from the Ecuadorian market, including compounds associated with additives, degradation products, and possible indicators of recycled PET contamination (Marín-Morocho et al., 2021). Formaldehyde migration from melamine tableware has also been reported under conditions simulating contact with hot or acidic foods (García Ibarra et al., 2016). In addition, microplastics have been detected in intravenous solutions used in clinical settings, suggesting that exposure may also occur through direct clinical administration routes. However, further studies are needed to assess toxicological relevance, particle characterization, and patient-level exposure (Casella et al., 2025).

Taken together, the reviewed studies document four exposure routes in Ecuador: dietary, water-borne, packaging-related, and clinical. Inhalation, the route most frequently reported in the international literature, was not examined in any of the included studies, and no study assessed health outcomes in exposed populations. Coverage is uneven across the documented routes, and differences in sampling protocols, particle-size criteria, and polymer identification methods limit comparison between studies. Progress will depend less on new isolated reports than on shared ground rules: harmonized protocols and particle-size criteria, confirmation of the polymers involved, strict contamination control during sampling, and risk frameworks that read food safety, water quality, chemical migration, and clinical exposure together rather than apart.

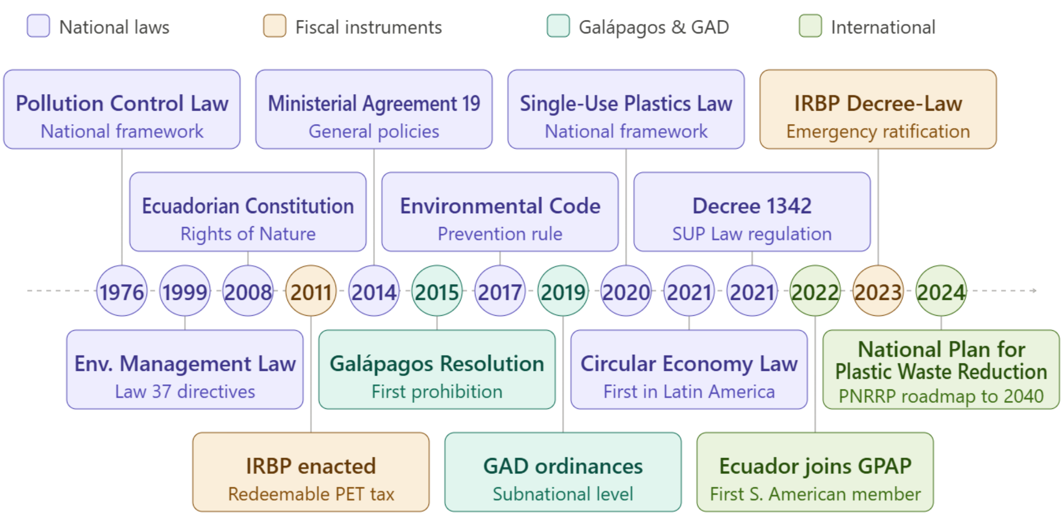
3.4 Regulatory evolution and implementation gaps in Ecuador's plastic pollution governance

Ecuador's regulatory framework on plastic pollution has evolved gradually over the last five decades. Early environmental legislation already recognized the need to regulate the disposal of non-biodegradable waste, including plastics (República del Ecuador, 1976), while later policy developments incorporated recycling and economic incentives as part of broader environmental management strategies (República del Ecuador, 1999). This framework gained a stronger constitutional basis in 2008, when the Constitution recognized the right to a healthy environment and the rights of Nature (Asamblea Constituyente, 2008).

More specific instruments were later incorporated into the national framework. These include Ministerial Agreement No. 19 of 2014, the Organic Environmental Code of 2017, the 2020 single-use plastics law and its regulation, the Inclusive Circular Economy Law of 2021, and recent extended producer responsibility instruments for specific plastic waste streams, including agricultural inputs (Asamblea Nacional del Ecuador, 2017, 2020, 2021; Ministerio del Ambiente, 2014; Ministerio del Ambiente Agua y Transición Ecológica, 2024b; Presidencia de la República del Ecuador, 2021). Fiscal measures have also contributed to this framework, particularly the excise tax on plastic bags and the redeemable tax on non-returnable plastic bottles, both designed to discourage consumption and promote recovery or recycling (Presidencia de la República del Ecuador, 2010; Presidencia del Ecuador, 2011; Servicio de Rentas Internas (SRI), 2020). Taken together, these instruments show that Ecuador has built a multi-layered regulatory framework for plastic pollution governance (Figure 5).

Figure 5 - Timeline of the evolution of Ecuador's legal and policy framework on plastic pollution (1976–2024). Milestones are color-coded by category: national framework laws (purple), fiscal instruments (amber), Galapagos and decentralized GAD ordinances (teal), and international strategic commitments (green). The timeline integrates fourteen key instruments, from the 1976 Pollution Control Law to the 2024 national roadmap for the reduction of plastic pollution

Figura 5 - Linha do tempo da evolução do arcabouço legal e de políticas do Equador sobre poluição por plásticos (1976–2024). Os marcos são codificados por cores por categoria: leis-quadro nacionais (roxo), instrumentos fiscais (âmbar), ordenanças de Galápagos e dos GADs descentralizados (azul-petróleo), e compromissos estratégicos internacionais (verde). A linha do tempo integra quatorze instrumentos fundamentais, desde a Lei de Controle de Poluição de 1976 até o roteiro nacional para a redução da poluição por plásticos, de 2024



Source: Prepared by the authors
Fonte: Elaborado pelos autores

Subnational regulation has also played an important role. The Galapagos Islands acted as an early regulatory laboratory through restrictions on plastic bags, expanded polystyrene, and other single-use plastic categories (Consejo de Gobierno del Régimen Especial de Galápagos, 2015). Municipal and provincial instruments in Quito, Portoviejo, and Manabí later incorporated measures such as recycler inclusion, recycled-content targets, restrictions on expanded polystyrene, biodegradability requirements, and technical exceptions for food safety-sensitive value chains (Concejo Metropolitano de Quito, 2019; Gobierno Autónomo Descentralizado Municipal del Cantón Portoviejo, 2018; Gobierno Provincial de Manabí, 2018). These experiences show that decentralized governments can promote regulatory innovation, although they also reveal the difficulty of coordinating national and local implementation.

Despite this regulatory progress, important implementation gaps remain. National statistics indicate that 84.2% of solid waste is collected without source separation and that 44.8% is disposed of in open dumps or emergency disposal cells (Instituto Nacional de Estadística y Censos, 2024). The recovery of materials such as PET is still constrained by informality, limited local processing capacity, and market barriers, which in some cases has led to dependence on transboundary plastic imports to meet recycled-content requirements (Hidalgo-Crespo et al., 2024). Other barriers include insufficient fiscal incentives, weak technical guidelines, limited coordination between national and local instruments, and policy approaches still focused mainly on end-of-life management rather than upstream redesign, product substitution, and circular value-chain transformation

(Ochoa-Herrera et al., 2025; Portilla-Jiménez, 2022; Rodríguez-Meza et al., 2025).

Ecuador has also moved toward broader international engagement and long-term planning. In 2022, the country joined the Global Plastic Action Partnership, becoming the first South American member of this initiative (Tedeneke, 2022). In 2024, the government presented a national roadmap for reducing the impacts of plastic pollution, structured around source reduction, systemic infrastructure, inclusive recycling, marine-coastal and insular ecosystem protection, and scientific data sovereignty. The roadmap set long-term goals of reducing plastic pollution by 60% and reaching 45% circularity in the plastic value chain by 2040 (Ministerio del Ambiente Agua y Transición Ecológica, 2024a). However, the effectiveness of these instruments will depend on implementation capacity, monitoring, financing, and coordination across scales.

Ecuador has legislated ahead of its capacity to implement. Nearly five decades of instruments, from the 1976 Pollution Control Law to single-use plastic bans and circular economy legislation, have produced an ambitious framework on paper; what lags behind is the machinery to enforce it, separate waste at source, and recover materials at scale. Given how plastic moves across the region's coasts and rivers, closing that gap depends on regional cooperation as much as on national capacity.

3.5 Circular economy responses, technological strategies, and research priorities

The reviewed studies document mitigation responses distributed across four areas: territorial waste management and prevention; industrial recycling and material applications; food-industry contamination control; and future research priorities. Across these areas, the identified responses concentrate on recovering and revalorizing plastics already in circulation, while upstream strategies such as product redesign, reuse, and material substitution appear only marginally. The distribution of the available evidence therefore mirrors the end-of-life orientation identified in the regulatory framework.

At the municipal and territorial levels, the transition toward a circular economy depends on effective source separation, collection systems, wastewater treatment, and waste-management infrastructure. Without adequate segregation at source, plastics are frequently mixed with wet organic waste, reducing the quality of recyclable materials and limiting biological recovery strategies (Saeteros-Hernández et al., 2025). In freshwater, coastal, and marine environments, mitigation also requires coordinated actions to address untreated discharges, fisheries-related debris, riverine inputs, and accumulation hotspots (Donoso & Rios-Touma, 2020; Figueroa-Pico et al., 2016; Gaibor et al., 2020; Lucas-Solis et al., 2021). Direct monitoring tools, physical barriers in rivers, oceanographic simulations, and citizen science can help identify retention areas, improve cleanup efficiency, and support long-term monitoring, particularly in coastal and insular environments such as Galapagos (Jones et al., 2021, 2022; Pinheiro et al., 2025; Ypma et al., 2022). These monitoring and cleanup strategies would also benefit from environmental education efforts that move beyond recycling-centered messages to incorporate prevention, reduction, responsible consumption, and source separation.

Ecuadorian research has also produced applied technological responses that are relevant to circular economy transitions. At industrial and pilot scales, studies have evaluated chemical and thermomechanical recycling, recovery of polystyrene, polyolefins, and polyvinyl chloride (PVC), energy recovery through pyrolysis, smart collection systems, and decentralized manufacturing strategies (Campuzano et al., 2024; Chango et al., 2015; Hidalgo Aguilera et al., 2017; Hidalgo-Crespo et al., 2020; Inca, Aldás, et al., 2016; Inca, Salguero, et al., 2016; Mancheno et al., 2016; Saltos et al., 2015). A favourable scientific opinion issued by the European Food Safety Authority on a "bottle-to-bottle" PET recycling process operated in Ecuador confirmed that recycled material obtained under specified conditions is suitable for food-contact applications (Lambré et al., 2022). Beyond its technical significance, this assessment shows that Ecuadorian recycling operations can meet international food-safety requirements when process control and input quality are adequately documented.

Within this same area, recycled plastics have also been explored in construction and environmental engineering applications. Studies have evaluated the incorporation of recycled PET, recycled high-density polyethylene (rHDPE), PVC, and other polymers into plastic wood, lightweight masonry, architectural panels, paving blocks, and asphalt mixtures, sometimes combined with local biomass such as rice husk or bamboo powder (Baykara et al., 2025; Bernal Jiménez, 2024; Chara Moreira et al., 2023; Duenas Barberan & Vera Rivera, 2017; Ortiz et al., 2024; Ortiz-Viñán & Herrera, 2026; Sangucho Barros et al., 2023). In wastewater treatment, PET fragments have been tested as bacterial support media, while ultrafiltration has been proposed as a potential technology for microplastic removal in drinking-water treatment (Cuartucci, 2020; Muñoz, Fuentes, et al., 2016; Muñoz, Reina, et al., 2016). Bio-based and biological alternatives, including PLA-abaca composites, sugarcane-derived films, and black soldier fly larvae for organic waste management in the presence of microplastics, show that innovation in Ecuador is not limited to recycling, but also includes material substitution and biological processing (Layedra et al., 2015; Pazmiño et al., 2023; Riofrio et al., 2022).

The evidence also points to the need for stronger contamination-control measures in food and beverage production chains. Studies on beverages, honey, milk, and canned tuna suggest that microplastic contamination may arise from packaging, upstream production, airborne deposition, water inputs, ingredients, and contact with industrial equipment (Diaz-Basantes et al., 2020, 2022; González-Puetate et al., 2025). Food-industry quality and safety systems should therefore begin to incorporate particle contamination, polymer identification, airborne controls, raw-material assessment, and processing-related sources. This does not imply that current products are necessarily unsafe, but it does indicate that microplastic monitoring should be progressively integrated into quality and safety frameworks.

Future research should concentrate on four fronts. The first is ecological: bioaccumulation, biomagnification, and trophic transfer, especially in top predators and endemic species, where sentinel organisms could anchor biomarker-based assessments of oxidative stress, inflammation, or contaminant co-exposure (Moreira-Mendieta et al., 2023; Villegas et al., 2021). The second is the tracing of sources and pathways, through hydrodynamic modeling of ocean transport (van Sebille et al., 2019), assessment of riverine inputs from untreated urban discharges (Donoso & Rios-Touma, 2020), the use of resident biota as indicators of retention in estuarine and wetland systems (Isea-León et al., 2023), and monitoring of atmospheric deposition and high-altitude transport (Cabrera et al., 2022). The third is methodological: harmonized sampling and analytical protocols, quality assurance, polymer confirmation by spectroscopic or thermal techniques, and risk-assessment frameworks, without which environmental data cannot be reliably linked to ecological effects, human exposure, circular-economy strategies, or regulatory decisions. A fourth gap cuts across these fronts: the scarcity of research on prevention, redesign, and substitution means that upstream policy targets currently lack the technical evidence base that end-of-life measures already have.

3.6 Study limitations

Several limitations should be considered when interpreting the findings of this review. First, the included studies were highly heterogeneous in terms of sampling design, environmental matrices, particle-size thresholds, analytical methods, polymer-identification techniques, and units of reporting. This heterogeneity limited direct quantitative comparisons across studies and did not allow a meta-analysis to be performed. Second, the spatial distribution of the evidence was uneven. Coastal and insular environments have received greater research attention, while some inland, terrestrial, Amazonian, high-altitude, and atmospheric-deposition matrices remain less studied. Third, although the search included international and regional databases, relevant grey literature, technical reports, theses, or unpublished monitoring data may not have been captured. Fourth, consistent with the scoping review methodology, the included studies were not subjected to a formal risk-of-bias or quality appraisal. The review therefore maps the extent and nature of the available evidence without weighing the methodological strength of individual studies.

The documentary legal analysis also has limitations. It allowed the reconstruction of Ecuador's legal, regulatory, and policy evolution on plastic pollution, but it did not provide a systematic evaluation of compliance, enforcement capacity, budget allocation, or the measurable environmental effectiveness of each instrument. Therefore, the implementation gaps identified in this review should be interpreted as evidence-informed patterns based on the available literature and official information, rather than as a comprehensive legal-impact assessment.

4. Conclusions

This scoping review, drawing on 109 studies and complemented by an analysis of Ecuador's legal and policy framework, supports three main conclusions about plastic and microplastic pollution in the country.

The first is that the problem is systemic rather than localized. Plastic has been documented not only along the coast and in Galapagos, but inland as well, from Andean rivers and coastal wetlands to Amazonian sediments and the snow of high-altitude glaciers. What once seemed a marine issue is better understood as a single, connected phenomenon, in which waste generated on land travels through rivers, ocean currents, fisheries, and even the atmosphere before settling in the most remote corners of the country.

The second concerns exposure, which extends well beyond ecosystems. The evidence shows plastics reaching Ecuadorian wildlife across marine, terrestrial, urban, and insular settings, and it is beginning to trace their arrival in people, through what they eat and drink and, more unexpectedly, through clinical routes such as intravenous solutions. This human dimension is still based on few studies and does not yet permit a full assessment of health risk. But it is enough to justify treating microplastics as a food-safety and water-quality concern now, rather than waiting for the evidence base to mature.

The third concerns governance. Over nearly five decades, Ecuador has built an ambitious regulatory architecture, from the 1976 Pollution Control Law to constitutional rights of Nature, single-use plastic bans, and circular economy legislation, and has entered international cooperation frameworks on plastic action. The decisive gaps are no longer legislative but operational: separating waste at source, building recycling and treatment infrastructure, and coordinating national ambition with local enforcement. Because plastic crosses borders through shared coasts and currents, closing those gaps will depend as much on regional cooperation and methodological standardization as on domestic resolve.

Taken together, these conclusions describe a country that has named the problem in law but has not yet built the capacity to act on it, and that has documented contamination far more thoroughly than it has studied its consequences. Three priorities follow from the evidence mapped here. The first is methodological: without harmonized sampling protocols, particle-size criteria, and polymer confirmation by spectroscopic or thermal techniques, environmental data cannot be linked to ecological effects, human exposure, or regulatory decisions. The second is epidemiological: no study included in this review examined health outcomes in exposed populations, which leaves food-safety and water-quality policy without a national evidence base. The third is operational: source separation conditions the performance of every downstream response, from recycling quality to material recovery, and remains the principal bottleneck of the Ecuadorian system. Addressing these priorities requires research and policy oriented toward prevention and redesign, not only toward recovering plastics already in circulation.

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