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ORIGINAL

Bibliometric analysis of bioremediation of hydrocarbon-contaminated soils in Ecuador 2019-2025

Análisis bibliométrico de biorremediación de suelos contaminados con hidrocarburos en Ecuador 2019-2025

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ABSTRACT

Introduction: biotechnology has developed techniques such as bioremediation, which seeks to restore contaminated soils through the use of microorganisms, plants, or organic amendments, reducing the concentration of contaminants without generating toxic secondary waste. It is necessary to compile, organize, and analyze research on bioremediation of hydrocarbon-contaminated soils in Ecuador.
Objective: to analyze the current state of scientific production on bioremediation of hydrocarbon-contaminated soils in Ecuador during the period 2019-2025, through a bibliometric study.
Method: scientific studies from the Scopus database were compiled and processed with the help of Biblioshiny (RDtudio) and Google Colab for analysis and visualization of key indicators: techniques, organisms, bioremediation strategies, publications by year, most cited studies, national affiliations, international collaborations, co-authorship networks, and journal quartiles.
Results: they show sustained growth in scientific production, with a significant peak in 2022 and 2023. The most commonly used bioremediation techniques were bioaugmentation, phytoremediation, and the use of native microorganisms, with the genus Pseudomonas predominating, reflecting a preference for sustainable methodologies adapted to local conditions. The main national affiliations are public universities such as the University of the Armed Forces, the National University of Chimborazo, and the Technical University of Manabí. International collaborations, although few, are found in countries such as Mexico, Spain, Italy, Brazil, and Venezuela. Despite the progress, most research is published in low-quartile journals, which limits its international visibility.
Conclusions: it is important to strengthen national and international collaboration networks and expand bibliometric analysis to include non-indexed documentary sources to achieve a more comprehensive view of scientific development in this area in the Ecuadorian context.

Keywords: Bioremediation; Hydrocarbons; Contaminated Soils; Ecuador; Scopus.

RESUMEN

Introducción: la biotecnología ha desarrollado técnicas como la biorremediación, que busca restaurar suelos contaminados mediante el uso de microorganismos, plantas o enmiendas orgánicas, reduciendo la concentración de contaminantes sin generar residuos secundarios tóxicos. Es necesario recopiar, ordenar y analizar las investigaciones sobre biorremediación de suelos contaminados con hidrocarburos en Ecuador.
Objetivo: analizar el estado actual de la producción científica sobre biorremediación de suelos contaminados con hidrocarburos en Ecuador durante el periodo 2019-2025, mediante un estudio bibliométrico.

Método: se recopiló y procesó estudios científicos de la base de datos Scopus, con ayuda de Biblioshiny (RDtudio) y Google Colab para análisis y visualización de indicadores claves: técnicas, organismos, estrategias de biorremediación, publicaciones por año, estudios más citados, afiliaciones nacionales, cooperaciones internacionales, redes de coactarías y cuartiles de las revistas.
Resultados: presentan un crecimiento sostenible en la producción científica, con un pico significativo en los años 2022 y 2023. Las técnicas de biorremediación más empleadas fueron bioaumentación, fitorremediación y uso de microorganismos autóctonos predominando el género Pseudomonas, reflejando una preferencia por metodologías sostenibles y adaptadas a condiciones locales. Las principales afiliaciones nacionales son universidades públicas como la Universidad de las Fuerzas Armadas, Universidad Nacional de Chimborazo, Universidad Técnica de Manabí. Las cooperaciones Internacionales, aunque son pocas, pero se encuentra países como México, España, Italia, Brasil y Venezuela. A pesar del avance, la mayoría de las investigaciones se publican en revistas de cuartiles bajos, lo que limita su visibilidad internacional.
Conclusiones: es importante fortalecer redes de colaboraciones nacionales e internacionales y ampliar el análisis bibliométrico hacia fuentes documentales no indexadas para lograr una visión más integral del desarrollo científico en esta área en contexto ecuatoriano.

Palabras claves: Biorremediación; Hidrocarburos; Suelos Contaminados; Ecuador; Scopus.

INTRODUCTION

Soil is considered a non-renewable resource and performs multiple essential functions that benefit all ecosystems and human well-being. It acts as a habitat for organisms, a genetic reserve, a carbon sink, a natural storage system, and a filter for substances. It is the basis for the production of food, biomass, and raw materials necessary for various economic activities.[1]

However, the extraction and transport of hydrocarbons, carried out daily around the world, pose a significant environmental risk, with accidental spills being one of the leading causes of severe soil degradation.[2] In megadiverse countries, where the economy depends heavily on oil activity, these events generate critical ecological impacts, especially in sensitive regions such as the Amazon.[3]

In addition to ecological impacts, the presence of hydrocarbons in the soil poses a risk to public health, as crude oil contains organic and inorganic compounds with toxic effects. Among these are polycyclic aromatic hydrocarbons (PAHs), known for their genotoxic and carcinogenic properties, which can alter liver and kidney function in both humans and animals.[4]

In response to this situation, biotechnology has developed techniques such as bioremediation, which seeks to restore contaminated soils through the use of microorganisms, plants, or organic amendments, reducing the concentration of contaminants without generating toxic secondary residues.[5]

In Ecuador, approaches such as the use of biochar from agro-industrial waste, such as rice husks, and the use of native bacteria capable of tolerating and degrading hydrocarbon-derived compounds have demonstrated the potential of bioremediation.[5] At the Termoesmeraldas power plant in Ecuador, the effectiveness of techniques such as bioaugmentation was demonstrated through the use of Pseudomonas aeruginosa, a bacterium originally isolated from an oil shale mine in Riutort, Spain. These bacteria, recognized for their ability to degrade petroleum-derived compounds even in adverse environmental conditions, were subsequently used on soils contaminated with oily sludge collected from controlled spill sites in La Libertad, on the southwestern coast of Ecuador. The results demonstrated the potential of adapted microbial consortia to be successfully transferred to tropical contexts through the use of advanced monitoring and control technologies.[6]

Although significant studies on the bioremediation of hydrocarbon-contaminated soils have been conducted in Ecuador, their number remains very limited compared to global scientific output.[5] This gap highlights the need to analyze the current state of Ecuadorian research, identify thematic gaps, the most productive authors, institutional collaborations, and the predominant methodologies used. Thus, this study aims to conduct a bibliometric analysis with a descriptive comparative approach that allows for the characterization and discussion of the evolution of scientific knowledge in this field in the country, in contrast to Latin American and global trends.

Research problem

The issue of bioremediation of soils contaminated with petroleum hydrocarbons is currently a clear environmental challenge for Ecuador. Due to the country's economic dependence on oil exploitation, evidence of hydrocarbon spills is common, particularly in Amazonian regions. This ecological problem affects biodiversity and natural resources, which are sources of subsistence for many local communities. In addition to posing ecological challenges, this environmental problem also necessitates social and economic solutions to mitigate the high costs associated with ecological and environmental restoration.

Although significant steps have been taken in the development of bioremediation research, there is still little consolidated information that allows for the clear identification of trends, predominant approaches, and knowledge gaps in this field within the Ecuadorian context. In response to this need, bibliometric analysis is a valuable tool for systematizing and evaluating the state of scientific production. Through this methodology, it is possible to understand how studies on bioremediation in hydrocarbon-contaminated soils have evolved, what techniques and organisms have been used, and which regions of the country have been most affected or least addressed in terms of research.

Ecuador, a country with remarkable biological diversity and unique ecological conditions, urgently requires sustainable remediation strategies tailored to its local realities. However, much of the existing research fails to contextualize its findings adequately or is scattered, making it challenging to apply for informed decision-making and the design of practical solutions. For this reason, an in-depth bibliometric analysis is needed to compile, organize, and analyze research on the bioremediation of hydrocarbon-contaminated soils in Ecuador. This analysis will not only provide insight into the current state of knowledge in the country but also guide future research, public policies, and concrete actions to address this environmental problem in a more comprehensive and contextualized manner.

This study is limited to the period from 2019 to June 6, 2025. Only scientific publications indexed in the Scopus database that refer to the bioremediation of hydrocarbon-contaminated soils in the Latin American context and with a focus mainly on Ecuador are considered.

From a conceptual point of view, this study will focus on identifying the techniques used, the organisms investigated, and academic collaborations. It will also analyze the socioeconomic and environmental conditions associated with the application of bioremediation strategies. Research related to other types of pollution or technologies other than the biological approach is excluded.

Soil contamination by hydrocarbons represents a significant environmental challenge for countries with oil activity, such as Ecuador. Although this is an urgent problem, the lack of national scientific production related to the bioremediation of these soils is striking. In this context, the present study offers a novel perspective by focusing on a bibliometric analysis of existing scientific contributions on bioremediation, especially those developed within Ecuadorian territory. To this end, the Scopus database was utilized, which is internationally recognized for its rigor and for hosting high-quality, scientifically relevant publications. Through this analysis, it is possible to identify the most widely used techniques, the organisms applied, the gaps in knowledge, and the scientific collaboration networks that have set the standard in this field. This study is designed to directly benefit researchers, universities, research centers, environmental entities, and decision-makers involved in the management of contaminated soils. By systematically highlighting national scientific production, the aim is to contribute to the strengthening of research policies, prioritize key issues, and more strategically direct funding toward studies with greater local relevance. The results serve as a basis for the development of educational and curricular strategies. By offering a clear overview of the areas of greatest need and impact, this work seeks not only to systematize current knowledge but also to draw up an updated map that facilitates decision-making in both the academic sphere and environmental management, promoting practical and sustainable solutions to the challenges facing the country.

General objective

To analyze the current state of scientific production on the bioremediation of hydrocarbon-contaminated soils in Ecuador (2019-2025) through a bibliometric study based on the Scopus database, identifying thematic trends, applied methodologies, collaboration networks, and scientific impact.

METHOD

This study presents a quantitative approach with the respective production support. Based on the fact that the data present key analyses, measurements, and verifiable evidence of the evolution of scientific production on the bioremediation of hydrocarbon-contaminated soils in Ecuador. The appropriate design is mentioned because it seeks to analyze key aspects such as the number of publications, the bioremediation techniques used in each of the studies, as well as the organisms (bacteria, plants, biological bioindicators, among others), the collaboration networks between authors, national affiliations, international cooperation, and the sources in which the scientific research was indexed.

The study was designed as a bibliometric analysis, supported by a systematic review, following the guidelines established by the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statement. This ensures that the process of collecting and analyzing information has been carried out with transparency, methodological rigor, and the possibility of being replicated.

To this end, theoretical and practical tools were combined. The theoretical methods helped to define the principal thematic axes of the study and the criteria for including or excluding publications, while the empirical methods allowed for the collection, filtering, and analysis of the available bibliographic information.

As a result, a refined database was constructed with studies published between 2019 and 2025, which made it possible to interpret scientific development in this field quantitatively: most active authors, participating institutions and countries, collaboration networks, most frequent keywords, thematic trends, annual growth in publications, and impact measured in number of citations.

A descriptive quantitative method was used, based on bibliometric techniques that allowed for the analysis of scientific production patterns, collaboration networks, thematic trends, and impact levels of publications on the bioremediation of contaminated soils. The approach was non-experimental and documentary, using tools such as Bibliometrix (R) and VOSviewer for the analysis of metadata exported from Scopus.

Figure 1. Methodological steps for data search, collection, and analysis

The population consisted of all scientific publications indexed in the Scopus database dealing with bioremediation of hydrocarbon-contaminated soils, filtered using keywords for Latin America

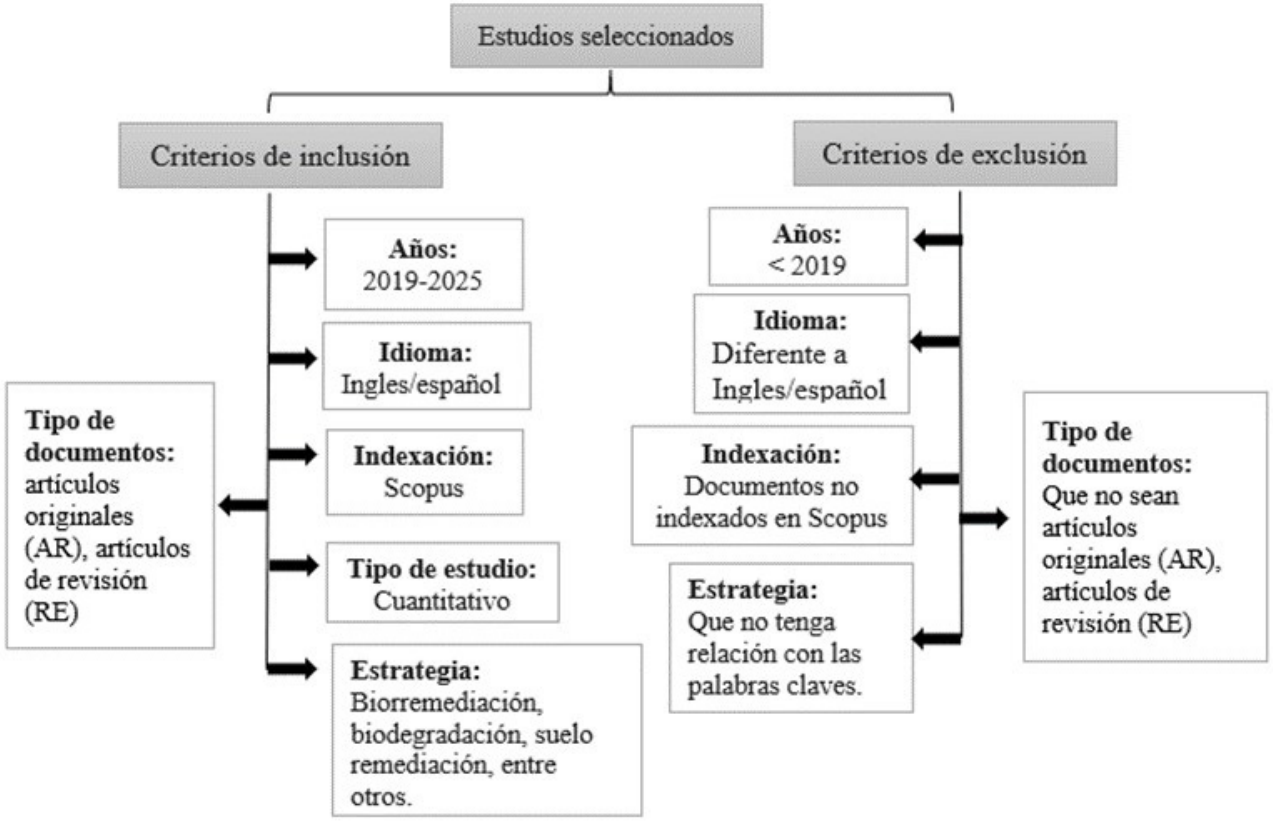

Figure 2. Inclusion and exclusion criteria applied for the selection of studies

TITLE-ABS-KEY (((“bioremediation” OR “biodegradation” OR “remediation”) AND (“oil” OR “hydrocarbons” OR “petroleum”) AND (“soil” OR “land”)) AND (“Latin America” OR “South America” OR “Mexico” OR “Brazil” OR “Colombia” OR “Argentina” OR “Chile” OR “Peru” OR “Ecuador” OR “Venezuela” OR “Uruguay” OR “Paraguay” OR “Bolivia” OR “Guyana” OR “Costa Rica” OR “El Salvador” OR “Guatemala” OR “Honduras” OR “Nicaragua” OR “Panama”)) AND PUBYEAR > 2018 AND PUBYEAR > 2018 AND PUBYEAR < 2026 AND (LIMIT-TO (DOCTYPE,”ar”) OR LIMIT-TO (DOCTYPE,”re”))

And for Ecuador without initial restrictions on year, document type, or access.

TITLE-ABS-KEY ((“bioremediation” OR “biodegradation” OR “soil remediation” OR “environmental cleanup”) AND (“oil” OR “hydrocarbons” OR “petroleum” OR “contamination” OR “pollution”) AND (“soil”)) AND (TITLE-ABS-KEY (“Ecuador” OR “Amazon region” OR “Oriente Basin”)) AND PUBYEAR > 2018.

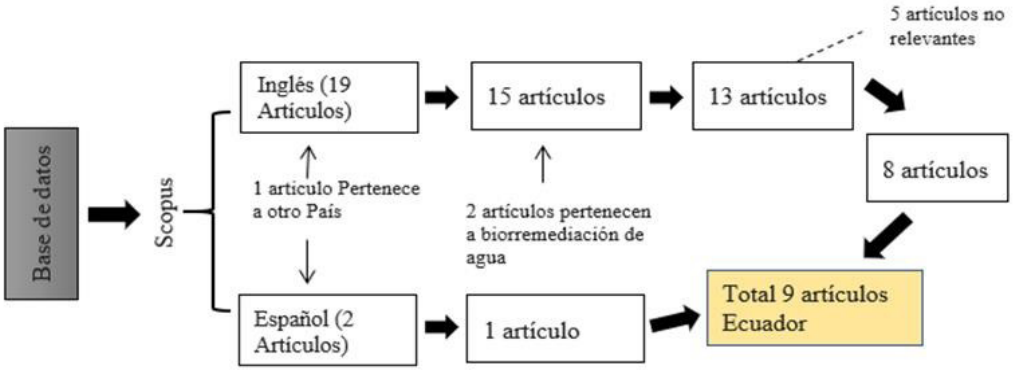

Figure 3. Outline of the data collection process

The bibliographic data were processed in five phases, illustrated in figure 4.

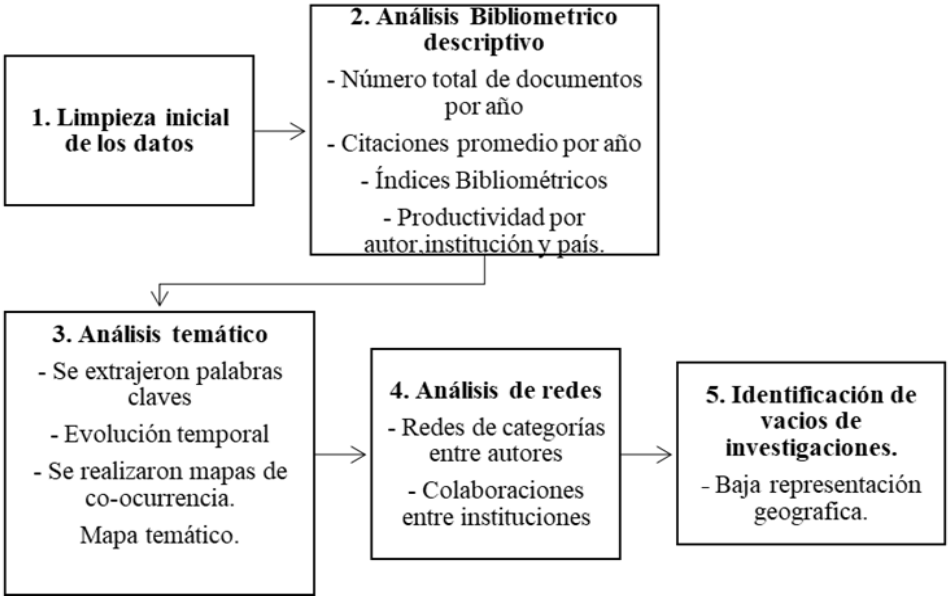

Figure 4. Statistical data processing

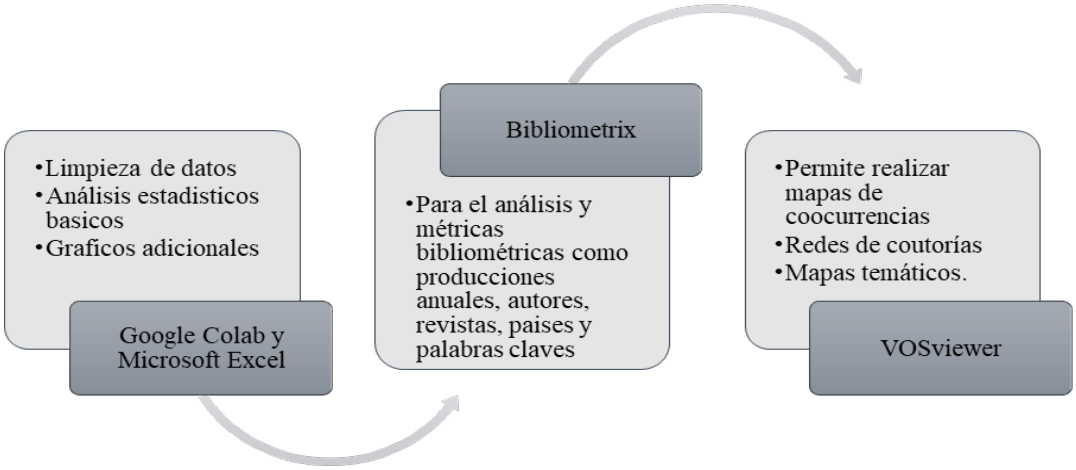

Figure 5. Main tools used

A purposive sample of articles was defined based on specific exclusion criteria and exclusion documents (figure 2).

The selection process was carried out using the advanced search in Scopus (figure 3), initially obtaining 21 records, of which 9 were selected after applying the PRISMA protocol (elimination of duplicates, review of thematic relevance, and verification of open access).

RESULTS

The results of the bibliometric analysis are presented, focusing on the scientific production related to the bioremediation of soils contaminated with hydrocarbons between 2019 and June 2025, with particular emphasis on the context of Ecuador. The results are presented in accordance with the specific objectives of the research, which are represented in tables and figures generated with tools such as Bibliometrix (R/Biblioshiny), Google Colab, Microsoft Excel, and VOSviewer.

A review of scientific output in Ecuador reveals that the primary topics related to soil contamination by hydrocarbons focus on the development of bioremediation techniques tailored to local ecological contexts, with a particular emphasis on the Amazon region. The methodologies most commonly applied in the studies reviewed are bioaugmentation and biostimulation, mainly using native bacteria and plant species. This technical orientation suggests a preference for sustainable, low-cost solutions with high ecological compatibility.

In addition, innovative proposals have been documented, such as the use of bioindicators for functional soil monitoring, as well as the incorporation of advanced technological tools, including spectroscopy, which allow processes to be evaluated without resorting to destructive methods. These strategies not only demonstrate methodological progress but also reflect a direct response to the particular socio-environmental conditions of Ecuador Socio-environmental conditions of Ecuador.

From a territorial perspective, geographical analysis indicates that studies are distributed relatively evenly among several cities in the country, with a higher concentration in Esmeraldas and representative areas of the Amazon. Although there is no marked difference between regions, this dispersion suggests diverse academic participation at the national level, reinforcing the multisectoral interest in addressing the problem of hydrocarbon contamination from a biotechnological and contextualized perspective.

Table 1 compiles some of the most representative studies on the bioremediation of hydrocarbon-contaminated soils conducted in Ecuador. These studies were selected for their technical relevance, local applicability, and contribution to the understanding of strategies adapted to the country's soil and climate conditions. As can be seen, the most widely used techniques are bioaugmentation and biostimulation, applied in different regions of the country, mainly in Amazonian areas. Specific sub-techniques are also evident, such as the use of organic amendments or bacterial consortia, which reinforce the focus on sustainable, low-cost solutions adapted to the ecological environment. Table 1 includes information on the authors, the location of the study, the technique applied, and the specific materials or approaches used in each case.

Table 1. Techniques used in bioremediation studies in Ecuador

Title	Authors	Study location	Techniques	Subtechnique
Oil Palm Bagasse as a Treatment for Soils Contaminated with Total Petroleum Hydrocarbons.	Orejuela-Romero et al.[7]	Francisco de Orellana	Biostimulation.	Organic amendments (oil palm bagasse).
Bioremediation of Soil Sample Contaminated with Crude Oil using rice husk-based biocarbon (Oryza Sativa)	Camacho et al.[3]	Esmeraldas	Biostimulation.	Amendment with biocarbon (rice husks)
Hydrocarbon tolerance evaluation of the microbiota associated with the Roystonea oleracea palm from Santay Island (Ecuador)	Andrade et al.[5]	Santay Island	Isolation and evaluation of microbial tolerance.	Biosurfactants.
Response of dung beetle diversity to remediation of soil ecosystems in the Ecuadorian Amazon.	Pozo-Rivera et al.[2]	Sucumbíos and Orellana.	Bioindicators.	Coprophagous beetles.
Metagenomic analysis of the microbial community at the Riutort oil shale mine (NE Spain): Potential applications in bioremediation and enhanced oil recovery.	González-Toril et al.[6]	Spain and Ecuador/ Libertada	Bioaugmentation	Microbial isolation
Bacterial selection of the Pseudomonas genus with the capacity to treat water and contaminated soils.	Escudero-López et al.[8]	Sucumbíos/Orellana	*In situ* microbial bioremediation	Bioaugmentation with native strains

Reduction of the soil environmental impact caused by the presence of total petroleum hydrocarbons (TPH) by using Pseudomonas sp.	Páliz et al.[9]	Orellana - AqLab Laboratory.	Bioaugmentation.	Native bacteria
Bioremediation of soil contaminated with hydrocarbons based on bacteria used as bioproducts.	García et al.[10]	Campo Sacha	Bioaugmentation.	Isolation, selection, and application of native bacteria
Assessing Bioremediation of Soils Polluted with Fuel Oil 6 by means of diffuse reflectance spectroscopy.	V. J. García et al.[11]	Esmeraldas	Bioaugmentation + spectroscopy.	Diffuse reference (Vis-NIR)

In order to identify the most recurrent approaches in the national scientific literature on bioremediation of hydrocarbon-contaminated soils, a frequency analysis of the technical terms used was carried out. Table 2 presents the terms with the highest frequency of occurrence, ordered in descending order, which facilitates the identification of thematic patterns and methodological priorities.

Table 2. Frequencies of technical terms related to bioremediation techniques

Terms	Frequency	Percentage
Biodegradation, Bioremediation, Hydrocarbons, and Soil Remediation	3	5
Biosurfactants, Total Petroleum Hydrocarbons, Degradation, Ecuador, Soil Pollution	2	3
Bacterium, Bagasse, Biotechnology, Bioaugmentation, Aerobic Bacteria	1	2

A word cloud was generated using the Biblioshiny program based on the most frequently mentioned terms in the studies analyzed. This presentation allows the comparative relevance of each term to be visualized, based on its appearance: the larger the font size, the greater the number of mentions, which is directly proportional. Figure 6 shows this word cloud, which highlights concepts such as *hydrocarbons, biodegradation, bioremediation, soil pollution, and Ecuador,* demonstrating its centrality in bioremediation research in the Ecuadorian context.

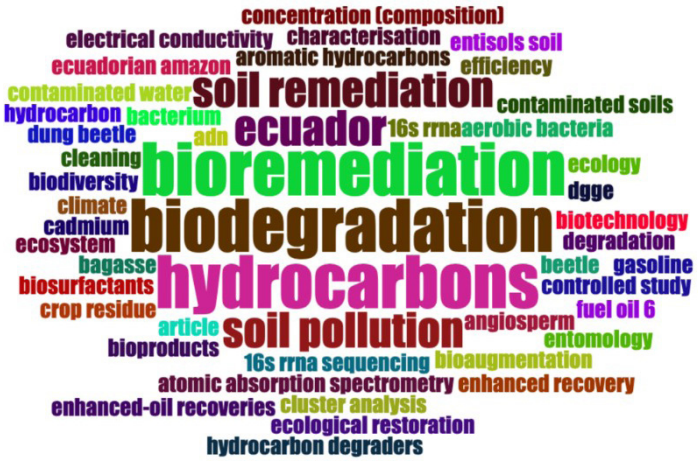

Figure 6. Word cloud of the most frequent bioremediation techniques in scientific studies in Ecuador from 2019 to 2025

In order to identify the biological organisms most frequently used in Ecuadorian studies of bioremediation of soil contaminated with hydrocarbons, table 3 was created, classifying the organisms used in each study.

Figure 7 shows the distribution of the types of organisms used in bioremediation studies conducted in Ecuador and international collaborations. There is a clear predominance of bacteria, which is in line with their proven efficiency in hydrocarbon degradation. To a lesser extent, the use of plants, such as rice (*Oryza sativa)* and palm (*Elaeis guineensis)* species, in phytoremediation approaches is reported. Finally, an isolated study uses insects from the *Scarabaeinae* subfamily, suggesting new exploratory avenues in the field of remediation.

Table 3. Organisms used in bioremediation studies in Ecuador

Studies	Study location	Organisms
Orejuela-Romero et al.[7]	Francisco de Orellana	Elaeis guineensis
Camacho et al.[3]	Emeralds	Oryza sativa
Andrade et al.[5]	Santay Island	Lysinibacillus fusiformis, Lysinibacillus boronitolerans, Alcaligenes faecalis, and Bacillus soli.
Pozo-Rivera et al.[2]	Sucumbíos and Orellana.	Scarabaeinae
González-Toril et al.[6]	Spain and Ecuador/ Libertada	Pseudomonas spp. and Brevundimonas spp.
Escudero-López et al.[8]	Sucumbíos/Orrellana	Pseudomonas stutzeri, Pseudomonas aeruginosa, and Pseudomonas putida.
Páliz et al.[9]	Orellana - AqLab Laboratory.	Pseudomonas spp, commercial strain Pseudomonas aeruginosa
R. A. V. García et al.[10]	Campo Sacha	Hydrocarbonoclastic bacteria
V. J. García et al.[11]	Esmeraldas	Pseudomonas aeruginosa

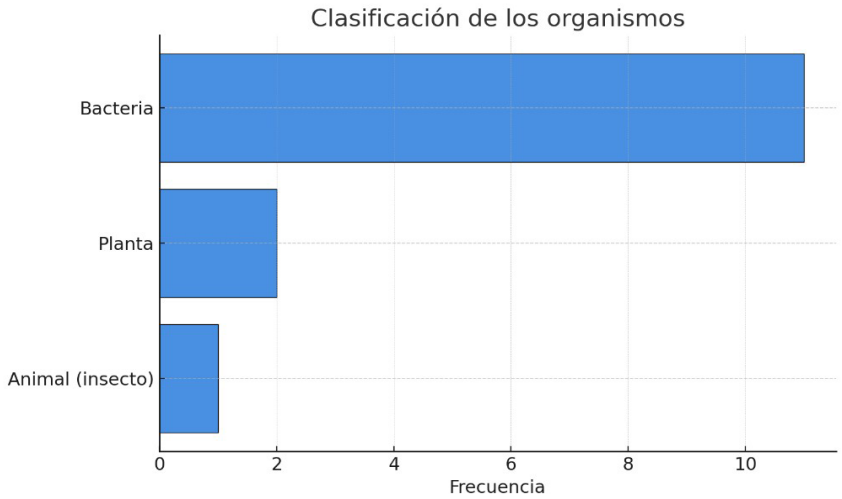

Figure 7. Classification of organisms used for bioremediation studies of hydrocarbon-contaminated soils in Ecuador

Table 4 shows the relationship between the environmental context, socioeconomic conditions, and bioremediation strategies applied in nine case studies conducted in different regions of Ecuador. In all cases, the environmental context is marked by the presence of soil contaminated by spills of oil or derivatives such as fuel oil, which have affected both natural ecosystems and agricultural areas.

In terms of the socioeconomic context, the studies identify conditions such as the vulnerability of rural and indigenous communities, economic dependence on agriculture, and the local availability of agro-industrial waste (such as palm bagasse and rice husks), which we have noted in most Latin American countries. These conditions have directly influenced the selection of remediation strategies with a local focus, low cost, and applicability in rural areas.

Table 4. Socioeconomic and environmental conditions associated with the application of bioremediation strategies

No.	Title	Environmental context	Socioeconomic context	Bioremediation strategy
1	Oil Palm Bagasse as a Treatment for Soils Contaminated with Total Petroleum Hydrocarbons	Francisco de Orellana presents soil affected by multiple oil spills.	Palm bagasse is an abundant and inexpensive agro-industrial waste product. In addition, it promotes the recovery of local by-products.	Palm bagasse is a local, inexpensive, and easily accessible by-product, making it a good technique for bioremediating soils contaminated with hydrocarbons.
2	Bioremediation of Soil Sample Contaminated with Crude Oil using Rice Husk-based Biocarbon (Oryza Sativa)	Esmeraldas has soil contaminated with oil spills from local refineries.	The use of rice husk biochar is an economical, replicable technique that is particularly well suited to rural areas.	The use of rice husk biochar is a sustainable and low-cost bioremediation solution, especially in sensitive soils.

3	Hydrocarbon tolerance evaluation of the microbiota associated with the Roystonea oeracea palm from Santay Island (Ecuador)	Santay Island has been affected by constant hydrocarbon pollution.	The identification of native plants capable of tolerating hydrocarbons and producing biosurfactants allows for the generation of accessible, low-cost bioremediation solutions.	One environmental solution is to take advantage of the local microbiota as an ecological and affordable bioremediation strategy due to its low cost.
4	Response of dung beetle diversity to remediation of soil ecosystem in the Ecuadorian Amazon.	Four different types of ecosystems in the Amazonian provinces that have previously been remediated were studied.	Biodegradable surfactants, soil reuse for agricultural purposes, and biological bioindicators (coprophagous beetles) were used for cleanup to assess soil recovery.	The combination of environmental bioremediation strategies, the use of biodegradable surfactants for cleaning, reuse for agricultural purposes, or reforestation are economical and feasible solutions for contaminated soils. Furthermore, the use of ecological bioindicators to verify ecological restoration is very feasible.
5	Metagenomic analysis of the microbial community at the Riutort oil shale mine (NE Spain): Potential applications in bioremediation and enhanced oil recovery	Presents an environmental context contaminated by oil extraction, transport, and spills.	Nearby populations, especially indigenous ones, are vulnerable in terms of health and economics.	The selection of native microorganisms or microbial consortia is proposed for future studies.
6	Bacterial selection of the Pseudomonas genus with the capacity to treat water and contaminated soils.	The Amazon region has historically been impacted by various oil spills that have caused serious environmental problems.	The provinces of Sucumbíos and Orellana are home to numerous rural and indigenous communities, which urgently need sustainable and low-cost solutions.	Bioaugmentation combined with biostimulation and environmental monitoring are considered solutions for future bioremediation studies.
7	Reduction of the soil environmental impact caused by the presence of total petroleum hydrocarbons (TPH) by using Pseudomonas sp	The soil from which the samples for laboratory analysis were obtained showed large accumulations of total hydrocarbons due to repeated oil spills that have been recorded in the province of Orellana.	Bioaugmentation with native bacteria extracted directly from the contaminated site is a low-cost solution and avoids the use of commercial strains that have to be imported, generating high costs.	Bioremediation of soil contaminated with hydrocarbons by extracting layers of bacteria from the site itself to create these bacterial microorganisms capable of degrading these heavy metals is a good environmental strategy.
8	Bioremediation of soil contaminated with hydrocarbons based on bacteria used as bioproducts	The site where the study was carried out is agricultural land affected by oil spills, which negatively alter the structure, microbiota, and fertility of the soil.	It is an area that depends on agriculture for its survival, so it is necessary and urgent to implement soil bioremediation strategies using techniques such as those used in this study.	Bioaugmentation with bioproducts is a good sustainable and economical strategy for future studies of bioremediation of soil contaminated with hydrocarbons.
9	Assessing Bioremediation of Soils Polluted with Fuel Oil 6 by Means of Diffuse- -Reflectance Spectroscopy.	The soils are contaminated with Fuel Oil No. 6 and show physicochemical alterations and diffuse reflectance spectroscopy, which hinders agricultural use and native microbiota diversity.	The combination of bioaugmentation (Pseudomonas aeruginosa) with diffuse reference spectroscopy (Vis-NIR) allows for economical and non-destructive monitoring.	Using this type of combination of technological (spectroscopy) and ecological (native microorganisms) techniques allows for the treatment of contaminated soils.

There is evidence of constant evolution in Ecuadorian scientific production, showing a peak increase from 2021 to 2023 (Figure 8). In addition, the evolution of the main authors of scientific production on scientific bioremediation in Latin American countries in the period 2019 to 2025 (Figure 9). At the Latin American level, Mexico is the country with the most citations (142 citations), followed by Brazil (132 citations). In Ecuadorian studies, the most cited is González-Toril et al.[6], 2023, which reaffirms the relevance of the local approach with international perspectives.

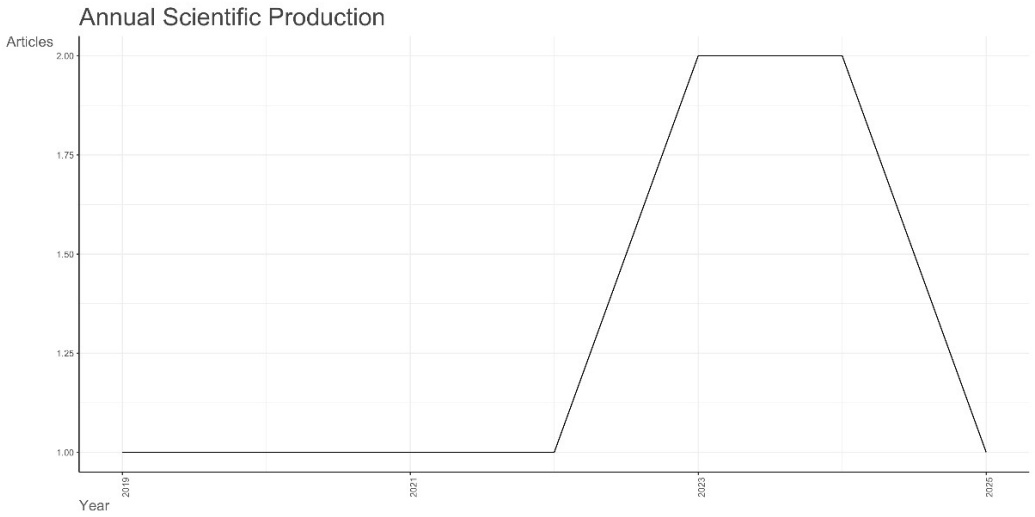

Figure 8. Temporal evolution of Ecuadorian production

Table 5 summarizes the main bibliometric indicators related to scientific production on the bioremediation of hydrocarbon-contaminated soils, focusing especially on the Latin American context. Among the most productive authors during the period 2020–2025, Rivera G. and Paz-González AD stand out, with consistent publications over time. They are followed by other relevant authors such as Adams RH. and Domínguez-Rodríguez VI., with active publications between 2020 and 2024, and Acuña AJ. and Cambarieri L., who concentrated their output between 2020 and 2021.

Table 5. Bibliometric indicators on bioremediation of hydrocarbon-contaminated soils

Evolution of the output of the most relevant authors over time	Latin America	Period	Authors
		2020-2025	Rivera G. and Paz-González AD.
		2020-2021	Acuña AJ. and Cambarieri L.
		2020-2024	Adams RH. and Domínguez-Rodriguez VI.
		2021-2022	Cruz-Hernandez MA.
		2020-2022	Elufisan TO. and Guo X.
		2022-2024	Gusman-Lopez O.
Most cited countries	Latin America	No. of citations	Countries
		142	Mexico
		132	Brazil
		24	Colombia
		16	Chile
Number of citations of scientific studies on bioremediation of contaminated soil	Ecuador	No. of citations	Studies
		5	González-Toril et al.[6]
		4	García et al.[10]
		2	Pozo-Rivera et al.[2]
		2	García et al.[11]
		2	Escudero et al.[8]
		2	Páliz et al.[9]
		1	Camacho et al.[3]
		0	Andrade et al.[5]
		0	Orejuela-Romero et al.[7]

Figure 9 visually represents the evolution of these authors over time, showing how they have remained or joined the scientific discussion in recent years.

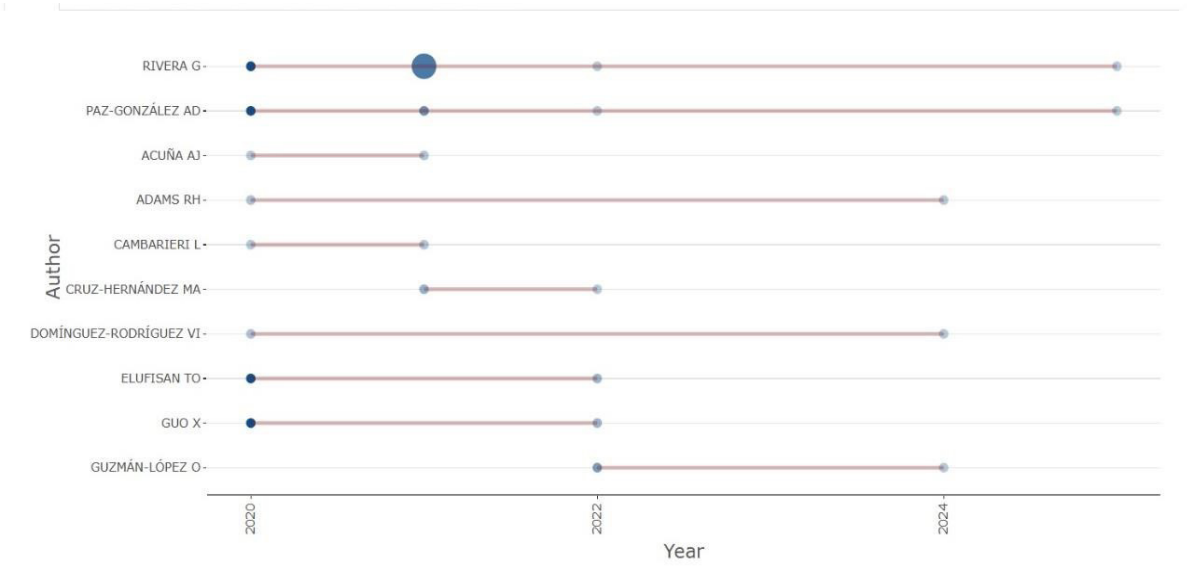

Figure 9. Evolution of authors in Latin American scientific production

In terms of the number of citations per country in Latin America, Mexico leads with 142 cumulative citations, followed by Brazil with 132, which demonstrates the high visibility and impact of their research in the region. Lower down the list are Colombia with 24 and Chile with 16, which could be related to a lower concentration of specialized research centers or the dispersion of scientific efforts in these countries.

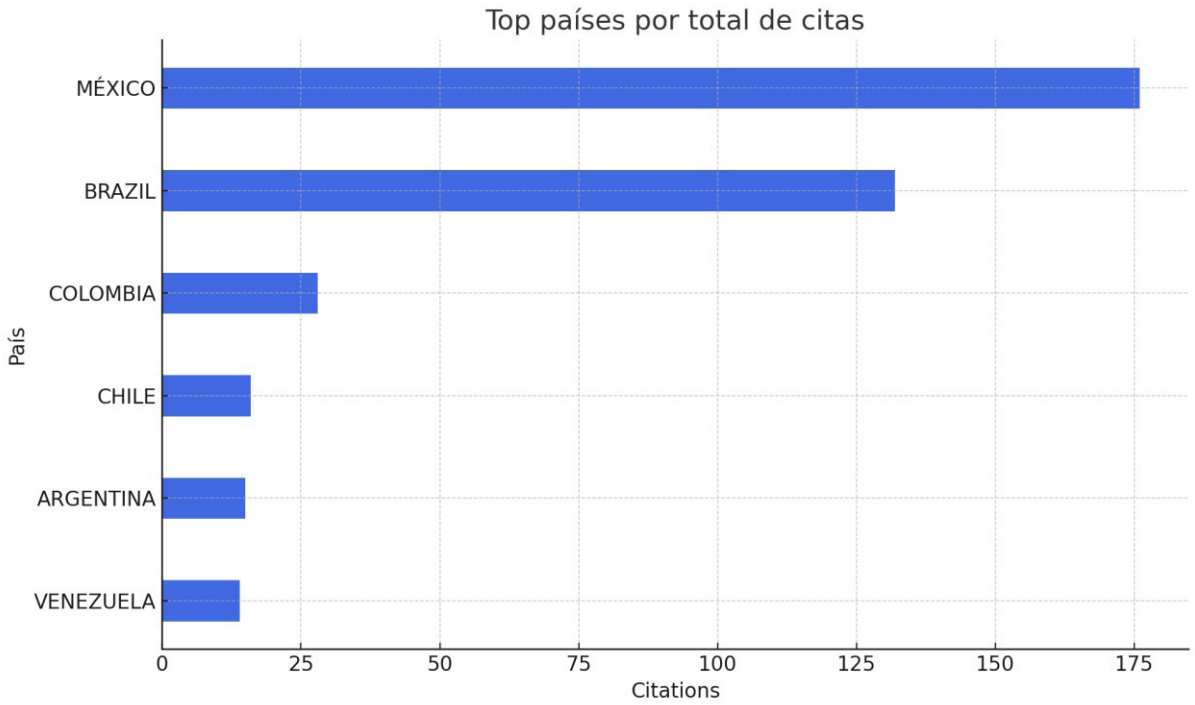

Figure 10. Top Latin American countries with the most citations

In the case of Ecuador, the analysis shows that national scientific production still has a low citation rate, with only a few studies standing out for their impact. The work of González-Toril et al.[6] leads with 5 citations, followed by that of García et al.[10] with 4. Other studies, such as those by Pozo-Rivera et al.[2], Escudero et al.[8] and Páliz et al.[9], have between 2 and 1 citations. In contrast, recent research such as that by Orejuela-Romero et al.[7] and Andrade et al.[5] has not yet been cited, which may be attributed to its recent publication or lack of dissemination in international databases.

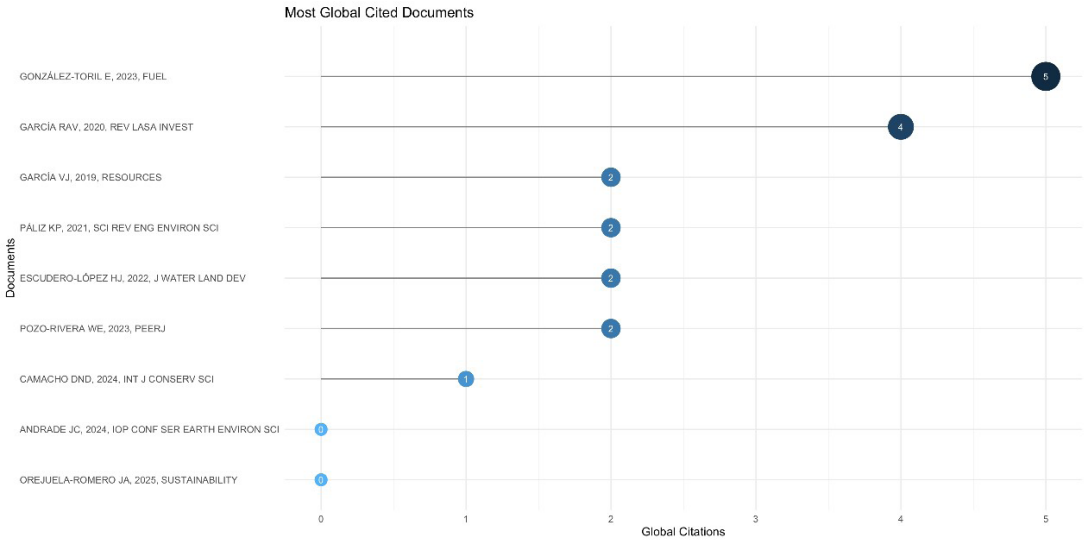

Figure 11. Number of citations in studies from Ecuador

The analysis of scientific collaboration networks on bioremediation of hydrocarbon-contaminated soils in Ecuador over the last five years reveals consistent participation by both national and international institutions. The co-authorships reflect interdisciplinary work, but there is no evidence of a significant connection between the authors. The most prominent national institutions are the University of the Armed Forces, the National University of Chimborazo, the Technical University of Manabí, and independent research centers, which are key players in the generation of scientific knowledge. On the other hand, there has been evidence of international cooperation with institutions in countries such as Spain, Italy, Brazil, and Venezuela, which have contributed to the development of Ecuadorian studies through methodological contributions, advanced analysis, microbial growth, model validation, and financing.

The results show that, although research groups in Ecuador address the issue of bioremediation of hydrocarbon-contaminated soils, collaboration between authors is not yet significant. As can be seen in Figure 12, most co-authorships are made up of small, isolated groups, without a consolidated network of national academic interaction. This fragmentation limits the possibility of forming robust scientific consortia to promote common interdisciplinary research agendas.

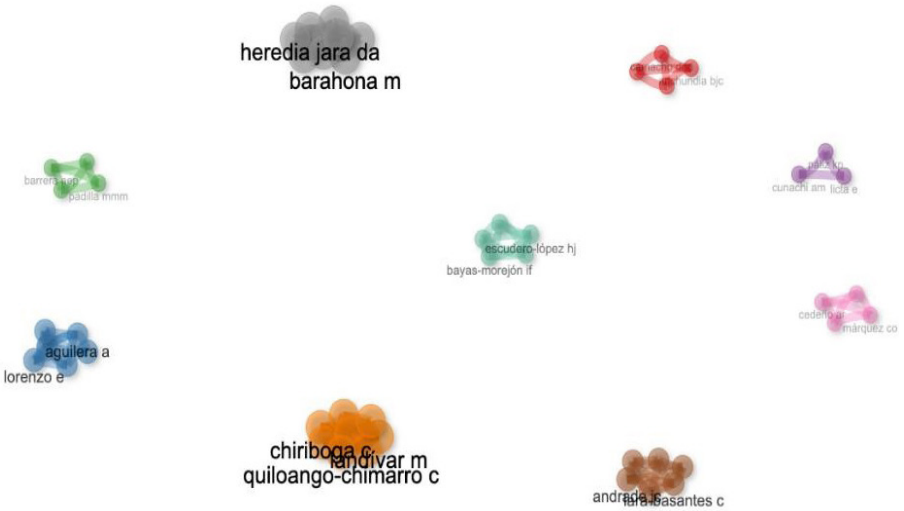

Figure 12. Co-authorship of studies in Ecuador

On the other hand, institutional affiliation reveals that the University of the Armed Forces (ESPE), the National University of Chimborazo, and the Technical University of Manabí lead scientific production in this thematic line (figure 13). There is also evidence of participation by independent researchers, which can be interpreted as an opening of the field to different modalities of academic production.

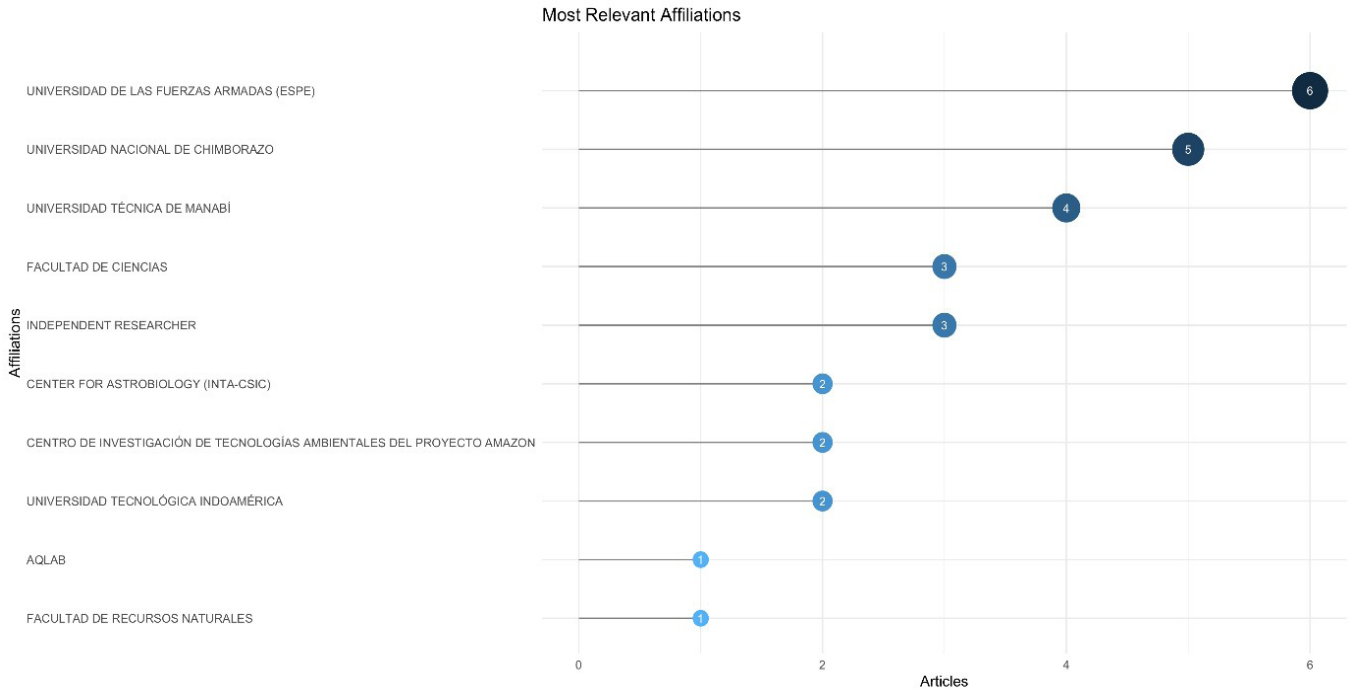

Figure 13. Institutional affiliations in scientific publications in Ecuador

In a broader context, when compared with the rest of Latin America, it can be seen that institutions such as the National Polytechnic Institute of Mexico, the Juárez Autonomous University of Tabasco, and the Federico Santa María Technical University of Chile have a considerably higher scientific output (figure 14). These universities stand out not only for their volume of publications, but also for the establishment of consolidated cooperative networks, which represent a regional benchmark in terms of collaborative strategies and the generation of knowledge applied to bioremediation.

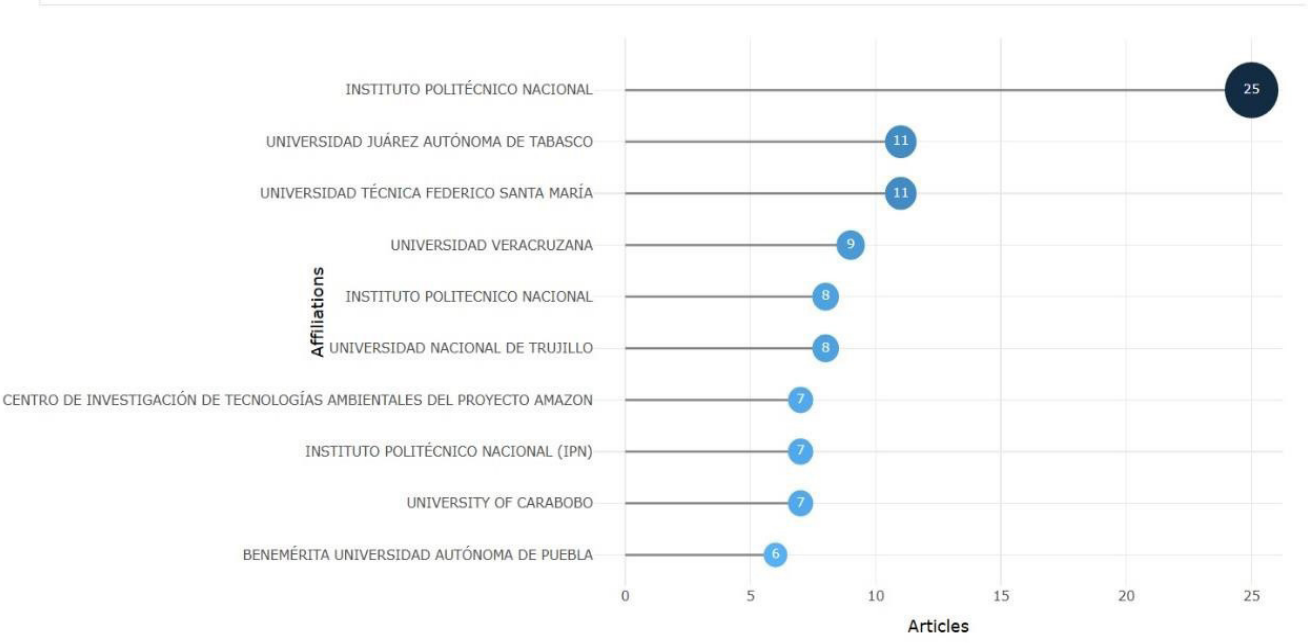

Figure 14. Most relevant affiliations of scientific studies on bioremediation of hydrocarbon-contaminated soils in Latin America

These findings highlight the need to strengthen institutional and scientific cooperation in Ecuador, both nationally and internationally, through collaborative networks that integrate capabilities.

Table 6. International cooperation in Ecuadorian studies

Study	Countries	Activity
Orejuela-Romero et al.[7]	Italy	Methodological support. Advanced analysis. Academic visibility.
Pozo-Rivera et al.[2]	Brazil	Contribution with methodologies and analysis.
González-Toril et al.[6]	Spain	Microbial development. (Riutort Consortium). Laboratory tests—Genetic analysis. Funding
García et al.[10]	Mexico	Contribution of knowledge and experience.
García et al.[11]	Venezuela	Validation and development of the spectroscopic model.

This world map highlights the international affiliations that Ecuador has established important scientific cooperation links with various countries, as shown in the Map of International Collaborations, figure 15. The greater intensity of color over Ecuadorian territory reflects its central role as the country of origin of studies on the bioremediation of soils contaminated with hydrocarbons. Among the countries with which collaborations have been identified, Spain and Italy stand out, whose institutions have contributed to methodological aspects, advanced analysis, and model validation. Likewise, links with Latin American nations such as Brazil, Mexico, Colombia, and Venezuela are evident, reinforcing a regional dynamic aimed at addressing shared environmental problems.

These scientific alliances have strengthened the technical and academic capacities of Ecuadorian teams, promoting an interdisciplinary and multicultural approach to the development of sustainable solutions.

Figure 15. Map of the distribution of international cooperation with studies in Ecuador

The scientific sources used in studies on the bioremediation of hydrocarbon-contaminated soils in Ecuador include a diverse set of journals, both specialized in the environment and multidisciplinary. The publications focused on sources such as Sustainability (Switzerland), PeerJ, and Resources are in the first quartile (Q1), which represents good scientific and academic support, as they are recognized and high-impact sources. Sources in quartiles (Q2 and Q3), such as the International Journal of Conservation Science, represent acceptable scientific quality, and journals in quartile (Q4) are less influential and generally have a less rigorous review process.

Figure 17 shows the geographical location of studies conducted in Ecuador on the bioremediation of soils contaminated with hydrocarbons. There is a higher concentration of research in the Amazon region, particularly in the provinces of Orellana and Sucumbíos, areas historically impacted by oil activities. This high recurrence reflects both the severity of the environmental problem in these areas and the scientific interest in proposing solutions adapted to the environment.

Secondly, studies in Esmeraldas, Guayas, and Chimborazo stand out, where laboratory proposals with practical implications have also been implemented. The distribution is complemented by research in specific areas such as Santay Island, revealing an effort to cover different ecosystem realities in the country.

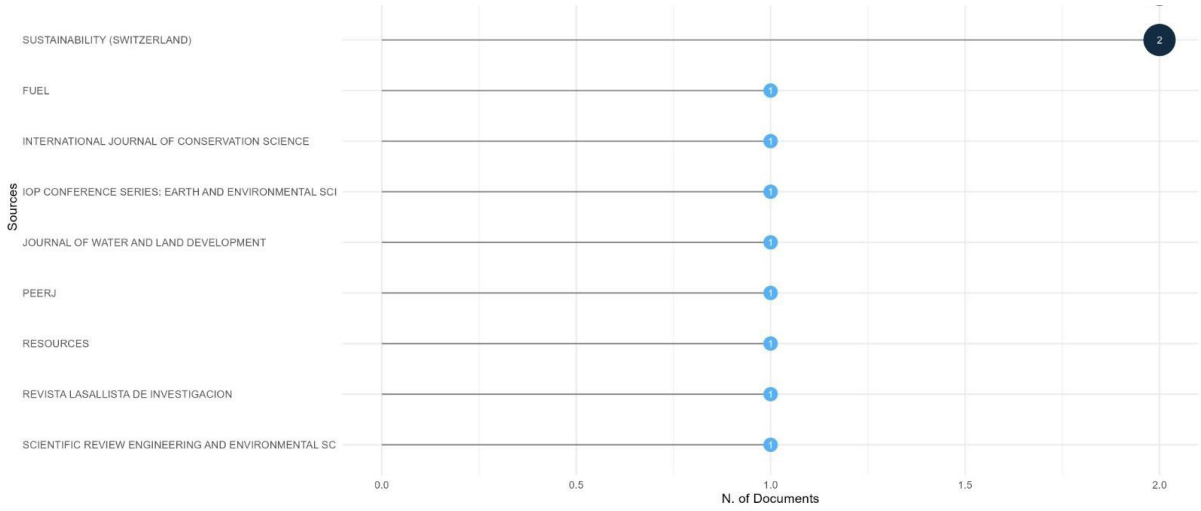

Figure 16. Main sources of scientific studies on bioremediation of hydrocarbon-contaminated soils in Ecuador

Table 7. Quartiles in sources of studies on bioremediation of contaminated soils in Ecuador (2019-2025)

Study	Source	Quartile
Orejuela-Romero et al.[7]	Sustainability (Switzerland)	Q1
González-Toril et al.[6]	PeerJ	
García et al.[11]	Resources	
Escudero et al.[10]	Journal of Water and Land Development	Q2
Calderon-Tapia et al.	AIMS Environmental Science	
Pozo-Rivera et al.[2]	Fuel	Q3
Páliz et al.[9]	Scientific Review Engineering and Environmental Sciences	
García et al.[10]	Lasallian Journal of Research	Q4

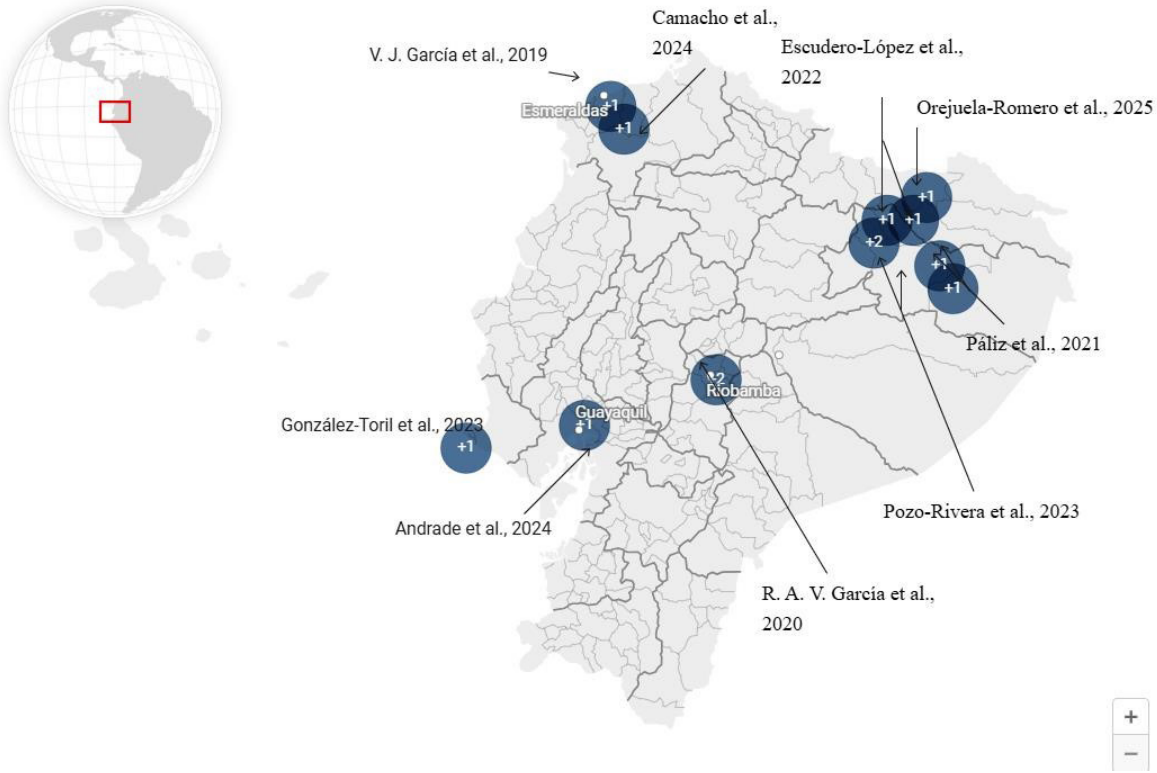

Figure 17. Map of Ecuador showing the location of scientific studies

DISCUSSION

This research study allowed for a critical analysis of scientific output on the bioremediation of hydrocarbon-contaminated soils in Ecuador between 2019 and early 2025, with an emphasis on methodological trends, authors involved, and collaboration networks. The results reveal that the quality, measured by quartiles, and the impact, measured by citations, show that even within the global scientific community, these measures are limited, and this growth has not yet become a consolidated or visible development worldwide. Most research is concentrated in a few institutions, and Ecuador currently has low levels of citation in the high-impact academic field. Working solely with the Scopus database, the existing gap becomes more clearly visible, as does the low frequency of publications in high-impact journals and the weak construction of inter-institutional collaboration networks. This reality demonstrates the urgent need to strengthen structural development. Although these challenges exceed the individual scope of a single study, this work provides empirical evidence that can serve as input for public policies, training programs, and institutional decisions aimed at closing the gap between Ecuador and the rest of the world.

One of the most relevant findings of our analysis in relation to the techniques applied and highlighted in studies in Ecuador is the predominance of bioaugmentation and biostimulation, as well as other strategies such as phytoremediation, especially in rural or Amazonian areas. Among the most widely used organisms are bacteria of the genus *Pseudomonas,* which are widely distributed throughout the world, but the use of native bacterial strains adapted to local ecological conditions has also been identified. In addition, several studies use agro-industrial waste, such as palm bagasse or rice husks, and apply monitoring methods using bioindicators. All of this reflects a clear orientation towards sustainable, low-cost, and contextualized solutions that respond to the country's socio-environmental needs. This trend is in line with international approaches that promote the use of local resources as a key element for the technical, ecological, and social viability of bioremediation processes and is consistent with the findings of Hoang et al.[12], who argue that the integration of local materials is essential to ensure the technical, ecological, and social viability of bioremediation processes in vulnerable territories. Thus, despite limitations in terms of international impact, the methodological approaches adopted in Ecuador show a promising path of their own, which could be consolidated through greater institutional and scientific support.

Composting combined with bacterial consortia is another fundamental area of applied research in environmental biotechnology, as it seeks not only to understand phenomena, but also to test and validate specific techniques that can be used to solve real environmental problems, as demonstrated by Orejuela-Romero et al.[7] and Camacho et al.[3], who are well documented and adapted to the local context. Complementarily, a broader regional review by Darío et al.[13] supports this trend, showing that bioremediation is currently the most widely used technique due to its high efficiency, with removal rates ranging from 8,1 % to 96,4 %, depending on the applied strategy. This analysis indicates that autochthonous bacteria account for 25,9 % of the techniques used, which is consistent with the results found in Ecuador, where native microorganisms also predominate as key agents in bioremediation processes.

Despite sustained growth in Ecuadorian scientific production on bioremediation, its volume and impact, as already mentioned, are still below those of countries such as Mexico, Brazil, Colombia, and Chile, where there are consolidated scientific networks and greater availability of research funding. This contrast highlights the need to strengthen structural capacities and scientific cooperation in the country.

A complementary analysis of the Latin American literature shows that, in at least eight countries, replicable good practices have been identified, especially in the use of combined techniques such as bioaugmentation with bacterial consortia and organic composting. For example, in Brazil, Rosa et al.[14] document high efficiency in the degradation of hydrocarbons through the use of agricultural waste and indigenous bacteria in Amazonian environments; in Mexico, studies such as that by Cruz-Hernández et al.[15] integrate biological monitoring with bioremediation techniques, achieving removal rates of over 80 %. These strategies not only demonstrate the technical feasibility of bioremediation, but also offer models that can be adapted to the Ecuadorian context, particularly in rural or Amazonian regions with economic limitations and high environmental vulnerability, thus reinforcing the validity of the local approach and facilitating the identification of good practices that can be replicated from other international contexts, especially in the use of combined techniques such as bioaugmentation with bacterial consortia and organic composting. For example, initiatives developed in Brazil, Mexico, and Spain have demonstrated high levels of efficiency in hydrocarbon removal through the use of native microorganisms, agricultural waste, and complementary technologies such as spectroscopy or biological monitoring. These strategies not only demonstrate the technical feasibility of bioremediation but also offer models that can be adapted to the Ecuadorian context, particularly in rural or Amazonian regions with economic limitations and high environmental vulnerability, thus reinforcing the validity of the local approach and facilitating the identification of good practices that can be replicated from other international contexts.

Another important finding that has emerged from the bibliometric analysis is the considerable percentage of Ecuadorian publications that appear in low-impact journals (Quartiles Q3 and Q4), which may limit the visibility

and influence of these studies in an international context. This situation is similar in Latin America, where Velásquez et al.[16] have analyzed the different journals indexed in Scopus and Web of Science (WoS), pointing out that, although there are increases, internationalization rates are low, with little international collaboration. This reality highlights the need to strengthen scientific quality, promote the indexing of publications in high-impact journals (Quartile Q1), and seek international collaborations.

The institutions leading Ecuadorian studies are the Armed Forces University (ESPE), the National University of Chimborazo, and research centers with outstanding participation in studies aimed at solving major environmental problems. Countries such as Spain, Mexico, Venezuela, and Italy have participated in Ecuadorian studies, contributing knowledge, analysis, technologies, data flow, and human capital training to seek sustainable strategies. In Brazil, initiatives such as Biota-FAPESP have been created, which have succeeded in integrating academic institutions, government agencies, NGOs, and even the private sector in projects focused on environmental improvements. Ecuador could apply these types of models on a smaller scale to strengthen consortia, national repositories, and meetings between authors or institutions with environmental and biotechnological focuses.

Another notable observation from the bibliometric analysis, which was very evident when viewing the map of Ecuador and its studies, is the absence of research on bioremediation of hydrocarbon-contaminated soils in southern Ecuador. This absence does not necessarily indicate a lack of environmental contamination. Still, it may be a response to a different thematic and territorial orientation of the research carried out in that area. Unlike the north, center, and west of the country, where oil activity has had a strong historical presence and therefore generates research focused on hydrocarbons, the southern provinces of Ecuador, such as Loja, Zamora Chinchipe, and El Oro, have been more associated with legal and illegal metal mining, which has led to a concentration of studies focused on heavy metal contamination, such as mercury, lead, and arsenic, in water bodies and soils.

In this context, the lack of publications on hydrocarbons in the south can be explained by the thematic specialization of local institutions and research centers, which respond to priority environmental issues in their territories. This highlights the need to promote more comprehensive and territorially coordinated research agendas that consider the diversity of pollutants and ecosystems affected at the national level. In addition, comparative research should be encouraged to analyze the impacts of different types of contamination (hydrocarbons vs. heavy metals) on soil, to generate differentiated but complementary technical solutions.

In short, the findings of this bibliometric analysis not only provide an understanding of the current state of research on bioremediation of hydrocarbon-contaminated soils in Ecuador, but also open up lines of reflection on the structural, institutional, and scientific challenges facing the country. Although significant methodological advances, a shift toward sustainable practices, and incipient international coordination have been identified, low citation rates, institutional concentration of knowledge, limited presence in high-impact journals, and territorial gaps highlight the need to consolidate a more robust, equitable, and coordinated research ecosystem. By offering a critical view backed by empirical evidence, this work can serve as input for the formulation of scientific policies, the design of financing strategies, and the strengthening of territorial and interinstitutional agendas, thus contributing to closing the gap between locally generated knowledge and its insertion into the global scientific circuit.

RECOMMENDATIONS

As a line of future work, we suggest expanding this type of bibliometric analysis to include other scientific databases such as Web of Science, RedALyC, SciELO, or Google Scholar. This would allow for the incorporation of relevant studies that do not appear in Scopus and offer a broader and more representative view of Ecuadorian scientific production on bioremediation.

It is also essential to promote opportunities for Ecuadorian researchers to meet, whether through national conferences, seminars, workshops, or virtual platforms. These opportunities can facilitate the exchange of ideas, the development of joint projects, and the strengthening of collaborative networks between universities, research centers, and other institutions, both public and private. One option to consider is the development of scientific consortia similar to the Biota network model in Brazil, which has proven effective in coordinating interdisciplinary efforts.

At the state level, it is recommended that institutions such as the Ministry of Environment, Energy, and Mines include bioremediation technologies developed by local researchers in their environmental regulations. These solutions, based on native microorganisms and offering affordable costs, can be key to addressing environmental problems in a sustainable and context-specific manner.

It is advisable to establish long-term partnerships with universities and research centers in countries with consolidated experience in this area, such as Mexico, Brazil, and Spain. These partnerships can promote the exchange of knowledge, technological resources, and methodologies.

Another important aspect is to promote the publication of Ecuadorian studies in English and in high-impact

scientific journals. This would raise the international profile of the work being done in the country and position Ecuador as an emerging leader in the field of bioremediation.

Similarly, it is essential to value and integrate the ancestral knowledge and expertise of local communities in the design and implementation of remediation projects. These communities, living directly with the environmental impacts, have experiences and practices that can enrich technological solutions from an intercultural and participatory perspective.

To strengthen access to knowledge, we propose the creation of a public digital platform where experimental results, protocols, scientific articles, theses, and other products related to bioremediation in Ecuador can be registered and consulted. This database should be freely accessible and available to researchers, students, decision-makers, and the general public.

In addition, it is recommended that universities and educational centers prioritize the training of professionals in key areas such as environmental microbiology, biotechnology, soil sciences, environmental chemistry, and conservation. Scholarship policies, financial support for academic mobility, and funds for the publication of scientific results can complement this.

Finally, mechanisms should be established to periodically monitor the evolution of scientific production in this field at least every three years. This evaluation would make it possible to identify progress, persistent challenges, and new areas of opportunity, thus guiding strategic decision-making based on updated data.

CONCLUSIONS

This bibliometric study on the bioremediation of hydrocarbon-contaminated soils in Ecuador revealed a sustained evolution in national scientific production between 2019 and 2025, in relation to the total of 21 studies, of which, after applying a rigorous process of cleaning, validation, and relevance analysis, nine scientific articles directly focused on the topic were selected. The main trends in bioremediation of hydrocarbon-contaminated soils in Ecuador show growth, with an increase from 2022 to 2023 onwards. Although still minimal compared to other Latin American countries such as Mexico or Brazil, this growth shows a growing commitment by academia and research centers to address environmental issues associated with oil activity, particularly in the Amazon region.

An assessment of the evolution over time and quantification of the impact using bibliometric indicators was proposed. It was found that, although Ecuadorian production is modest in quantitative terms, there are signs of consolidation from 2021 onwards. At the regional level, Mexico is the country with the most citations (142), followed by Brazil with 132, which demonstrates the high level of scientific research on bioremediation in these countries. In the Ecuadorian context, the article with the most citations was that of Gonzales-Torres et al. with five citations, reflecting the low level of visibility of national studies compared to those of other Latin American countries. However, this analysis suggests opportunities to enhance Ecuadorian scientific output through international publication strategies and academic collaboration.

The most frequently used techniques in Ecuadorian studies were bioaugmentation, biostimulation, and phytoremediation, with a notable use of native bacteria, especially of the genus *Pseudomonas*. This pattern coincides with Latin American trends, where solutions based on local microorganisms are also prioritized for their efficiency, low cost, and ecological adaptability. Additionally, the incorporation of agro-industrial waste such as palm bagasse or rice husks and the use of technologies such as spectroscopy reflect integrative, sustainable, and innovative approaches.

In the analysis of co-authorship networks and institutional collaborations, it was deduced that Ecuadorian researchers tend to work in isolation, without consolidated co-authorship networks. No patterns of co-authorship or mechanisms of integration between local universities were evident. The results also highlight that, although there is academic production in various regions of the country, it is mainly concentrated in the Amazonian and coastal provinces affected by spills, and is led by institutions such as the University of the Armed Forces (ESPE) and the National University of Chimborazo. However, Ecuadorian publications are predominantly found in Q3 and Q4 quartile journals and show limited scientific collaboration networks, which reduces their impact and internationalization. Of the nine articles selected, it was found that the three leading journals —Sustainability, PeerJ, and Resources —are of high quality (Q1), while the other studies are of medium quality (Q2 and Q3) or low quality (Q4). These results indicate that a significant proportion of high-impact journals are found in lower visibility factors. Therefore, choosing higher-quality journals can help studies gain greater national and international visibility.

The comparison of Latin American studies reinforced the different findings. Latin American filters identified similar patterns, such as techniques, where bioaugmentation and phytoremediation are the most widely used, as well as the implementation of organic waste. Countries such as Mexico and Brazil have managed to consolidate national networks, which contrasts with the reality in Ecuador, where there are still no formal platforms linking authors and public or private academic institutions.

In general, Ecuador showed an increase in scientific studies, with methodological approaches that are adapted to local conditions, but faces significant limitations in citations and regional and international

collaborations. This thesis has highlighted the urgent need to promote research networks, institutional policies that support scientific publications, and the creation of repositories for national and global authors. In this way, it will be possible to consolidate a science and biotechnology system that responds to the challenges facing the country and thus strengthen sustainable solutions to soil contamination with hydrocarbons. The experience of regional programs such as Biota-FAPESP suggests that Ecuador could advance in the creation of more solid scientific cooperation networks, promoting inter-institutional consortia and greater visibility of its studies in global forums.

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FINANCING

None.

CONFLICT OF INTEREST

Authors declare that there is no conflict of interest.

AUTHORSHIP CONTRIBUTION

Conceptualization: Solange del Rocío Lituma Carriel.
Data curation: Solange del Rocío Lituma Carriel.
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