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Integrated watershed management in Ecuador: Challenges, opportunities, and perspectives for sustainable development

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ABSTRACT

Effective water resource management is crucial for sustainable development, particularly in Ecuador, where diverse geographical and climatic conditions create unique challenges. This review article examines the advancements, challenges, and opportunities in integrated watershed management across various river basins in Ecuador. By analyzing critical issues such as pollution, deforestation, erosion, and resource exploitation, the study highlights the complexities involved in managing water resources. The use of Geographic Information Systems (GIS) and Integrated Water Resources Management (IWRM) strategies is emphasized as vital tools for addressing these challenges. The article also explores the importance of stakeholder coordination, equitable water distribution, and the need for robust environmental regulations. Through a comprehensive review of scientific literature and case studies, this study provides valuable insights and recommendations for developing future policies and strategies that ensure sustainable water management and ecosystem conservation in Ecuador.

Keywords: watersheds; water resources; sustainable development; environmental conservation; Ecuador.

1. Introduction

The proper management of water resources is a fundamental aspect for the sustainable development of any country, and Ecuador is no exception. The geographical and climatic diversity of Ecuador, ranging from the highlands of the Andes to the vast Amazon rainforest and tropical coastal regions, presents a unique complexity in terms of watershed and water resource management. In this context, understanding and effectively managing watersheds become a priority to ensure a safe and equitable water supply for the diverse needs of the population, as well as to protect and conserve associated aquatic and terrestrial ecosystems.

A watershed is defined as a natural hydrological and geophysical unit with defined boundaries, the management and conservation of which are crucial to ensure the quality and quantity of available water (Ragi & Mallikarjuna, 2023). The precise identification of these watersheds and the estimation of water supply are essential initial steps for planning and executing protection and mitigation activities related to water resources. It is important to consider the hydrology of a River Basin and the erosive impact of its waters, to identify vulnerable areas and favorable periods where erosion occurs (Chahban et al., 2024). In this regard, the use of tools such as Geographic Information Systems (GIS) has become fundamental for this purpose.

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Watershed management involves the implementation of comprehensive practices for soil protection, use, and conservation, as well as efficient water management within a specific watershed (Prakash & Verma, 2023). In Ecuador, as in many other countries, various strategies and policies have been adopted to address these challenges. In the hydrographic basin of the Amazon River in Manaus, Brazil, the ICA (water quality index) was used as a tool for evaluating the quality of surface waters (Duvoisin et al., 2024). These include integrated governance models and decision support tools, which assist in strategic planning and communication among stakeholders (Marcillo & Roberto, 2021; Mera-Parra et al., 2022; Arteaga et al., 2020).

Watershed management encompasses a range of activities from planning to coordination and administration of water resources within a specific administrative unit. In Ecuador, as elsewhere, watersheds are accepted territorial units for the integrated management of water resources and other natural resources (Dourojeanni et al., 2002). However, the effective implementation of integrated water resources management faces several challenges, such as subordination to other sectors and the unique attributes of water that make its management complex (Grigg, 2014).

Internationally, Integrated Water Resources Management (IWRM) has emerged as an interdisciplinary approach to manage water resources in a balanced and sustainable manner. IWRM seeks to achieve maximum economic and social welfare without compromising the sustainability of associated ecosystems (Rotaru et al., 2019). This approach has been widely adopted globally and is recognized as a pathway to sustainable development and efficient and equitable water resources management (Santos, 2019; Lapuerta Jaramillo, 2022).

In this context, this review article aims to explore the advancements, challenges, and prospects in water resources and watershed management in Ecuador. To achieve this, a comprehensive review of available scientific and technical literature will be conducted, focusing on aspects such as watershed definition and management, management strategies and policies, and challenges in implementing IWRM. It is expected that this analysis will contribute to a better understanding of the issues and opportunities in water resources management in Ecuador and provide key information for the development of future policies and strategies in this field.

2. Methodology

A rigorous search of scientific literature was carried out. The databases Scopus, SciELO, and Latindex. reports and technical projects were consulted. This approach allowed for an integrated understanding of the current state of knowledge and debates surrounding basin management. The search strategy is explained below.

Identification of information sources

A comprehensive search for relevant documents was conducted, including scientific articles, academic theses, government reports, and publications from international and non-governmental organizations related to water resources and watershed management in Ecuador. This process was carried out using the following search algorithm: [watershed AND management] AND [conservation] AND [Ecuador], applied to article titles, abstracts, and keywords.

Document selection

Priority was given to the most pertinent and up-to-date documents addressing key aspects of water resources management within the Ecuadorian context. This included original research, systematic reviews, and relevant technical reports pertaining to the study's subject matter.

Initially, 48 results were identified, including articles, session documents, book chapters, and review papers. Publications unrelated to the proposed topics were excluded, resulting in a refined list of 40 original documents. Additionally, 38 new studies were included (Figure 1).

Thematic analysis

A thematic analysis of the selected documents was performed, identifying patterns, trends, challenges, and opportunities in water resources and basin management in Ecuador. Special attention was paid to aspects such as regulations, conservation practices, environmental and socio-economic impacts, among others.

Results synthesis

Through bibliometric analysis, the most relevant and significant findings from the reviewed documents were identified and synthesized, highlighting the main themes, approaches, and conclusions emerging from the existing literature on the subject. The information was organized in a coherent, chronological, and structured manner to facilitate understanding and analysis.

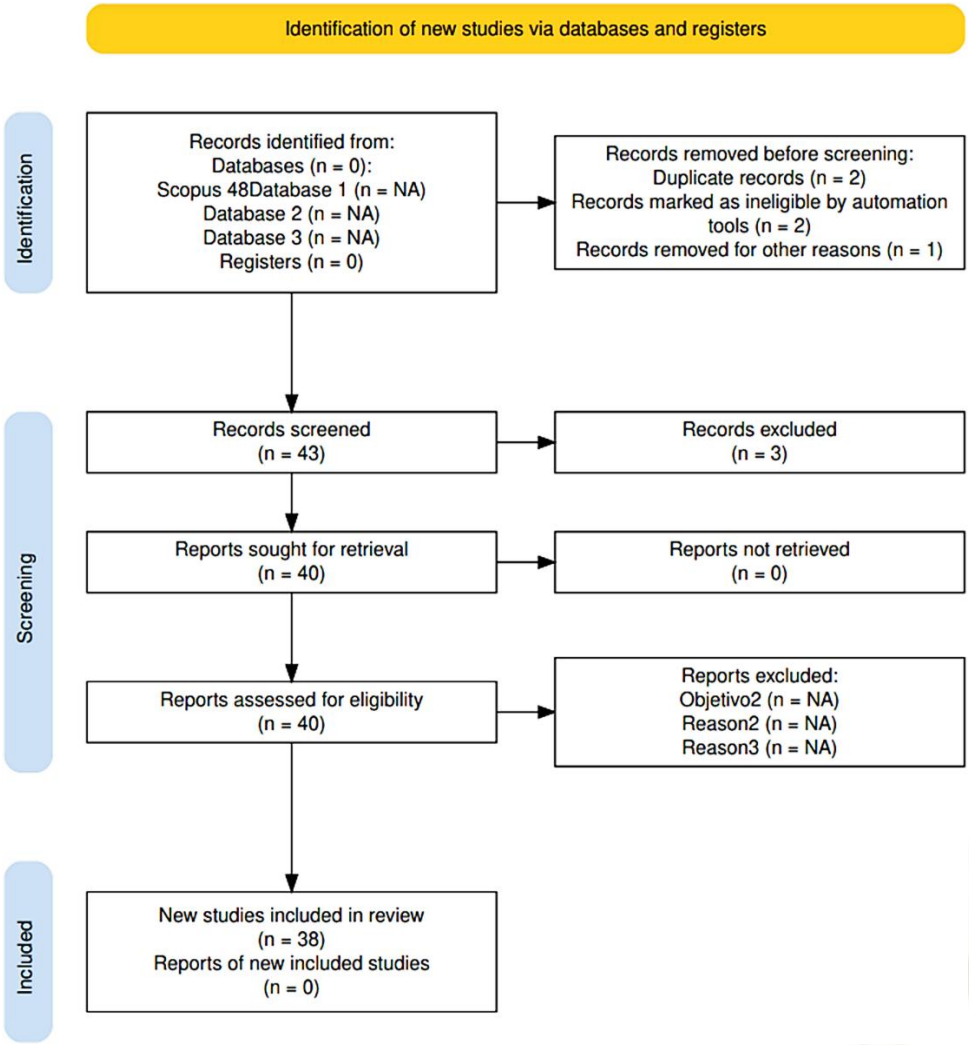

Figure 1. Bibliographic Review Using the PRISMA Methodology.

3. Results and discussion

Watershed management in Ecuador

Effective watershed management is vital to ensure sustainable access to water and protect aquatic ecosystems in Ecuador. Through the analysis of available literature, several key aspects related to this topic can be highlighted, which are analyzed in the following sections.

Concept of watersheds and the Ecuadorian context

Watersheds, also known as drainage basins, are geographical areas that collect and channel water to a common discharge point. Ecuador has a broad legal framework to reduce environmental and social impacts on watersheds, including the Constitution of the Republic of 2008, the Organic Code of Territorial Organization, Autonomy, and Decentralization (COOTAD), the Organic Environmental Code (COA), and the Creation of Opportunities Plan 2021-2025. However, watersheds have been affected by government interventions, especially during periods of economic boom such as the oil and cocoa bonanza. These interventions have significant economic, political, and social repercussions (Schodt, 2019).

Analysis of watersheds and their importance for water management

Detailed analysis of watersheds is essential for efficient water management in Ecuador. It provides crucial information about surface water supply, water quality, and land use patterns, helping to understand water availability and distribution in different regions of the country (Zemtsov & Savichev, 2015). Moreover, this analysis is fundamental for estimating water and food security and for developing sustainable water management plans (Salmoral et al., 2018; Carrión-Mero et al., 2021). Understanding surface water supply allows identifying available water sources and assessing their potential to meet human and environmental demands. Additionally, water quality analysis provides information on water suitability for different uses, such as human consumption, agriculture, and ecosystem conservation.

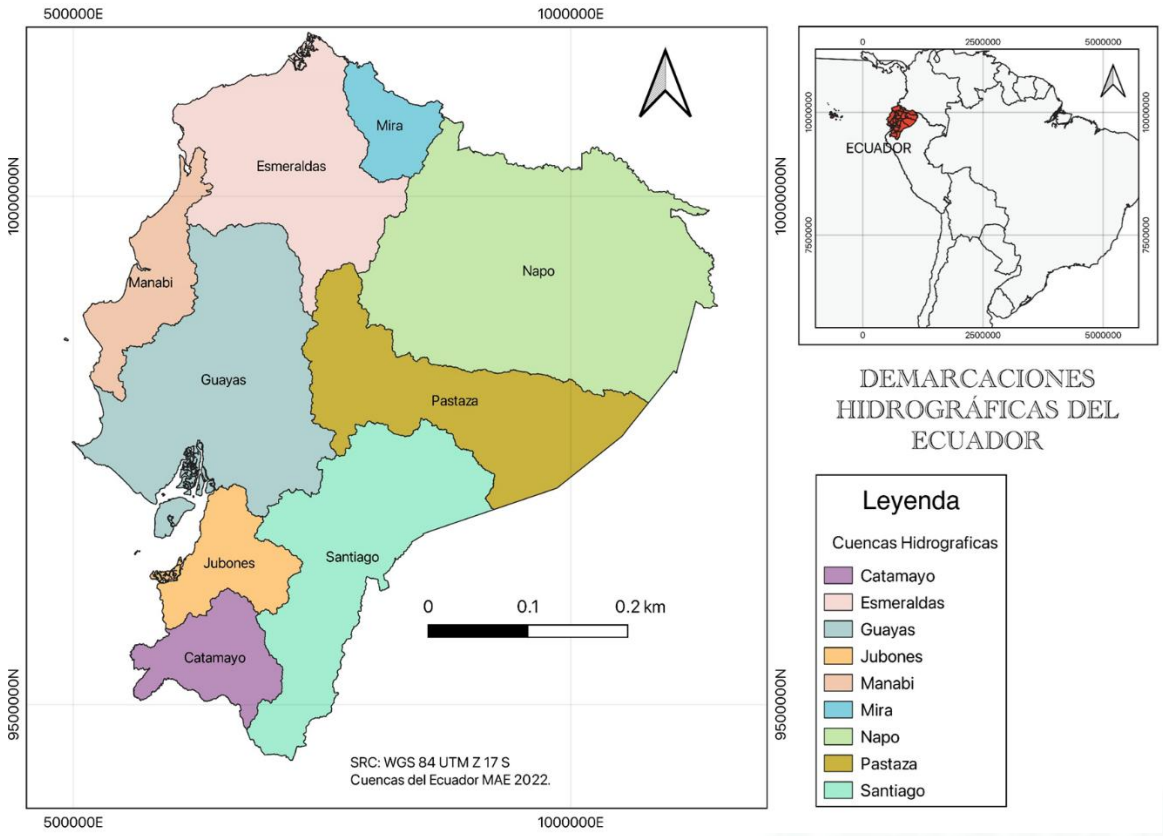

Figure 2. Watersheds in Ecuador (Adapted from "Integrated Management of Water Resources and Governance: Vinces River Sub-Basin, Los Ríos Province-Ecuador", by Muñoz & Bustos, 2021).

Conservation and sustainable water management in Ecuador

Water conservation and proper management are critical in Ecuador due to inequalities in resource distribution and adverse environmental impacts. Soil erosion is becoming a problem that threatens agriculture worldwide (Li et al. 2022). Annual soil loss in South America grows at rates between 20 and 40 t/ha/year (Melkam 2003).

Knowing the interaction between topography, precipitation, erosion and sedimentation is of utmost importance for the management of water resources (Chahban et al., 2024). For example, the silting of reservoirs like La Esperanza reservoir in the province of Manabí illustrates how water erosion can be exacerbated by geographical and geological factors (Velásquez et al., 2023). It is essential to implement policies and practices that protect and restore aquatic ecosystems nationwide.

Water conservation involves not only protecting water sources but also adopting sustainable land and water use practices. This includes implementing sustainable agriculture techniques, reducing water pollution, and promoting reforestation and ecosystem restoration.

Biological and ecological water quality in Ecuadorian watersheds

Analysis of biological and ecological water quality in Ecuadorian watersheds provides valuable information on the state of aquatic ecosystems and the impacts of human activities. Studies such as those conducted by Jerves-Cobo et al. (2018) and Damanik-Ambarita et al. (2016) highlight how pollution and land use affect water health and associated ecosystem services. Continuous monitoring of water quality and aquatic biodiversity is crucial for identifying environmental problems and taking corrective actions. This may include implementing stricter regulations on pollutant discharge, restoring degraded aquatic habitats, and public education on the importance of water conservation.

Environmental and social impact of watersheds in Ecuador

The environmental and social impact of watersheds in Ecuador is complex and multifaceted. Factors such as social dynamics, agricultural practices, and urbanization affect the health of aquatic ecosystems and water availability for the population (Sherwood et al., 2014; Henkel &

Lodemann, 2014; Rebaï, 2019). For example, managing anthropogenic activities in the Pastaza River basin, especially oil industry operations, has wreaked havoc in the middle and lower regions, causing landslides, floods, and severe environmental damage.

Additionally, alterations in the high-altitude paramos due to deforestation, expansion of agricultural frontier, illegal logging, and forest fires. Moreover, landslides in the middle zone have led to soil cracking, while sedimentation and floods are observed in the lower zone, resulting from poor watershed management and lack of awareness among the population. It is crucial to implement integrated water resources management strategies that promote sustainable development and better water governance (Albornoz & Machado, 2016). The social impact of water management must also be considered, as management decisions can affect the livelihoods of local communities and generate conflicts over water access and control. Public participation in decision-making and equity in the distribution of water benefits and costs are key aspects to address these issues.

Challenges of IWRM in Ecuador

IWRM offers several benefits for watershed management in Ecuador, including sustainable development and better water governance (Sahvaeva, 2021; Campbell, 2016). However, it faces significant challenges, such as the complexity of river systems and resource scarcity (Torregrosa & Sevilla, 2019). Understanding the specific issues affecting Ecuador's river basins is crucial for the effective implementation of IWRM. These challenges, summarized below (Figure 2 and Appendix in Table A1), illustrate the diverse and critical issues faced by different river basins in Ecuador.

Guayas river basin: This basin is severely impacted by industrial and domestic wastewater, toxic waste, soil erosion, floating solids, agricultural activities, changes in land use, river sedimentation, and the construction of hydroelectric dams (Ilbay-Yupa et al., 2019; Baquerizo et al., 2019).

Mira-Mataje river basin: Key issues here include soil erosion, water contamination, agricultural frontier expansion, the use of agrochemicals, untreated wastewater, deforestation, mining activities, colonization pressures, solid waste accumulation, and a lack of effective environmental management policies (Yan Zhang et al., 2016-a; Terán Rosero, 2018).

Napo river basin: This basin suffers from water scarcity for human consumption, inadequate agricultural and livestock practices, mining and petroleum exploitation, deforestation, erosion, anthropogenic pressure on protected areas, poorly planned housing projects, and ineffective solid and liquid waste management leading to natural resource degradation (Yan Zhang et al., 2016-a).

Pastaza river basin: Issues in this basin include inappropriate land use, extraction of petroleum, timber, and other resources, water contamination, soil loss, biodiversity loss, flooding, poor agricultural practices, excessive use of agrochemicals and fertilizers, expansion of the agricultural frontier, and the discharge of industrial and domestic wastewater along with solid waste (Pérez, 2016).

Puyango-Catamayo river basin: This basin faces water resource scarcity, soil erosion, unequal water distribution, mining activities, non-compliance with environmental regulations, expansion of agricultural and aquaculture frontiers, a primary agroexport model, urbanization, untreated sewage and solid waste disposal, surface and groundwater contamination, and agrochemical leaching (Jimy & Mena, 2022; Silva, 2022).

Santiago river basin: The Santiago basin is challenged by deforestation, soil erosion, poor water resource management, irresponsible use of agrochemicals, inadequate agricultural practices, and contamination of water sources from agrochemicals and residues from artisanal mining (Yan Zhang et al., 2016a).

Esmeraldas river basin: This basin's challenges include agricultural frontier expansion, land occupation without property titles, a deficit in sanitation and potable water infrastructure, natural resource degradation, improper disposal of liquid and solid waste in streams and rivers, pressure on protected areas, extraction of hydrocarbons and minerals, and poor agricultural and livestock practices (Yan Zhang et al., 2016).

Jubones river basin: The main issues here are soil erosion, seasonal droughts, water scarcity, flooding, and poor water quality (Cordero, 2013; CISPDR, 2017).

Manabí river basin: Challenges in this basin include flooding, inadequate soil and crop management, agrochemical and fertilizer runoff, sedimentation, untreated sewage dis-charge, and wastewater from shrimp farming (Macías Párraga & Aguirre, 2010).

Effective implementation of IWRM requires coordination among various stakeholders, including governments, local communities, non-governmental organizations, and the private sector. Additionally, it is crucial to address inequities in water access and promote sustainable water resources management practices that benefit all stakeholders. IWRM is urged to become a benchmark for public water management models and the design of its institutions at the national level. In terms of policy development, IWRM should be seen as a continuous improvement process. This involves an ongoing cycle of diagnosis, policy formulation, implementation, and evaluation, ensuring that water management strategies are updated regularly based on new data and insights (Martínez et al., 2018). Addressing the myriad challenges highlighted in Ecuador's river basins will be critical for the success of IWRM and for achieving sustainable water resource management in the country.

Perspectives

To advance sustainable watershed management in Ecuador, the following focus areas for future research and actions are proposed.

Strengthening water governance: There is a need to improve coordination among different levels of government, as well as promote conscious participation of local communities and stakeholders in decision-making about water management.

Promotion of sustainable agricultural practices: Measures should be implemented to reduce water pollution from agrochemicals and promote sustainable agricultural practices that conserve soils and water resources.

Conservation of aquatic ecosystems: It is essential to protect and restore aquatic ecosystems, such as rivers, lakes, and wetlands, to maintain biodiversity and the ecosystem services they provide.

Technological innovation: The application of innovative technologies, such as remote sensing and geographic information systems, can improve monitoring and management of water resources, enabling more precise and timely decision-making.

Challenges and opportunities for IWRM in Ecuador

Effective IWRM in Ecuador involves addressing a range of challenges while seizing various opportunities. These aspects should be considered independently to enhance watershed management practices and outcomes (See appendix in Table A2).

Challenges

Raising awareness: One major challenge is increasing awareness among authorities and the public about the importance and functions of watersheds. Without this understanding, it is difficult to achieve broad support for sustainable management practices and necessary reforms.

Water pollution: Water pollution from industrial, agricultural, and domestic sources remains a significant issue. Addressing this problem is crucial for improving water quality and protecting ecosystem health.

Operationalizing plans: Implementing national and local water management plans effectively is challenging due to the need for comprehensive planning, coordination, and adequate resources.

Soil erosion: Soil erosion leads to land degradation and reduced agricultural productivity. Effective soil conservation measures and sustainable land management practices are required to combat this issue.

Waste management: Inadequate treatment and disposal of solid and liquid waste pose risks to both environmental and public health. Proper waste management practices are essential.

Regulation of activities: Regulating agricultural, mining, and petroleum activities to minimize their environmental impact is a challenge that requires strong governance and enforcement of environmental regulations.

Water access: Ensuring equitable access to water resources is a persistent challenge that can exacerbate social inequalities and hinder sustainable development.

Ecosystem conservation: Conserving vital ecosystem resources such as forests and wetlands is critical for maintaining biodiversity and ecosystem services. The degradation of these resources presents a significant challenge.

Opportunities

Increasing awareness: Educating authorities and the public about the importance of watersheds can improve food security and promote sustainable land and water management practices.

Reducing pollution: Addressing water pollution presents an opportunity to enhance water quality, which can support ecotourism and conservation efforts.

Implementing plans: Effective operationalization of national and local water management plans can lead to better conservation of natural resources and their sustainable use.

Mitigating erosion: Combating soil erosion can improve environmental safety and enhance the quality of life for communities by preventing further land degradation.

Improving waste management: Developing robust waste management systems can enhance public health and contribute to local development through better waste treatment and resource recovery.

Regulating activities: Proper regulation of agricultural, mining, and petroleum activities can encourage sustainable practices and promote local development.

Equitable water distribution: Ensuring fair water distribution can support local development and facilitate the use of hydroelectric energy, contributing to sustainable energy solutions.

Conserving ecosystems: Protecting and restoring ecosystem resources can improve ecosystem services, such as water purify-cation and flood regulation, benefiting both human communities and the environment.

By addressing these challenges and seizing these opportunities, Ecuador could move towards more effective and sustainable management of its watersheds, ensuring equitable access to water and protecting natural resources for future generations.

4. Conclusions

The analysis and integration of information on watershed management in Ecuador reveal a series of key challenges and opportunities for sustainable water management in the country. From the review of scientific studies, government reports, and technical documents, the following conclusions can be drawn:

Multifaceted challenges. Ecuador faces a range of challenges in managing its watersheds, from environmental degradation to unequal water distribution and social conflicts. These challenges result from a variety of interconnected factors, including pressure on natural resources, urban and agricultural growth, and lack of coordination among stakeholders involved in water management.

Importance of integrated management. Integrated water resources management emerges as a fundamental approach to addressing the challenges of watershed management in Ecuador. This approach recognizes the interconnectedness of environmental, social, and economic aspects of water management and seeks to promote coordination and collaboration among different sectors and stakeholders.

Need for concrete policies and actions. While Ecuador has a solid legal framework for water resources management, its effective implementation remains a challenge. Greater political will and financial resources are needed to translate policies into concrete actions that promote the conservation of aquatic ecosystems, improve water quality, and ensure equitable access to water for all sectors of society.

Incorporation of scientific knowledge. Scientific research plays a crucial role in watershed management, providing fundamental data and analysis for informed decision-making. It is essential to foster collaboration among scientists, policymakers, and local communities to ensure that water management is based on solid scientific evidence and traditional knowledge.

Conflict of Interest

The authors declare that there is no conflict of interest.

Author contributions

Conceptualization: RS, MCG; Formal analysis: RS, MCG; Investigation: EP, DG, EA, MCG; Writing-review & editing: RS, DG, MCG; Methodology: EP, RS, EA; Resources: RS, DG; Supervision: RS, MCG; Visualization: DG, RS; Project administration: MCG.

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APPENDIX

Table A1. Summary of the problems of the basins in Ecuador

N°	River Basin	Area (km²)	Provinces	Population	Issue	Source
1	Guayas	32.890	Bolívar, Chimborazo, Cotopaxi, Pichincha, Cañar y Tungurahua, Los Ríos, Manabí, Guayas	5'592.025	The pollution from industrial and wastewater, toxic waste, soil pollution, floating solids, agricultural practices, land use changes, river sedimentation, and the construction of hydroelectric dams are critical factors that significantly impact water resources.	Ilbay-Yupa et al., 2019; Baquerizo et al., 2019.
2	Mira-Mataje	6.903	Ibarra, Carchi, Esmeraldas	538.727	Erosion, water pollution, expansion of agricultural frontier, use of agrochemicals, discharge of wastewater, deforestation, mining activities, colonization invasion, accumulation of solid waste, and lack of effective environmental management policies are critical factors that negatively affect ecosystems and sustainable natural resource management.	CISPDR, 2016; Terán Rosero, 2018.
3	Napo	65.325	Carchi, Cotopaxi, Napo, Pastaza, Pichincha, Sucumbios, Orellana	436.000	Water deficit, expansion of agricultural frontier, inadequate agricultural and livestock practices, absence of environmental policies in mining and oil exploitation, overexploitation of forests, soil erosion, poorly planned housing projects, ineffective management of solid and liquid waste, and the consequent degradation of natural resources.	CISPDR, 2016.
4	Pastaza	32.128	Cotopaxi, Tungurahua, Chimborazo y Pastaza	1'424.985	Improper land use, extraction of oil, timber, and other resources, water pollution, loss of soil and flora and fauna species, floods, poor agricultural practices, excessive use of agrochemicals and fertilizers, expansion of agricultural frontier, discharge of sewage and industrial water, and inefficient solid waste management.	CISPDR, 2016.
5	Puyango-Catamayo	10.900	Loja, El Oro	302.922	Water scarcity, erosion, unequal water distribution, mining, non-compliance with environmental regulations, expansion of agricultural and aquacultural frontiers, primary agro-export model, urbanization, discharge of sewage and solid waste, contamination of surface and groundwater, and leaching of agrochemicals.	Jimy & Mena, 2022; Silva C, 2022.
6	Santiago	34.479	Azuay, Cañar, Chiborazo, Loja, Morona Santiago y Zamora Chinchipe	1'119.381	Deforestation, erosion, inadequate water resource management, irresponsible use of agrochemicals, poor agricultural practices, contamination from agrochemicals and artisanal mining residues, and water source pollution.	CISPDR, 2016.
7	Esmeraldas	32.043	Cotopaxi, Esmeraldas, Imbabura, Manabí, Pichincha, Santo Domingo de Tsachilas, Zona no delimitada (Las Golondrinas)	3'938.781	Expansion of agricultural frontier, occupation of land without property titles, deficit in sanitation and drinking water infrastructure, degradation of natural resources, improper disposal of liquid and solid waste in streams and rivers, pressure on protected areas, extraction of hydrocarbons and minerals, and poor agricultural and livestock practices.	CISPDR, 2016.
8	Jubones	10.527	Azuay, El Oro, Guayas, Loja	728.016	Soil erosion, seasonal droughts, water scarcity, floods, and poor water quality.	Cordero, I. 2013; CISPDR, 2016.
9	Manabí	11.502	Esmeraldas, Manabí y Santa Elena	1'125.860	Floods, improper soil and crop management, runoff of agrochemicals and fertilizers, sedimentation, untreated discharge of wastewater, and wastewater from shrimp farms.	Macías Párraga & Aguirre, 2010.

Table A2. Challenges and opportunities for integrated watershed management in Ecuador

Challenges	Opportunities
Raise awareness among authorities and the Ecuadorian population about the importance and functions of watersheds	Strengthen food security and sovereignty
Reduce water pollution	Promote ecotourism
Operationalize the National Water Plan and Territorial Development and Planning Plans	Conserve natural resources
Reduce soil erosion	Provide a safe environment for residents
Treat solid and liquid waste	Protect public health
Regulate agricultural, mining, and petroleum activities	Encourage local development
Ensure equitable water distribution	Harness hydroelectric energy
Conserve ecosystem resources	