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Indicators of scientific production show limited and fragmented information for integrated aquatic quality on La Plata River transboundary basin

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ABSTRACT

The La Plata River Basin (LPRB) is the second-largest basin in South America, encompassing five countries: Argentina, Brazil, Bolivia, Paraguay, and Uruguay. It spans diverse regions, from the Andean mountains to the Pantanal wetlands, and from arid areas to the Pampas biome. Major cities are situated along the rivers, all facing different environmental pressures. Records of water quality assessments are scarce and fragmented, and there is no available comprehensive environmental quality study involving all five countries across the entire basin. Here we perform a bibliometric and science mapping analysis to describe the scientific knowledge and institutional collaboration of monitoring aquatic environments in the entirely basin. We searched and selected articles for each major river comprising the basin and with specific keywords related to monitoring and environmental assessments in two bibliographic repositories (SciELO and Scopus). There were 357 documents published in SciELO and 672 in Scopus on monitoring water quality in the LPRB from 1977 to 2023. Results show that there is limited information on the environmental quality aspects of the LPRB. No publications cover the entire basin and all five countries. Most studies have been conducted in the estuarine region and particular sub-basins of Brazil, Argentina, and Uruguay. Despite the studies on the basin for more than 5 decades, there is an urgent need to integrate the entire basin in research efforts to develop comprehensive monitoring programs for sustainable environmental management.

1. Introduction

Whole basin management (WBM) promotes the integrative conservation of high-quality water to ensure the sustainability of overall environmental health. Monitoring programs on basins, aquifers, coasts, and oceans are fundamental to protect the water quality and support a wide range of human activities. The expansion of human activities such as urbanization, mining, and intensive agriculture is increasing threats and pressures (e.g., increased river damming for electricity and irrigation). If these activities are not managed sustainably, those conducted in upstream areas can negatively impact water quality at downstream sites (McGrane, 2016; Luo et al., 2020; Narangarvuu et al., 2023). A comprehensive approach to manage a whole system, including their multi-dimensional characteristics (ecological, social, economic, etc.) is possible by considering river basin and coastal areas management as a whole (UN, Environment Programme, 1997). Achieving integrated environmental information for transboundary macro-basins is a major challenge for the sustainable management of water resources. This aligns with Sustainable Development Goal 6 (SDG 6), established by the United Nations in 2015, which focuses on protecting aquatic ecosystems, promoting efficient water use, reducing pollution, and ensuring a safe, sustainable water supply for both human needs and environmental health worldwide.

Large river basins, which usually cover the territory of several countries, need an international committee to address integrative environmental quality issues of the watershed. Indeed, the signing of the 2030 Agenda for Sustainable Development and its goals framework for water resources facilitates transboundary water cooperation through academic and scientific collaboration, defining milestones and promoting cooperation among countries.

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(McCracken and Meyer, 2018). Academic networks provide a crucial framework for collaboratively establishing environmental quantitative descriptors that can assist decision-makers in socio-ecosystem management. The development of these networks can be analyzed through scientific output, with universities playing a key role in supporting the standardization of methods for water quality assessment and monitoring.

Usually, researchers assess environmental quality and biodiversity patterns on temporal and spatial scales that do not cover an entire system (e.g. a basin). Due to local jurisdiction in terms of environmental monitoring and management, transboundary basins present a natural fragmentation at institutions, monitoring programs and research levels (Bréthaut and Rodriguez Echavarria, 2024). While international scientific collaboration seems to be inherent to WBM of transboundary big basins, it is noticeable that most large basins in developing countries do not have a scientific basic network to sustain a WBM programs. A WBM implies the ability to integrate basic knowledge and coordinate and standardized monitoring programs, in order to have a sustainable use of water resources and to avoid potential transboundary conflicts. Specifically for the aquatic systems, the WBM is the basic management unit, involving all socio-ecosystems and including stakeholders and different management levels and governance (Jønch-Clausen and Fugl, 2001; Coscossis, 2004).

Near half of the world human population lives in transboundary freshwater systems, remarking the importance of the sustainable and balanced water management. Transboundary WBMs are implemented in some regions, such as the case of the Danube basin in Europe, with efforts involving all countries to monitoring the quality of the basin (Šauer et al., 2023). The Transnational monitoring network of Danube basin, created in 1996, is an important tool under the Danube River Protection Convention (DRPC), whose contracting parties are committed to collaborate in the field of monitoring and assessment (Linnerooth-Bayer and Murcott, 1996). The network provides a well-balanced overall view of pollution and long-term trends in water quality and pollution loads in the major rivers of the Danube River Basin. The data is later used by an International Commission for the Protection of the Danube River. In North-America, the Rio Grande-Bravo basin is another example, with well-established environmental indicator to assess this transboundary water governance (Johns and VanNijnatten, 2021).

In South America, La Plata river basin (LPRB) which includes subbasins from Argentina, Brazil, Bolivia, Paraguay and Uruguay needs to develop integrated environmental management tools for a sustainable development. Register and analysis of the scientific published information regarding environmental quality and monitoring along the LPRB is a necessary step in order to know the up to date, the level of information and integration in this transboundary basin. The lack of this network is due to the non-integrative political agenda for the LPRB monitoring and management between the five countries, laying in a heterogeneity of normatives and standards for water quality (CIC, 2017).

1.1. Indicators of scientific activity for environmental management

The analysis of scientific activity, understanding and quantifying when and how much science is produced and where, is a way to assess the recent knowledge in a specific topic. These investigations and the dissemination of the results are useful for policy-making and management planning (Szteren and Lercari, 2022). Quantitative research indicators play a key role for developing future management strategies, which leads to the identification of research and management priorities (Palacios et al., 2011; Charles, 2017; Szteren and Lercari, 2022). Bibliometrics are needed to diagnose state of the art related to scientific production, determine the most active countries, identify knowledge gaps, topics and geographic areas where most information is produced (Bornmann and Mutz, 2015). The quantitative analysis of publications of the academic community is widely accepted to evaluate trends and patterns in most areas of scientific research (Ellegaard and Wallin, 2015). Just to mention some examples: Bilalova et al. (2023) recently conducted a global analysis on the effectiveness of Integrated Water Resource Management (IWRM) in relation to SDG indicators; Araujo et al. (2024) reviewed non-timber forest product research in the Amazon, identifying key knowledge gaps; and Tan et al. (2021) mapped global trends in green energy and environmental technologies through a bibliometric study. However, research efforts on baseline information and monitoring water quality and pollution in the LPRB is scant and fragmented (CIC, 2017a). The knowledge of the whole scientific research on the water quality of the basin is, in fact, a need to define standardized water quality criteria indexes for the Río de la Plata basin, like the proposed for agriculture activities worldwide (Johnston et al., 2024). Thus, indicators derived from scientometric and science mapping (i.e. the process of visually representing the structure, development, and interconnections of scientific knowledge across disciplines, topics, or research areas) may be useful for transboundary integration of basic information and would help for policy-making and management to develop WBM strategies for LPRB.

1.2. La plata river basin (LPRB)

South American freshwater basins (e.g. Amazonia, Orinoco and LPRB) show conflicting interests between environmental conservation policies and economic uses, such as urban development, tourism, mining industry, agriculture, ports, dredging and fisheries expansions. These activities generate different pressures that poses serious risk for integrity and human wellbeing (Campuzano et al., 2013). The LPRB covers a huge extension including territories from five South American countries, Argentina, Bolivia, Brazil, Paraguay, and Uruguay (Fig. 1). In hydrological terms it is the second basin of the continent in magnitude after the Amazonas, and is formed by three main hydrographic sub-basins: Parana, Paraguay, Uruguay and the sub-basin of the Río de la Plata estuary (García-Alonso et al., 2019). The LPRB generates an enormous outflow, 25,000 $m^3 s^{-1}$, which transports huge amount of dissolved salts and fine sediment into the Atlantic Ocean (Berbery and Barros, 2002).

Approximately 60% of the South American human population lives in the LPRB, which includes the capital cities (Asunción; Brasília; Buenos Aires and Montevideo), and one Bolivian big city (Sucre) (Fig. 1). In the LPRB is produced about 70% of the five countries GDP (Gross Domestic Product), (García-Alonso et al., 2019). An intensive land use and occupation results in considerable pressure on LPRB water quality, such as nutrient enrichment and contamination from urban and agricultural activities (CIC, 2017).

Different anthropic threats affect the LPRB water quality (Nogueira et al., 2021). Along the basin we can visualize different drivers and activities generating particular environmental pressures. At the Northeast of the basin, one of the most important physical interference on the fluvial systems is the construction of hydropower dams (Stevaux et al., 2009). Intensive river damming especially affects the upper sections of the Parana and Uruguay Rivers, where several cascades of reservoirs are in operation (Fig. 1). In addition to electricity, reservoirs provide other valuable services for society – irrigation, navigation, flood control, cage aquaculture and recreational beaches. Severe land used changes also occurred along the basin, mostly for agriculture activities (Alencar et al., 2020).

In relation with the governance there is an Intergovernmental Coordinator Committee (CIC, in Portuguese and Spanish) of LPRB, created upon the initiation of the treaty of LPRB in 1969 (CIC, 2017). However, it has a scant collaboration with the academy and decision makers on transboundary monitoring actions in the basin and in the resolution of conflicts on land uses and resources (Espíndola and Ribeiro, 2020). In different parts of the basin, commissions or committees exist to address various issues such as fisheries, damming for electricity generation, and fluvial transport (Villar et al., 2023).

Despite the importance and the size of the LPRB, almost no whole basin management exist and transboundary governance needs to be

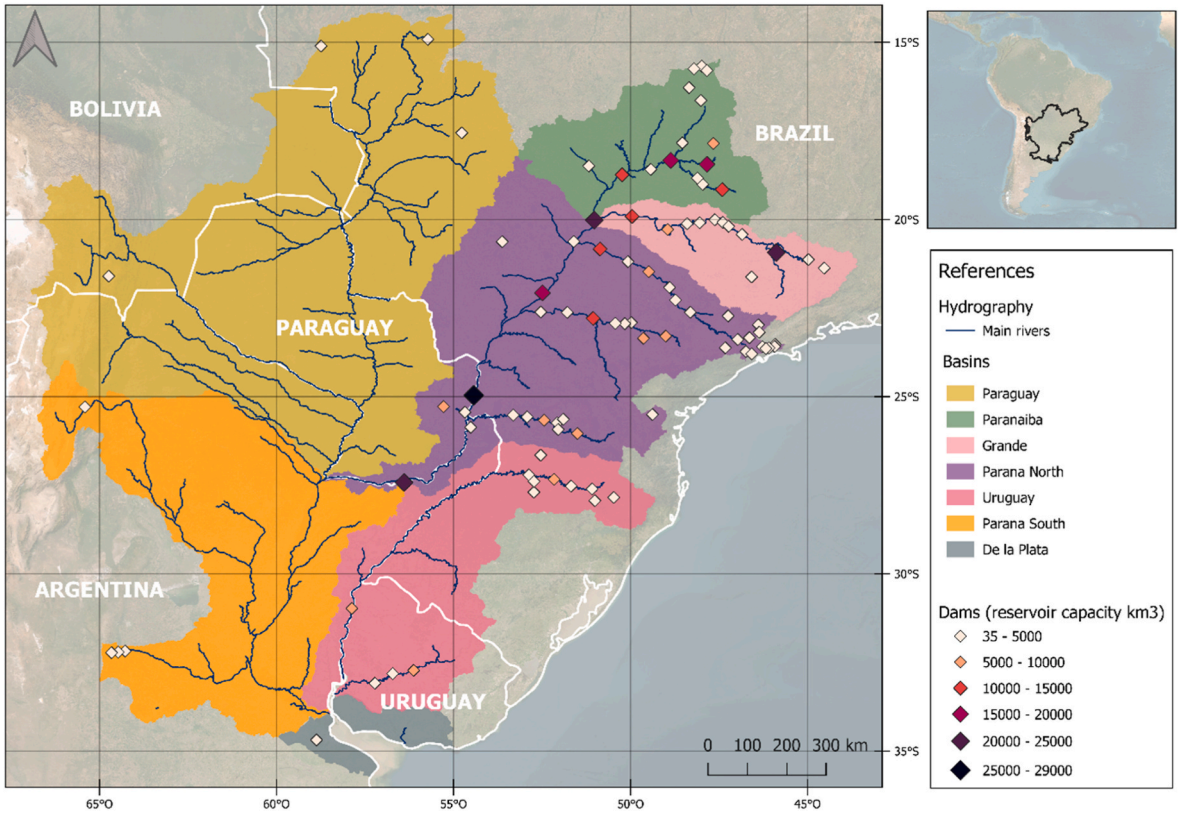

Fig. 1. Map of the La Plata River Basin. Depicted big cities, dams, and major sub-basins.

strengthened in several aspects, including consensus of monitoring programs (Villar et al., 2023). In fact, for the UN Sustainable Development programs Agenda for 2030, and in particular for clean water and sanitation goals, it is suggested to implement integrative management of water resources in all levels, including transboundary cooperation (Benson et al., 2020).

This study aims to examine the current state of knowledge on scientific results of integrated water quality within the LPRB. Utilizing scientific publications derived indicators (from Scopus and SciELO), we analyzed collaborative research trends, thematic foci, and key publications, describing national participation levels, as the basis for an integrated monitoring program. We searched for influential journals, authors, and articles, as well as collaboration networks between countries and researchers. Our analysis searched primarily for research themes related to water quality in the basin river's, exploring their interrelationships. Perspectives on strengthening basic studies and monitoring efforts for environmental quality within the basin are proposed.

2. Methods

2.1. Bibliographic database assembly

The analysis of the development and state of the art of water quality research efforts in the LPRB was carried out by forming two collections of bibliographic references, based on terms searched in existing scientific papers in Scopus (global database) and SciELO (regional database). These collections were used for a bibliometric review on the one hand and for science mapping analysis of scientific cooperation networks (co-authorship and co-occurrence of keywords) on the other hand. Scopus is the largest abstract and citation database of peer-reviewed literature: scientific journals, books and conference proceedings. Scopus was chosen since access to this database is guaranteed by the State of Uruguay (country affiliation address of the authors), which subsidizes the subscription annually for all country citizens. SciELO (Scientific Electronic Library Online) is a bibliographic database, digital library, and cooperative electronic publishing model of open access journals. SciELO was created to meet the scientific communication needs of developing countries and provides an efficient way to increase visibility and access to scientific literature. Today there are 16 countries in the SciELO network and its journal collections: Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Ecuador, Mexico, Paraguay, Peru, Portugal, South Africa, Spain, Uruguay, and Venezuela.

In order to obtain the publications related to water quality in the LPRB, advanced searches were carried out in each database using the names of the main tributary. For this purpose, the area was subdivided into ten meso-basins, corresponding to the ten main tributary rivers (Fig. 1; Table 1).

The names of the rivers and key concepts were searched for in the title, abstract and keywords (TITLE-ABS-KEY) according to the following string:

(TITLE-ABS-KEY ("X river") OR (TITLE-ABS-KEY ("La Plata basin") OR (TITLE-ABS-KEY ("La Plata river") OR (TITLE-ABS-KEY ("Rio de la Plata estuary") AND (TITLE-ABS-KEY ("water quality")) OR ((TITLE-ABS-KEY ("monitoring")) OR ((TITLE-ABS-KEY ("pollution")) OR ((TITLE-ABS-KEY ("contamination")).

Where "X river" is one of the following: Santa Lucía, Luján, Salado, Parana, Tietê, Paraguay, Apa, Cuiabá, Miranda, Jauru, Sao Lourenco, Taquari, Paranaiba, Ivaí.

Grande, Bermejo, Pilcomayo, Pardo, Anhanduí, Iguazú, Paranapanema, Uruguay, Rio Negro, Quaraí, Canoas, Miriñay, Ibicuí-Santa María, Ijuí.

In this way, a search was carried out for each of the rivers (X) and then a single collection was formed containing all the results from Scopus on the one hand and SciELO on the other hand.

The primary databases obtained were visually reviewed by all co-authors (curated) to ensure the relevance of the references obtained. At this stage, criteria for inclusion and exclusion of scientific papers were applied. For the permanence of the articles in the final lists, their

Table 1
Description (lengths and basin area) of rivers analyzed in this study from different sub-basins tributaries of the La Plata River Basin.

Sub-basins	Rivers	Length (km)	Area (km^2)	Countries
Río de la Plata estuary	Santa Lucía	248	12300	Uruguay
	Luján	128	3300	Argentina
	Salado	640	170000	Argentina
Parana	Parana	4880	2583000	Brazil/Argentina/ Paraguay
	Tietê	1150	150000	Brazil
	Pilcomayo	2695	1170000	Bolivia/Paraguay/ Brazil/Argentina
	Paraguay	380	4098	Paraguay/Brazil
	Apa	980	102750	Brazil
	Cuiabá	490	42994	Brazil
	Miranda	ND	Pantanal	Brazil
	Jauru	842	Pantanal	Brazil
	Sao Lourenco	1193	34400	Brazil
	Pardo	685	36622	Brazil
	Taquari	ND	82665	Brazil
	Paranaiba	1060	123162	Argentina/Bolivia
	Ivaí	573	3638	Brazil
	Grande	1320	62000	Argentina/ Paraguay/Brazil
	Bermejo	929	100800	Brazil
	Iguazú	570	22808	Brazil/Argentina
	Paranapanema	285	10977	Brazil
Uruguay	Uruguay	1779	370000	Argentina/Brazil/ Uruguay
	Miriñay	285	10977	Argentina
	Río Negro	750	70714	Uruguay/Brazil
	Cuareim	340	14750	Uruguay/Brazil
	Canoas	570	35131	Brazil
	Ijuí	542	10766	Brazil

correspondence to aquatic bodies was verified, including the water column and/or sediment compartments, all environmental variables and any study in any type of organism or level of organization. In the same way, exclusion criteria were applied for those articles that were not from the aquatic ecosystems, laboratory experimental articles, and articles corresponding to hydrological and theoretical models. The information for the indicators of scientific production were obtained from the metadata available in the bibliographic fields (e.g. authors, affiliation countries, sources, citation, etc.) of the selected databases. Only the 20 most-cited documents were entirely read to discuss the most academically relevant aspects in greater detail.

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA; O'Dea et al., 2021) were followed in our bibliographic review to provide transparency and reduce bias in document selection, as recommended by Aria and Cuccurullo (2017). The PRISMA flow diagram (Page et al., 2021) is provided as digital supplementary material (Online Supplementary Material 1), along with a detailed description of the methods used.

2.2. Bibliometric description

The production of academic works in the LPRB was analyzed at the level of authors, documents, sources and countries using conventional bibliometric indices for the period analyzed. The evaluation of the collections included the total number of documents, the average number of documents per year, the average number of citations per document, the number of sources (e.g. journals, books, chapters, etc.). The number of each type of document (e.g. reviews, notes, etc.) was also determined, as well as the total number of authors, the collaboration rate of authors, documents per author, authors per document and co-authors per document. The frequency of countries found and authors in the papers was assessed and the most cited papers and authors during the study period were identified. This information was arranged in rankings to highlight the most relevant cases in the collection as a whole. To perform the quantitative bibliometric analysis of the collections, the specialized package bibliometrix (Aria and Cuccurullo, 2017) of the R program (R Core Team, 2016) was used.

2.3. Science mapping

Relationships between authors, countries and concepts were addressed by mapping scientific networks. In this type of network, nodes can be, for example, researchers, countries, institutions or keywords while the edges indicate the relationships between pairs of nodes. In this work, three types of bibliometric networks have been carried out: co-authorship, country co-authorship and keyword co-occurrence.

In co-authorship-based bibliometric networks, researchers, research institutions or countries are linked to each other based on the number of publications they jointly authored (Luukkonen et al., 1992). This allows to delineate the properties of the research community focused on LPRB monitoring (Peters and Van Raan, 1993) and to describe the main research groups and their interactions (collaboration) through co-authorship of papers. Similarly, we implemented the network of country co-occurrence in authorship to visualize high-level collaboration between countries.

Additionally, we implemented the concept co-occurrence network based on the keywords provided by the author of a publication. The number of co-occurrences of two keywords is the number of publications in which both words appear together in the keyword list (Peters and Van Raan, 1993). Following this logic, a co-occurrence map was implemented to visualize the conceptual structure of the field of research on the monitoring of LPRB (Courtial, 1994; Delecroix and Epstein, 2004). The words used in the bibliometric search such as "monitoring", "pollution" etc. and words related to names of countries, cities and specific sites were discarded as they were not considered informative. The conceptual map obtained allows the identification of clusters of the predominant research areas in the document collection.

The mapping of co-author and co-occurrence networks was carried out with the VOSviewer software (van Eck and Waltman, 2009). In the first instance, a similarity matrix is calculated based on the co-occurrence matrix (van Eck and Waltman, 2010), then a map is produced by applying the VOS mapping technique to the similarity matrix and finally the map is translated, rotated and mirrored (van Eck and Waltman, 2009) to achieve a visually informative representation.

3. Results

A number of 1029 articles were identified to belong on environment monitoring studies in aquatic ecosystems along the LPRB. From the total, 672 studies were identified on Scopus and 357 in SciELO. Few works involve several sub-basins, however none of the articles analyzed cover the entire LPRB in the 5 countries. The most integrative scientific document on water quality is Nogueira et al. (2021), although Argentinian Andean region as well as the entirely Bolivian part of the basin were not studied. The results obtained denoted publications in 26 rivers covering the main sub-basins (Table 1).

There were 357 documents published in SciELO and 672 in Scopus on water quality monitoring in the LPRB from 1977 to 2023. The temporal trend of number of documents could be attributed to three periods (Fig. 2A): From 1977 to 1990, there was very little production with no growth. Scopus always had more documents than SciELO. From 1990 to 2011, there was a significant increase in production, and later in Scopus reaching a peak of 50 documents in 2021. From 2011 to the present, there have been large fluctuations and stagnation. The overall annual increase rate of publications in Scopus was 1.37%. The publications in SciELO follow a similar trend, but to a much lesser extent, the annual increase rate reached 4.62%. The rivers in the basin where the most documents are produced are generally similar between the two databases, SciELO and Scopus, but there are some notable differences

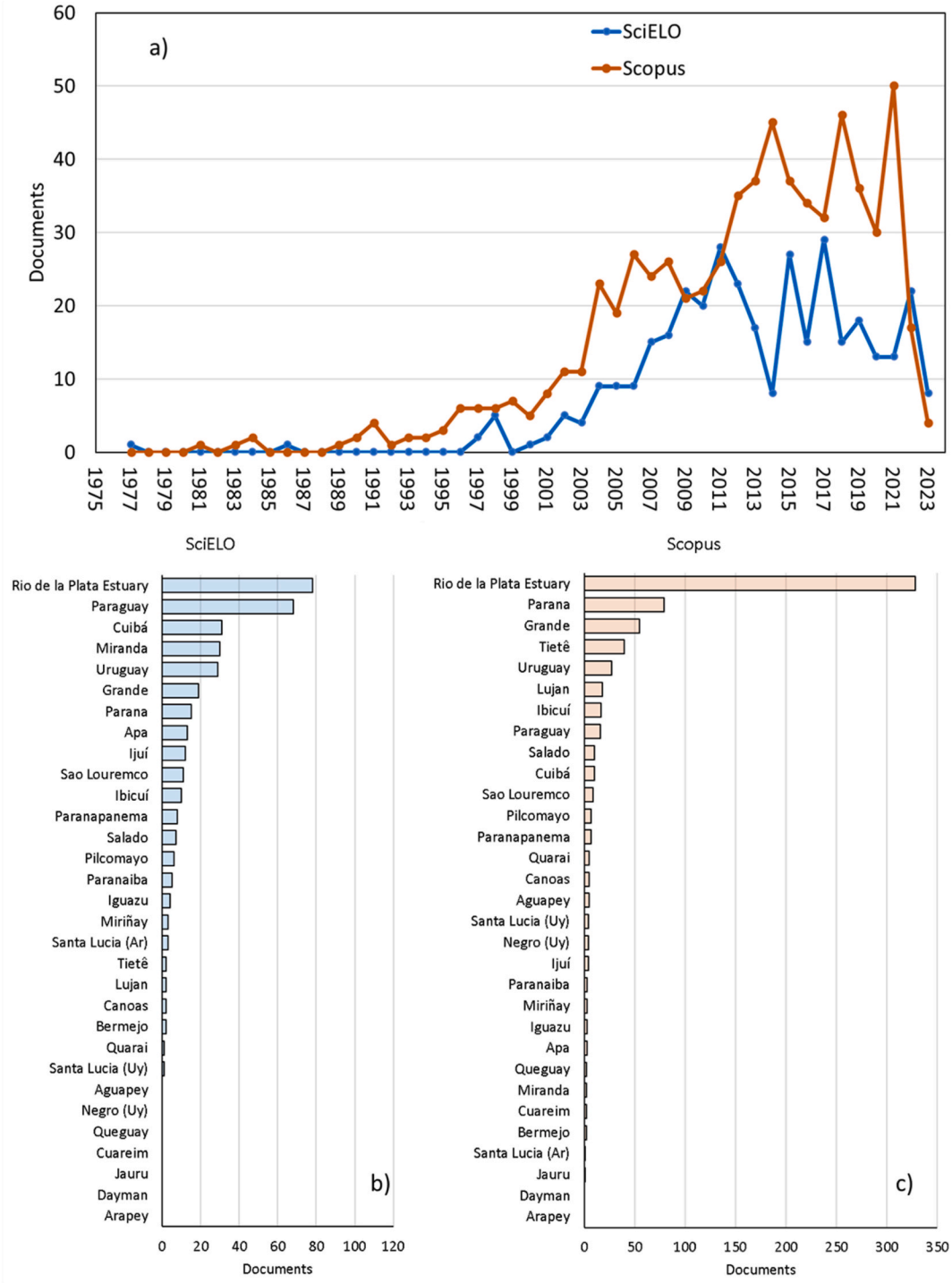

Fig. 2. Annual total number of scientific publications about the La Plata River Basin in the Scopus and SciELO databases (a) and total number of documents produced for each of the analyzed rivers in the SciELO (b) and Scopus databases (c).

(Fig. 2B). The estuary region of the LPRB is the most studied area of the basin in both databases. It is followed by the Parana, Grande, Tietê, and Uruguay rivers in Scopus, and by the Paraguay, Cuiaba, and Miranda rivers in SciELO.

Analyzing the countries involved in publications, Fig. 3 shows the quantity of research papers produced by South American and other countries related to environmental monitoring at the LPRB, as listed in both databases. Scopus has twice the number of publications than SciELO, indicating a major preference for journal with international circulation. Among the LPRB, the most prolific countries were Argentina, Brazil, Uruguay, with scant information from Bolivia and Paraguay. The rest of publications are mostly in collaboration with United States, Germany and Spain.

Fig. 4 shows the marked disparities in the overall number of articles produced by the 20 most prolific sources of publications pertaining to the LPRB. The SciELO database contains more regional publications, whereas Scopus contains more international publications. In Fig. 4A most of the regional journals are from Brazil and Argentina and in general focused on local environmental aspects of particular rivers. At international publication scale (Fig. 4B) most of the articles were

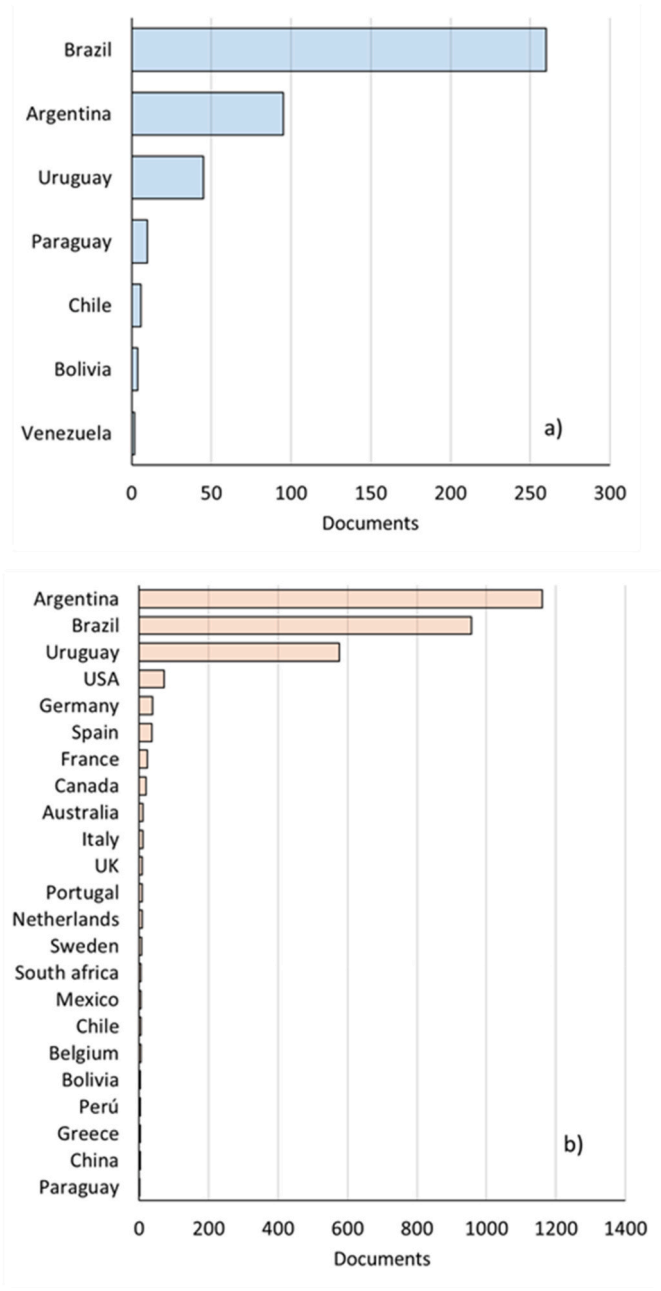

Fig. 3. Number of documents per country related to the La Plata River Basin listed on both databases. (a) SciELO; (b) Scopus.

published in Elsevier journals, followed by Springer and few independent publishers. Comparing both repositories, a qualitative difference can be observed including differences in the subject matter of the articles, with more biological aspects in regional publications and sometime implying field sampling effort and less analytical and expensive environmental studies which are published in international journals. The dominance of regional journals (SciELO) suggests that there is a strong interest in the LPRB in South America, while the dominance of international journals in Scopus is focused in determined areas of the basin, performing novel studies with international relevance.

The co-authorship network of articles published on the LPRB (Fig. 5), consists of 32 clusters, or research groups, comprising a total of 300 researchers. Several clusters show strong connections between them, while a significant number of small clusters are totally unconnected. Notorious interconnected clusters located in Uruguay are led by researchers such as Muniz, Calliari, Defeo, etc. There are also significant clusters in Argentina, led by researchers such as Colombo, Simionato, Jaureguizar, Acha, Gómez, Mianzán, Boltovskoy, etc., and in Brazil, led by researchers such as Demello, and Volpedo among others. Notably, the researchers from Argentina and Brazil appear to be less interconnected than those from Uruguay.

Looking forward to determine the consistency on co-authorship network among countries producing documents related to the LPRB based on the Scopus database (Fig. 6), we observed that there is not scientific collaboration among the five countries where exist the LPRB. The network consists of 14 countries, with Argentine, Brazil and Uruguay as the most important countries based in the number of documents and links (citations among countries. Fig. 6), although this interaction does not form a scientific publication cluster. The most important countries did not form groups between them. Instead, they are connected with outer region nations. This suggests that there is a strong collaboration between researchers from different regions of the world, but that there is still room for improvement in the collaboration between researchers from the LPRB.

Fig. 7, shows four clusters of keywords, each of which is associated with a different research theme. Cluster 1: Pollution (sedimentology, heavy metals, analytics methods, sewage, geologic). Cluster 2: Toxicity (fish, toxicity, chemistry, biomarkers, bioaccumulation), Cluster 3: Environmental change (salinity, turbidity, climate change, floods, hydrology) and Cluster 4: Biodiversity (biodiversity, species diversity, crustacea, polychaeta, fishes, ecological populations). The figure also shows the connections between the keywords. These connections indicate that the keywords are often used in the same documents. For example, the keyword “sedimentology” is connected to the keywords “heavy metals” and “analytics methods,” suggesting that these keywords are often used in studies of the pollution of sediments with heavy metals.

4. Discussion

Our study, focused on the production of scientific documents about water quality in the LPRB, shows a clear lack of cohesion among the research groups of the different involved countries. A substantial number of studies have been conducted on environmental quality, water assessment and monitoring in different aquatic ecosystems within the LPRB. However, despite this volume of research, there is a noted absence of studies addressing environmental monitoring for the entire basin, evidencing that the scientific investigations are fragmented or focuses on specific sub-regions or rivers within the basin.

The LPRB has limited academic data, with water quality studies beginning in the 1970s (Table 2). The low production of research documents from 1977 to 1990 likely resulted from a lack of awareness, funding, and resources. The increase in publications from 1990 to 2011 may reflect growing awareness, better funding, and improved sampling and analytical technologies. The fluctuations and stagnation from 2011 onwards could be attributed to factors such as the global economic crisis, shifting funding priorities, and the rising complexity of water quality monitoring. Research from 1977 to 2023 can be divided into three periods: minimal growth from 1977 to 1990, a significant increase from 1990 to 2011, and fluctuating trends since 2011. Scopus published more documents than SciELO during the first period (Table 2). From 1990 to 2011, Scopus showed a peak in 2011 with 50 documents, reflecting heightened environmental awareness and improved research methods. The annual growth rate of publications is 1.37% for Scopus and 4.62% for SciELO, likely due to SciELO’s increasing prominence in Latin America. While research output has grown, it has not been consistent, with recent periods of stagnation (Table 2).

The pattern of increased production of scientific articles is common across most scientific disciplines. This trend is observed in various research areas (Lercari, 2021; Szteren and Lercari, 2022), including river water quality assessment (Wang et al., 2016). Possible causes for this increase include heightened environmental awareness,

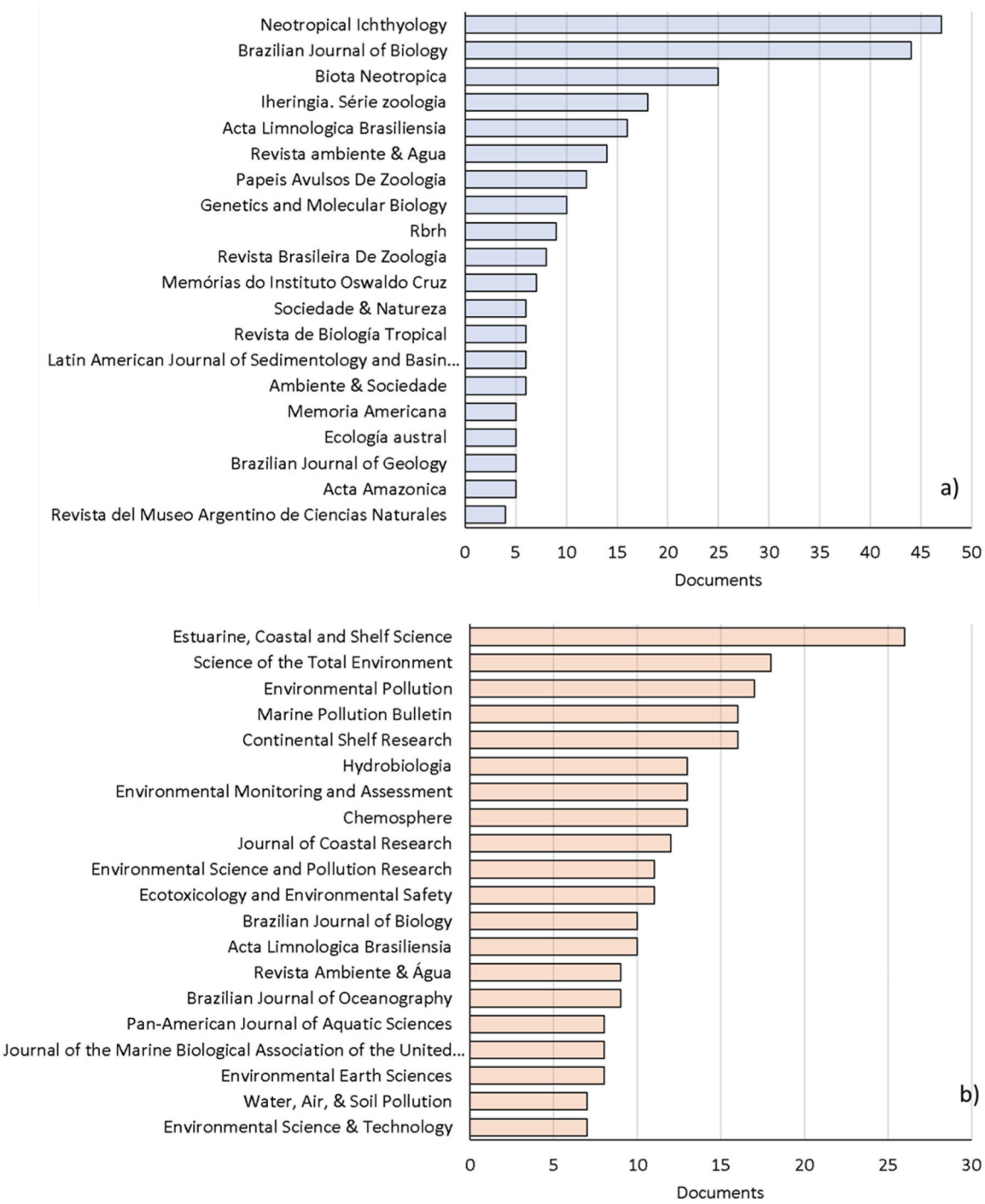

Fig. 4. Total articles produced by the 20 most frequent sources of publications referring to the La Plata River Basin. a) SciELO; b) Scopus.

advancements in research methodologies, greater availability of funding, and improved collaboration among researchers globally.

The identified publications cover 26 rivers across the main subbasins of the LPRB, varying in length and basin size, from smaller rivers like the Luján in Argentina to the expansive Paraná River system in the northern part of the basin. The most frequently studied rivers in both databases show consistency, reflecting broad agreement on key areas of concern within the basin. The Río de la Plata estuary is the most researched zone, likely due to its ecological importance, economic value, and higher pollution levels or habitat modifications (García-Alonso et al., 2019). Scopus focuses on the Paraná, Grande, Tietê, and Uruguay rivers, while SciELO emphasizes the Paraguay, Cuiaba, and Miranda rivers, likely reflecting regional research priorities. Publication numbers may correlate with ecosystem size or population density, as seen in other global monitoring programs, such as the Brahmaputra (Chakraborty et al., 2016), Nile (Dahshan et al., 2016), Yangtze (Peng et al., 2018), Danube (Linnerooth-Bayer and Murcott, 1996), and Amazonas (OCTA, 2023).

The analysis of research contributions from various countries reveals that most environmental quality research on the LPRB, as recorded in Scopus, comes from South American countries, particularly Argentina, Brazil, and Uruguay. In contrast, Bolivia has fewer publications, and Paraguay has none. Several factors may limit scientific collaboration between countries, including physical distance, which increases

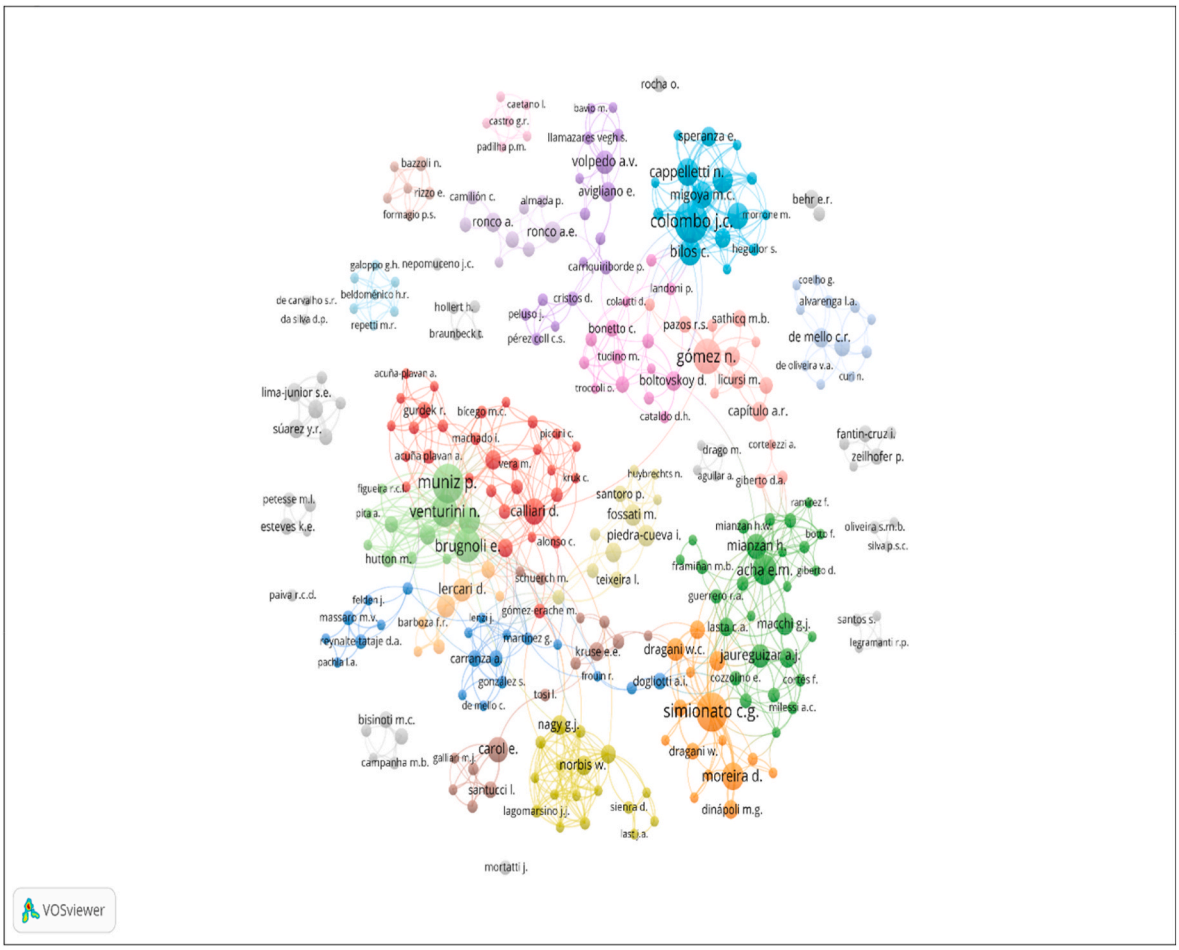

Fig. 5. Visualization of the co-authorship network of articles published related to the La Plata River Basin, based on Scopus database. Some authors names are omitted to facilitate the visualization. https://tinyurl.com/2qr4arj7.

coordination costs and complicates face-to-face interactions (Hoekman et al., 2010). Institutional differences, such as funding schemes and norms, can also impede alignment (Hoekman et al., 2010). National funding policies often prioritize domestic collaborations, and cultural and language barriers further favor national research. International collaborations, particularly with the U.S., Germany, and Spain, are more common, reflecting global interest in LPRB environmental studies (Tolochko and Vadrot, 2021). These partnerships may be facilitated by access to advanced lab equipment or analysis services, which are often limited in the region, and by the presence of South American post-graduate students at these institutions. This underscores international cooperation in studying basic sciences for monitoring the LPRB, as seen in other scientific fields (Tolochko and Vadrot, 2021).

To foster robust international scientific collaboration, countries can implement a multi-pronged approach encompassing funding, infrastructure, legal frameworks, and interpersonal connections (Scherngell and Barber, 2009). Dedicated funding programs are needed specifically designed for collaborative research, incentivizing cross-border scientific endeavors (e.g. in EU with European Parliament report, 2017). Integrating research infrastructure and data networks across national boundaries can facilitate collaboration by providing shared access to resources and reducing duplication of effort. Also, clear legal frameworks addressing intellectual property rights, data sharing, and research standards are crucial for building trust and transparency among collaborating institutions (Sonnenwald, 2007).

There are notable discrepancies in the volume and source distribution of publications on environmental research in the LPRB. The SciELO database predominantly features regional publications, mainly from Brazil, Argentina and Uruguay, focusing on local environmental issues of specific rivers, reflecting national interest and investment (Spinak, 2014). Considering the other countries involving in the basin, Paraguay and Bolivia also showed a major representation in Scielo (see Fig. 3). In contrast, Scopus includes more international contributions, with many articles published in journals by prominent publishing houses like Elsevier and Springer. This suggests a broader research scope and access to advanced methodologies and technologies. Regional journals often emphasize biological aspects and fieldwork due to proximity to the basin, while international journals tend to publish more analytical and technically advanced research, aiming for global impact. The predominance of regional journals in SciELO indicates a strong local scientific community engaged with basin-specific issues, whereas the presence of international journals in Scopus shows that research from the basin has global significance (Santa and Herrero Solana, 2010). This highlights the importance of supporting both local and international research to better understand and manage the complex water systems of the Rio de la Plata Basin.

Analyzing the co-authorship network of articles related to the LPRB, we observe a web of scholarly collaboration composed of 32 clusters, representing various research groups and encompassing around 300 researchers in total. The network illustrates varying degrees of connectivity, with several robust clusters that are interlinked, while other, smaller clusters remain isolated, indicating siloed research efforts or specialized niches of inquiry within the broader field.

It is particularly noteworthy that the key interconnected clusters are situated in Uruguay, with influential researchers such as Muniz, P; Calliari, D. and Defeo O., spearheading these efforts. Meanwhile, in

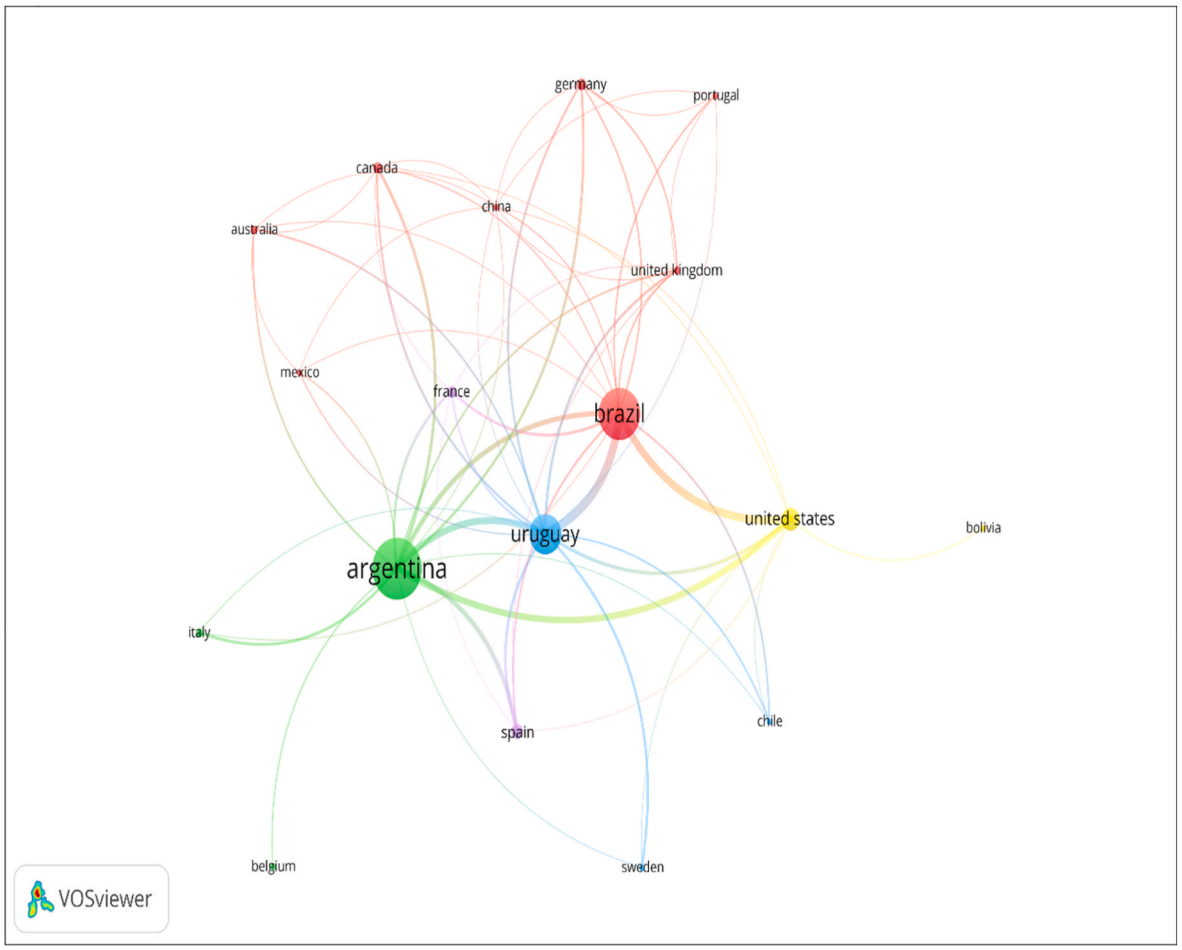

Fig. 6. Co-authorship network among countries producing documents related to the La Plata River Basin based on the Scopus database. https://tinyurl.com/2z64sj76.

Argentina, significant research groups are led by figures like Colombo F.; Simionato, C.; Acha, M.; Gómez, N.; Volpedo, A.V. and Boltovskoy, A. Brazil also hosts important clusters headed by researchers such as De Mello, K.; Bisinoti, M.C. and Lima Junior S.E. However, the network analysis points to less interconnectivity between Argentine and Brazilian researchers as compared to their Uruguayan counterparts, suggesting potential gaps or areas for enhanced communication and collaboration.

Shifting the focus to the integration of the co-authorship network among countries generating research on the LPRB, based on data collated from the Scopus database, a lack of scientific collaboration among the five countries within the basin is again discernible. The co-authorship network spans 14 countries, with Uruguay, Argentina, and Brazil standing out as the most significant contributors. Yet, rather than forming a cohesive local cluster, these key countries are shown to be linked with nations outside the region. This pattern evidences the existing global collaborations but also a need for strengthening regional ties among researchers in the LPRB area.

Considering the different focuses of limnologists working on riverine systems and oceanographers studying the estuarine part of the basin, it is understandable that scientific and methodological differences may pose challenges to collaboration. These fields often use distinct terminologies, perspectives, and research methods, making integration difficult. The observed disparities in collaboration could stem from such disciplinary divides (Downing, 2014). To achieve a more integrated and comprehensive understanding of the complex environmental dynamics of the LPRB, bridging these gaps and fostering interdisciplinary and inter-regional partnerships are crucial for future research endeavors.

The research themes emerging from the analysis of environmental quality in the LPRB are distinguished by four interconnected areas. Pollution is a central focus, with studies frequently examining sediment contamination, levels of heavy metals, and the methods to analyze these pollutants (Snowsill et al., 2024). Toxicity is another significant area, where research often involves the assessment of hazardous substances in aquatic organisms, utilizing biomarkers and bioaccumulation data (García-Alonso et al., 2011). Environmental change is also a key research theme, investigating the effects of changes in salinity, turbidity, and the impacts of climate change and extreme weather events like floods on the hydrology of the basin (Li et al., 2020). Lastly, biodiversity and species diversity are critical areas of study, with particular attention on various aquatic species and ecological populations (Zambaldi and Pompeu, 2020). These themes represent the nexus of interdisciplinary work in the basin, acknowledging that efforts to understand one aspect invariably involve or affect the others.

To align with the United Nations Agenda 2030 and SDG 6 on sustainable water management, enhancing transnational collaboration in the LPRB is crucial (UN, 2015). This includes improving pollution monitoring, standardizing toxicity assessments (Snowsill et al., 2024), addressing climate change (Li et al., 2020), and coordinating conservation strategies (Zambaldi and Pompeu, 2020). Collaboration among researchers and policymakers from Uruguay, Argentina, Brazil, Paraguay, and Bolivia is key for data sharing and joint research. Global partnerships can drive progress toward SDG 6 and address water quality challenges.

Despite efforts by the Intergovernmental Coordinating Committee (CIC, 2017a; 2017b), opportunities remain to improve transboundary water management in the LPRB. Challenges in decision-making and

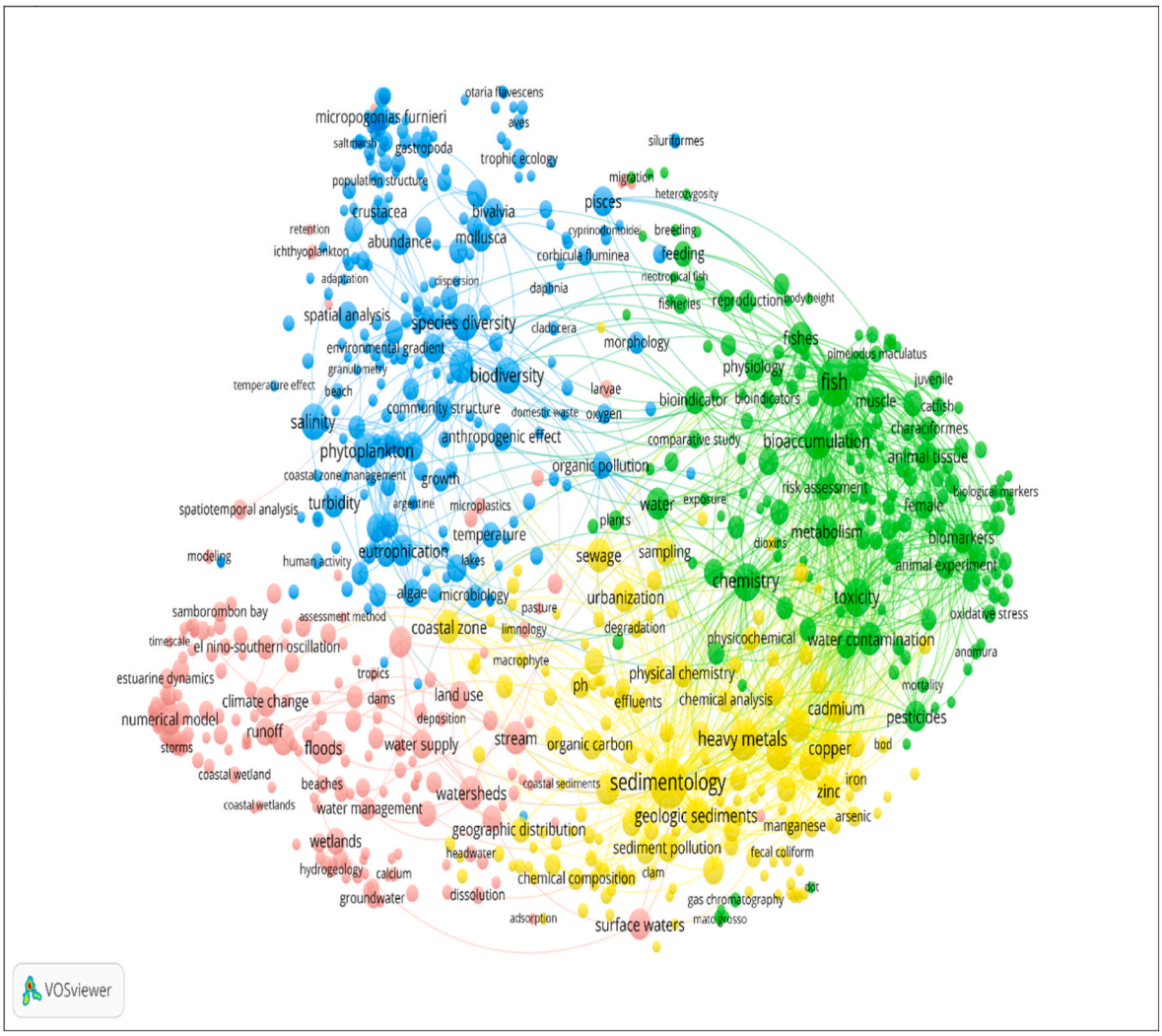

Fig. 7. Visualization of the network of co-currencies of keywords in scientific documents related to the La Plata River Basin based on the Scopus database. https://tinyurl.com/2aqhndbo

coordination hinder research on key issues like water quality. While the Decision Support System excels in hydrometeorological data, adding water quality parameters would provide a more complete understanding of the basin's health. A recent water quality assessment, updating the 2016 review (CIC, 2017a), highlights the lack of standardization. The United Nations Agenda 2030, particularly SDG 6, provides a framework to enhance collaboration (https://unesdoc.unesco.org/ark:/48223/pf0000243651). Aligning with these goals can strengthen academic networks, promote water diplomacy, and improve sustainable water management in the LPRB. A new GEF project (GEF, 2024) emphasizes stakeholder engagement and collaboration, offering hope for better integration of basin-wide water quality monitoring, especially with academic involvement.

5. Conclusion

Our analysis of scientific research on water quality in the LPRB reveals significant fragmentation and a lack of cohesive collaboration among the involved countries. Despite substantial research efforts, the absence of integrated studies across the entire basin highlights the need for enhanced transboundary coordination. To ensure the sustainable management of the basin's water resources, we recommend strengthening the role of the CIC in coordinating joint research and policy implementation, enhancing data sharing and standardization of monitoring methodologies, and fostering international and interdisciplinary collaborations.

It is crucial to emphasize the role of academic institutions in conducting research network and capacity building. By involving academic institutions, we can ensure that cutting-edge science informs management practices and that local expertise is developed. Prioritizing investments in research and capacity building within universities can mitigate this issue, ensuring that funds are effectively used to support sustainable development goals. By aligning these efforts with the objectives of the United Nations 2030 Agenda, particularly SDG 6, we can achieve significant progress in safeguarding the environmental health and sustainable development of the LPRB.

CRediT authorship contribution statement

Javier García-Alonso: Writing – review & editing, Writing – original draft, Investigation, Conceptualization. **Alexis Rodríguez-Yaniero:** Investigation. **Diego Lercari:** Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence

Table 2
Bibliometric description of publications registered in Scopus and SciELO databases associated to the La Plata River Basin. NA: not available.

Description	SciELO	Scopus
Main information about data		
Time-span	1977:2023	1972:2023
Sources (Journals, Books, etc)	87	275
Documents	357	672
Annual Growth Rate %	4.62%	1.37
Document Average Age	NA	11.1
Average citations per doc	NA	20.76
References	NA	29884
Document contents		
Keywords Plus (ID)	NA	4325
Author's Keywords (DE)	2158	1774
Authors		
Authors	1292	1867
Authors of single-authored docs	NA	23
Authors collaboration		
Single-authored docs	NA	25
Co-Authors per Doc	NA	4.49
International co-authorships %	NA	22.47
Document types		
Article	NA	626
Book chapter	NA	16
Conference paper	NA	16
Note	NA	1
Review	NA	13

the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.indic.2025.100651.

Data availability

Data will be made available on request.

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