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Articles

A systematic review of scientific research on the Santiago River

Una revisión sistemática sobre investigaciones científicas sobre el Río Santiago

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Abstract

The socio-ecological dynamics of rivers is perhaps one of the most analytically complex systems, where environmental, ecological, biological, social, economic, cultural or political processes, among others, are integrated. In this sense, it is important to know different ways of analyzing those socio-ecological dynamics that develop around these ecosystems. Thus, the objective of this document is to show, based on a systematic review of the scientific literature, the trends and analytical gaps in research over the last twenty years aimed at analyzing various social and ecological dynamics around the Santiago River, located in the Lerma-Santiago hydrological region, Mexico. To do so, we start from the SALSA framework, which guided the four stages of this research, and from the PRISMA protocol, as a detailed guide to the components in each stage of this research. It is suggested that future research should take into account the problems that directly affect the Santiago River, for example, the pollution crisis, the loss of aquatic biodiversity and its implications, regional inequalities in research coverage, fragmentation in the governance of the Santiago River or the proposal of priority actions for the comprehensive management of the basin.

Keywords: River basins, scientific research, water resources management, content analysis, sustainable development, Mexico.

Resumen

La dinámica socioecológica de los ríos se trata, quizá, de uno de los sistemas de mayor complejidad analítica, donde se integran procesos ambientales, ecológicos, biológicos, sociales, económicos, culturales o políticos, entre otros. En este sentido, es importante conocer diversas

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formas de analizar aquellas dinámicas socioecológicas que se desarrollan en torno a estos ecosistemas. Así, el objetivo de este documento es mostrar, a partir de una revisión sistemática de la literatura científica, las tendencias y vacíos analíticos en las investigaciones realizadas los últimos veinte años orientadas al análisis de diversas dinámicas sociales y ecológicas en torno al río Santiago, ubicado en la región hidrológica Lerma-Santiago, México, para lo cual se parte del marco metodológico SALSA, que orientó las cuatro etapas de esta investigación, y del protocolo PRISMA, como una guía detallada de los componentes en cada etapa de esta investigación. Se sugiere tomar en cuenta para futuras investigaciones las problemáticas que afectan directamente al río Santiago, como la crisis de contaminación; la pérdida de biodiversidad acuática y sus implicaciones; la investigación concentrada en regiones muy puntuales que genera ciertas desigualdades regionales en la cobertura de investigación, lo cual limita que algunas zonas del río se integren a los planes de gobernanza y, por consecuencia, se percibe una fragmentación en la gobernanza del río Santiago y en la gestión integral de la cuenca.

Palabras clave: cuenca fluvial, investigación científica, gestión de los recursos hídricos, análisis de contenido, desarrollo sostenible, México.

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Introduction

The intensity and uncontrolled growth of anthropogenic dynamics have induced intense socio-environmental changes in the world with significant secondary effects (Chapin III *et al*., 2000; Bray, Ellis, Armijo-Canto, & Beck, 2004; Turner *et al*., 2001; García-Espino & Valdés-Fernández, 2019; Roldán-Villanueva, 2021). Among these changes have been emerging problems related to water quality and consumption or the diversion and pollution of rivers and lakes in the world (Li *et al*., 2022; McDonald, Weber, Padowski, Boucher, & Shemie, 2016; Duan *et al*., 2016; Raman, Bouwmeester, & Mohan, 2009). Although during the last three decades rivers have been considered one of the main components providing multisectoral ecosystem services in rural and urban territories, mainly (Sánchez, 2024; Petsch *et al*., 2023; Shaad *et al*., 2022; Böck *et al*., 2018; Basak *et al*., 2021), scientific research is continuous and growing that warns about pollution in lakes and rivers around the world, which leads to serious problems related for the health and long-term conservation of social and ecological systems (Kakade *et al*., 2021; Lin, Yang, & Xu, 2022; Hassan-Al-Taai, 2021; Lin *et al*., 2024; Wei, Rao, Liu, Wang, & Cao, 2024).

In Mexico, the management of rivers, especially those that have been reached by urban centers, is one of the most complex environmental challenges today. One of the main problems is the lack of knowledge and understanding of the systemic dynamics of rivers behave, which leads to the implementation of "solutions" that end up with socio-environmental impacts that are difficult to reverse and many times, rivers end up paved, piped, as discharges of solid waste and sewage, or open-air garbage

dumps, causing social and ecological diseases, floods and socio-ecological imbalances.

From the approaches of complexity and network theory, rivers have the characteristics to be studied as networks of complex open systems that remain in constant dynamics and, because of this, have the peculiar ability to articulate and structure the territory, in fact, authors such as Thoms and Sheldon (2019) argue that it is the unpredictability and coupling of rivers that dominates the behavior of the Earth's surface, so that scientific research related to the study of rivers is increasingly challenging due to rapid climatic, landscape, and social changes (Gilvear, Greenwood, Thoms, & Wood, 2016). Therefore, it is necessary for concepts, methodologies, and research to remain in a state of constant updating, restructuring, and learning. It is therefore the responsibility of academia to update those concepts and ways of analyzing the reality of rivers and their dynamic behavior, since management applicable to the present day must be supported by up-to-date and interdisciplinary science. Some examples of these interdisciplinary approaches in river science are the studies by Collier, Baker, David, Górski and Pingram (2019), and Habit *et al*. (2019), who suggest that although there is specialized scientific knowledge about rivers, it is necessary to integrate that knowledge of river science into models or broad analytical frameworks to improve their management towards sustainability.

For the Mexican case, specialists such as Núñez (2024) express that Mexico is currently facing one of its greatest challenges: the water crisis. This is a challenge that puts terrestrial ecosystems at risk, particularly rivers and the ecosystem services that they provide (Martínez, Kralisch, Escolero, & Perevochtchikova, 2015). Such challenge implies the problems of the country's rivers, which have ended up piped, polluted,

paved, or used as deposits for toxic, industrial, or solid waste that end up with affectations towards social and ecological systems. One of the challenges to be overcome is the permanence of science and academia under the shadow of individualism per se, since in order for knowledge production to have a strong impact on the solution of these types of problems, it is important not only to update scientific knowledge, but also the collaboration and communication of science for the support of decision-making and policy formulators.

In this sense, it is essential to update knowledge about the ecological and social processes involved in the management and analysis of rivers, therefore, this research focuses on a geographical region with a strong water importance for the western region of the country. It is the Santiago River or Río Grande de Santiago, considered one of the most important rivers in Mexico and one of the most polluted in the country because it receives discharges from factories, farms, human settlements, and leachates into the riverbed, so high levels of heavy metals concentrated at different points of the river. In this regard, there is scientific evidence that this contamination in the river has been the cause of serious health problems for the population of the towns surrounding the riverbed, for example: cancer diagnoses, respiratory problems, kidney diseases, and deaths from poisoning (Arellano-Aguilar, Ortega-Elorza, & Gesundheit-Montero, 2012; Montes-Rubio *et al.*, 2021).

Although there is a wide accumulation of knowledge related to the river and the socio-ecological processes that occur in its geographical territory, no scientific evidence was found that provides an overview of the current state of knowledge to understand research trends and challenges, as well as the results and suggestions proposed for this issue from academia. Therefore, this document aims to show the

methodological process and results of a systematic review of the scientific literature produced over the last twenty years in relation to the socioecological processes perceived in the Santiago River, which covers different municipalities in the states of Jalisco and Nayarit.

Based on the objective of this research, the following guiding questions were proposed for its development: What are the disciplinary or analytical visions interested in the socioecological processes and management of the Santiago River? What are the most widely theories, methodologies, or research concepts and topics related to the Santiago River? What results have been obtained based on the most widely used research trends? What type of research has the greatest impact on the reality of the river? Where does the research come from (geographical area, institutions, and journals)? What challenges or analytical gaps are identified for the future in the research analyzed?

It is worth mentioning that this type of systematic review has various methodological and theoretical implications, as well as implications for decision-making at the academic and political levels (García-Perdomo, 2015; Page *et al*., 2021). Thus, this document follows the structure of the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol and is divided into the following five sections: an introduction, where the objective of the research is justified and presented; the methodological section; the results; the discussions; and a section on final reflections (Page *et al*., 2021).

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Materials and methods

Geographical location of the Santiago River

The Santiago River is located in central-western Mexico within the Lerma-Santiago-Pacific basin, not only is it a geographically extensive water ecosystem, but its complexity and scale make it one of the regions with the most significant ichthyofaunal diversity in the country.

Although the basin in which the river is located covers six states; Hidalgo, Querétaro, Guanajuato, and Michoacán, the Santiago River itself flows only through the states of Jalisco and Nayarit before emptying into the Pacific coast. Its source is in the northeastern part of Lake Chapala, and at least six major dams have been built along its course in the northwestern part of the country. Figure 1 shows the geographical location of the river, as well as its dams and main tributaries located on the eastern bank of the river, which originate at elevations above 2 500 meters above sea level.

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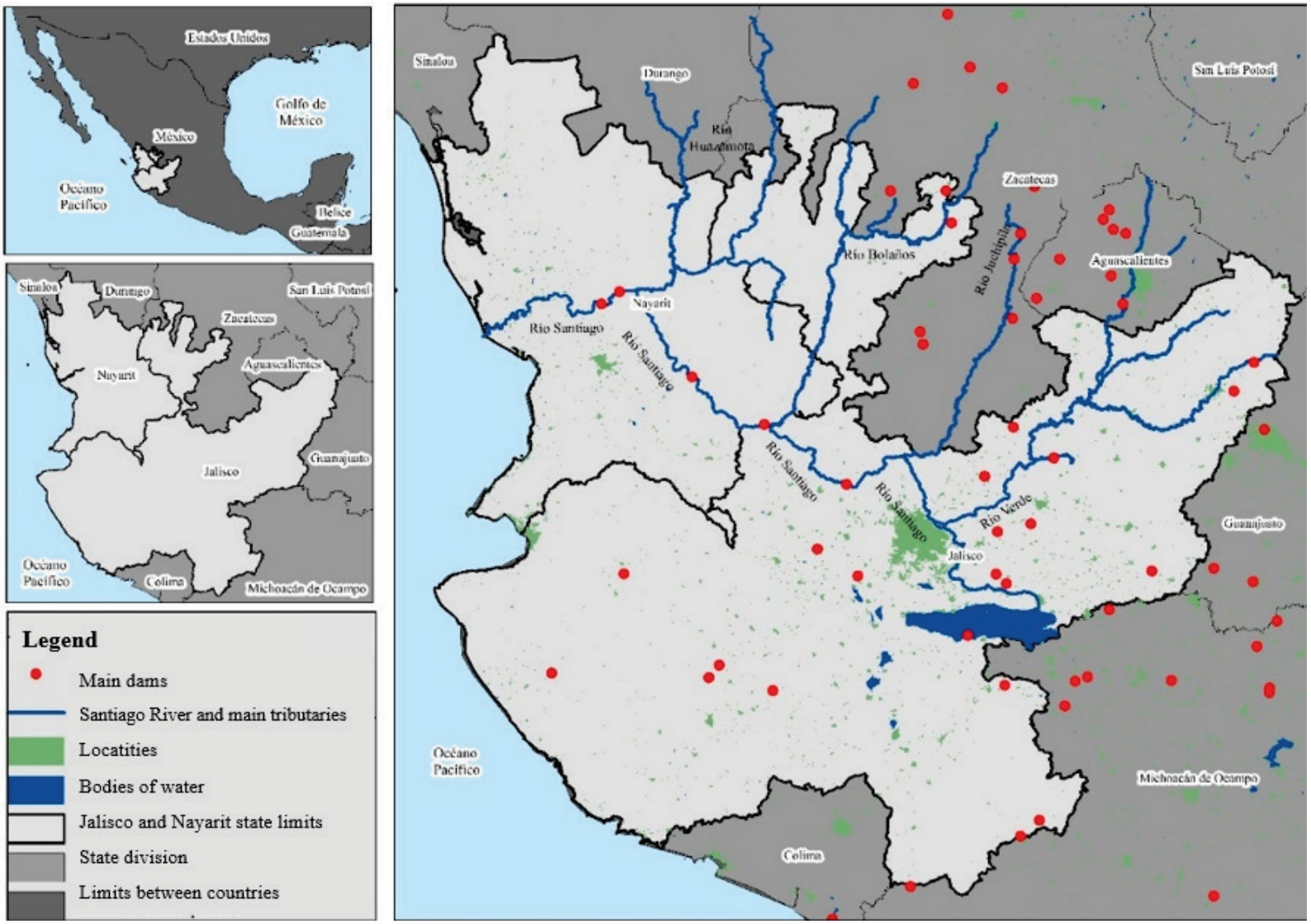

Figure 1. Geographic location of the Santiago River. Source: prepared by the authors using data from INEGI (2024) and Conagua (n. d.).

Various studies have already demonstrated the social and ecological relevance of the Santiago River for the country (Bollo-Manent, Montaño-Salazar, & Hernández-Santana, 2017; Montes-Rubio *et al*., 2021; Gómez-Balandra, Díaz-Pardo, & Gutiérrez-Hernández, 2012). However, it is important to mention that it is the second longest river in Mexico and one

of the rivers that has provided food, crops, and clean water for consumption. However, there are currently nearly 400 companies installed located along its course, ranging from technology to food companies with different types of polluting emissions, generating enormous waste dumps with multiple socio-environmental impacts (Montes-Rubio *et al*., 2021; Gómez-Balandra *et al*., 2012).

It is important to mention that Montes-Rubio *et al*. (2021) argue, as historical context, that the Santiago River once functioned entirely as a source of food, employment, income, and recreation. During the second half of the 20th century and up to the present day, the river's provision of benefits has changed, and it is now perceived as a source of pollution and constant danger due to industrialization and urban growth in differentlocations. This has led to a certain loss of the sense of belonging and identity of riverside communities and to poor daily livestock and agricultural practices such as stray livestock and the use of water for irrigation that is highly contaminated by industrial and urban processes (Montes-Rubio *et al*., 2021).

Methodological approach

Given that a systematic review of the literature is a rigorous method for synthesizing and updating the state of knowledge in various disciplines, research topics, or geographical regions with a long and dense research tradition, and with a growing number of publications, frameworks are essential to guide the task of systematizing and analyzing large amounts of information and to ensure reproducibility for future research (Stockholm Environmental Institute, 2017). Therefore, this systematic review of the scientific literature was guided by the SALSA (Search,

Appraisal, Synthesis, Analysis) methodological framework, which guided the four stages of this research, and the PRISMA protocol, which is a detailed explanatory guide on the components to be considered at each stage of the work (Codina, 2020; García-Perdomo, 2015; Hutton, Catalá-López, & Moher, 2016; Urrutia, Tort, & Bonfill, 2005).

The SALSA framework considers the following four stages of systematic review: 1) Search, 2) AppraisaL, 3) Synthesis, 4) Analysis. In fact, these stages are not only validated, but undoubtedly necessary, as each one defines the specific criteria of the systematic review process (Codina, 2020) and with the support of the PRISMA protocol (Privileged Reporting Components for Systematic Reviews and Meta-Analyses), which functions as a checklist to guide the researcher in the task of documenting, in a transparent manner, the objective of the review, how it was done, and what was found. In other words, the PRISMA protocol provides the criteria to guide and ensure the presentation of relevant information (Page *et al*., 2021). The selection of these frameworks, SALSA and PRISMA, is due to the fact that they are regarded not only as methodological protocols, but also as the two generic stages of work for the development of the analytical route in this research.

The first stage —searching for publications related to the Santiago River— was carried out in the scientific information databases Redalyc, Scielo, and Scopus, these are three relevant databases in Latin America and internationally due to their large collection of academic journal publications from different countries with open access in the case of Redalyc and Scielo, or institutional access in the case of Scopus. In addition to accessibility, it is important to mention that the journals indexed in these databases develop double-blind peer review processes for each of their publications, this helps to reduce the possibility of errors

or defects in scientific research and provides greater objectivity in systematic review because it guarantees that the selected research has undergone a rigorous review process (Page *et al*., 2021). It should be noted that, although the delimitation of the search concepts is extremely precise, the tools, search system, filtering, and downloads of documents that have these databases are relatively simple to manipulate.

The exploration and search for documents was carried out during the month of August 2024 from a structured search syntax with concepts or keywords from the region of interest, which is the Santiago River, also known as the Río Grande de Santiago as it passes through different municipalities between Jalisco and Nayarit. The search for these concepts was limited to titles, abstracts and keywords of the results found in the last twenty years (2004–2024) in English and Spanish, filtered solely for Mexico. The search syntax was introduced as follows: ((“RÍO SANTIAGO” OR “RIO SANTIAGO” OR “RÍO GRANDE DE SANTIAGO” OR “RIO GRANDE DE SANTIAGO” OR “SANTIAGO RIVER”) AND (“GUADALAJARA” OR “MÉXICO” OR “MEXICO” OR “NAYARIT” OR “JALISCO”)).

In the second stage, evaluation, these search and filtering criteria yielded a total of 331 documents (44 results in Scopus, 10 in Scielo, and 277 in Redalyc), which were evaluated one by one and 234 were discarded, as they were essays, reflections, and filtered research from other countries such as Ecuador or states such as San Luis Potosí, where there are rivers with the name Santiago. In this sense, 97 documents were selected in this stage, which consist of scientific research with results from a case analyzed in some of its portions between Jalisco and Nayarit and which suggest the Santiago River as an object of study or in which the river has a close relationship with the object of study based on social or ecological processes.

After rereading the 97 documents selected in the evaluation stage, in the third stage the sample of studies was further synthesized, duplicate documents were discarded, and research that did not focus on the Santiago River in Jalisco or Nayarit was also discarded, the name only appeared in the documents to reference locations or physiographic elements. With this synthesis and filtering system, a total of 64 documents were selected for the fourth stage of analysis. The 64 resulting studieswere then systematized and analyzed using the qualitative analysis software Atlas.ti (Cisneros-Puebla, 2003) with the support of a set of 18 variables grouped into four categories. Figure 2 shows an abstractof the methodological process described above, while Table 1 reflects the categories and generic variables considered for this analysis.

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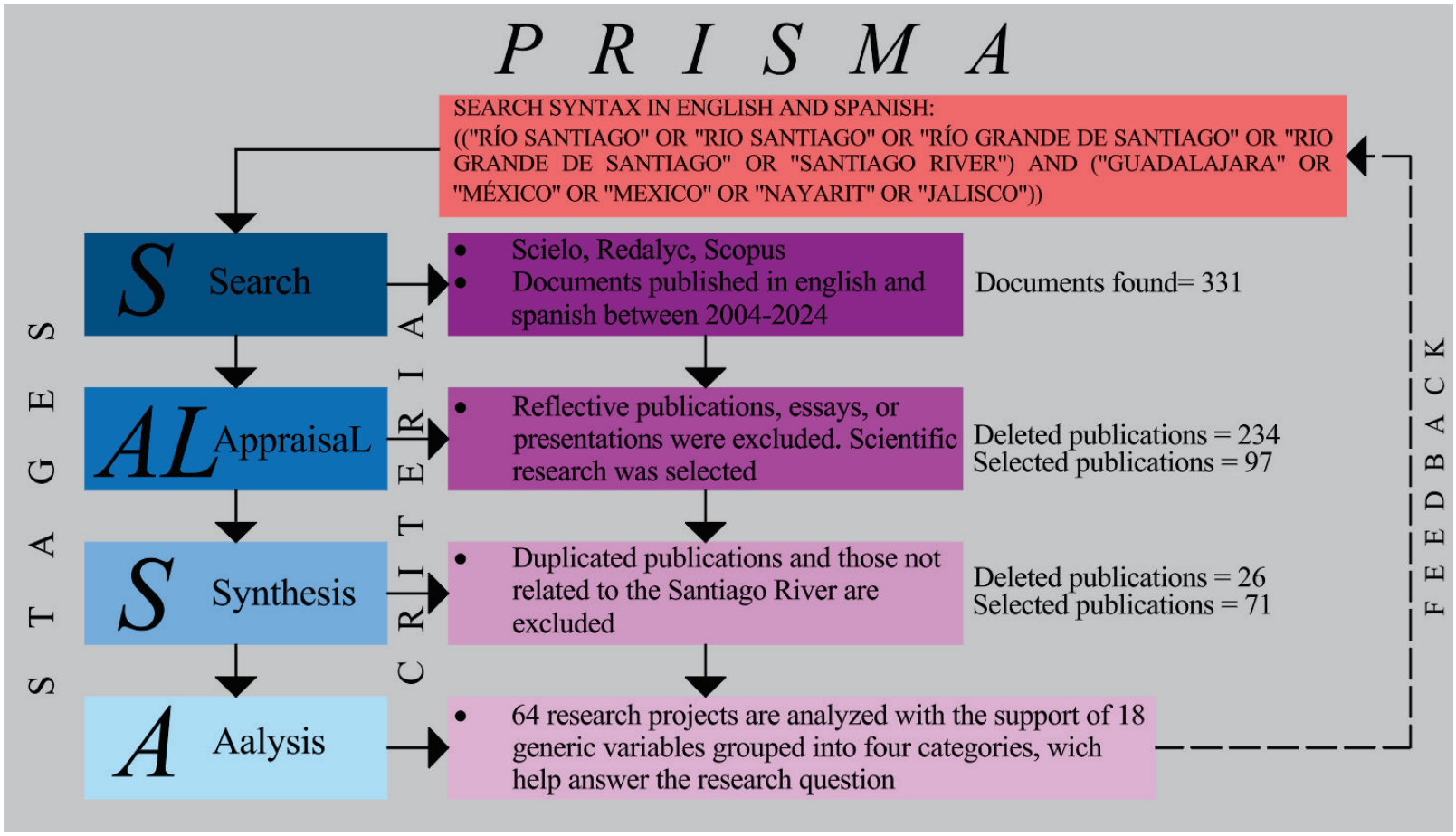

Figure 2. Stages of the methodological process.

Table 1. Categories and variables of analysis.

Category	Variables
Author characteristics	a) Country b) Institution affiliation (at the moment of publication)
Publication characteristics	c) Year d) Journal e) Journal institution f) Indexing location
Research scope	g) Case study (geographical area) h) Analysis i) Diagnosis/description j) Simulation k) Incidence
Research trends	l) Disciplinary perspective m) Methodological basis n) Theoretical basis o) Identification of issues, challenges, opportunities, analytical gaps p) Techniques for gathering and analyzing information q) Research approaches (qualitative, quantitative, mixed) r) Most cited authors

Results and discussions

The chronology of research directly related to the Santiago River shows a cyclical trend with ups and downs in terms of publications in indexed journals. Figure 3 shows two peaks in scientific production corresponding to the years 2010 and 2019-2020. However, despite the ups and downs, the trend line (dashed line in Figure 3) reveals that there has been no increase in scientific production on the Santiago River, this despite the exponential urgency to mitigate and reverse environmental problems,

strong points of pollution, health or species conservation, among other problems in this geographical area (Alatorre-Zamora, Campos-Enríquez, Belmonte-Jiménez, & Ibarra-Nuño, 2014; González-Gallegos, Morales-Arias, & Rodríguez-Hernández, 2012; Montes-Rubio *et al*., 2021; Pérez-Ponce-de-León, Zambrano, Domínguez-Domínguez, Pérez-Rodríguez, & Escalera-Vázquez, 2008; Pérez-Rodríguez, Pérez-Ponce-de-León, Domínguez-Domínguez, & Doadrio, 2009). According to the trend line, scientific production behavior focused on the Santiago River has had a slight downward inclination. This tendency of publications reflects the need and task that, in the first place, the academic and scientific sphere has to support research and raise awareness of these issues, above all through scientific production and its various forms of dissemination; secondly, it would be important to send this scientific production to the various political actors and decision makers involved in environmental issues related to rivers, basins, biodiversity, health, pollution, tourism, and public policy design.

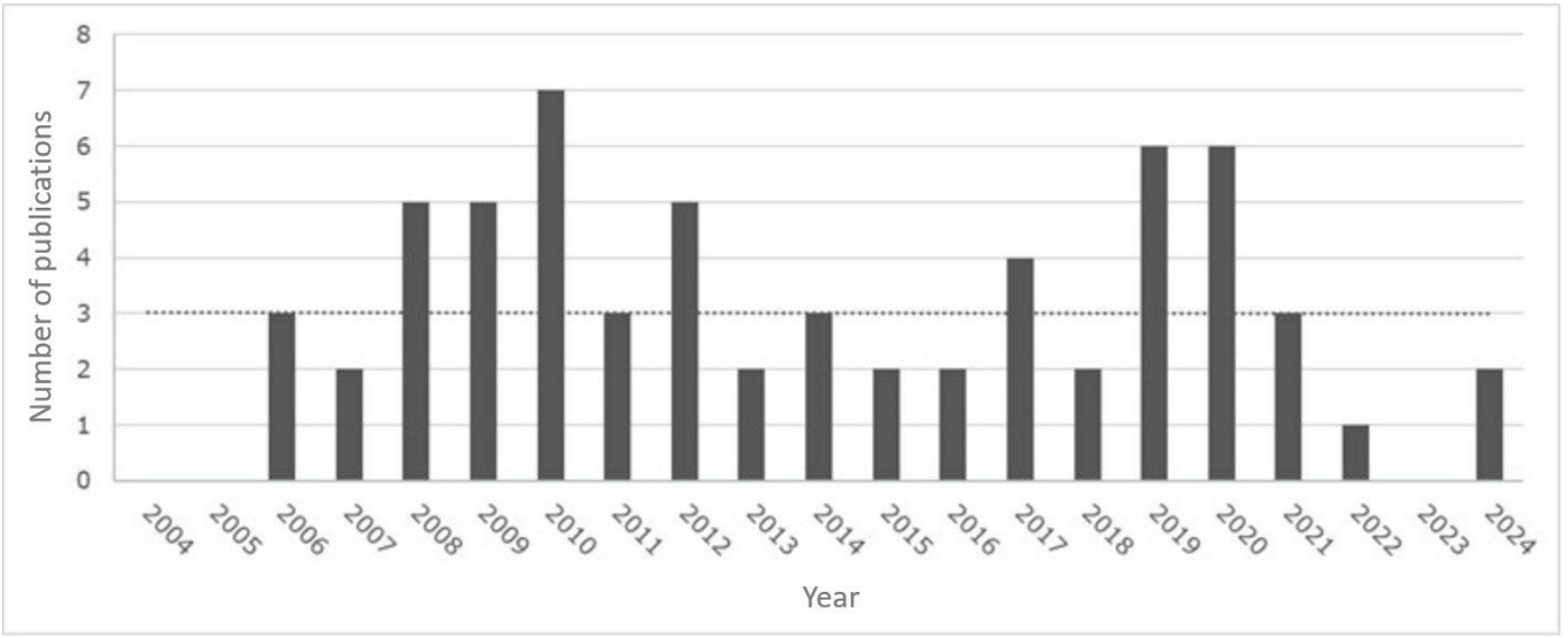

Figure 3. Number of scientific publications in indexed journals per year.

In addition to the name of the Santiago River, among the most frequently mentioned concepts are water, pollution, water quality, watershed, the concept of species related mainly to animal biodiversity, management, infrastructure, waste, dams, or industrial in relation to industrial corridors, and other relevant concepts that directly influence the Santiago River and its resources (Figure 4). It is worth mentioning that, although the most frequently identified concepts include pollution, water, environment, and population, the research on fish biodiversity stands out particularly above others (Acevedo-Rosas, Hernández-Galaviz, & Cházaro-Basáñez, 2008; Gómez-Balandra *et al*., 2012; Macías-Rodríguez, Sahagún-Godínez, & Lomelí-Sención, 2020; Pérez-Ponce-de-León *et al*., 2008; Pérez-Rodríguez *et al*., 2009; Tapia-Varela *et al*., 2021). However, the discussion related to ichthyology, limnology, or parasitology is related to other relevant topics, as their arguments focus on the need to maintain

the river in healthy conditions to conserve not only endemic fish species but also other types of biodiversity, both plant and animal (González-Gallegos *et al*., 2012; Hernández-Hurtado, Romero-Villaruel, & Hernández-Hurtado, 2011; Quezada-Hipólito *et al*., 2019; Ahumada-Carrillo, Arenas-Monroy, & Íñiguez, 2013).

Figure 4. Most relevant topics represented in keywords.

Figure 5 shows the geographical regions of study where scientific research has mainly focused on the course of the river, among other regions are: various points in the Guadalajara metropolitan area, the municipalities of El Salto, Juanacatlán, and Ocotlán (to a lesser extent) related to river pollution by industrial corridors located at different points in these municipalities, which dispose of different types of polluting waste; Matatlán and Huaxtla are also among the case studies due to the landfills located at these points, which, through leachates infiltrating the subsoil, end up polluting various points of the river; another area of major research interest is the region known as the Barranca de Huentitán, northeast of the Guadalajara Metropolitan Area, which has been preserved for tourist and scenic purposes; various regions at the mouth of the river in Nayarit; and dams located along the riverbed, such as the El Cajón, Aguamilpa, La Yesca, Arcediano, San Rafael, Santa Rosa, and Amado Nervo dams. However, it is necessary to integrate participatory action research activities and involve the populations of these places in order to raise awareness, in addition to strengthening regulatory frameworks and compliance through constant surveillance and monitoring of those actors and activities that strongly influence the river ecosystem.

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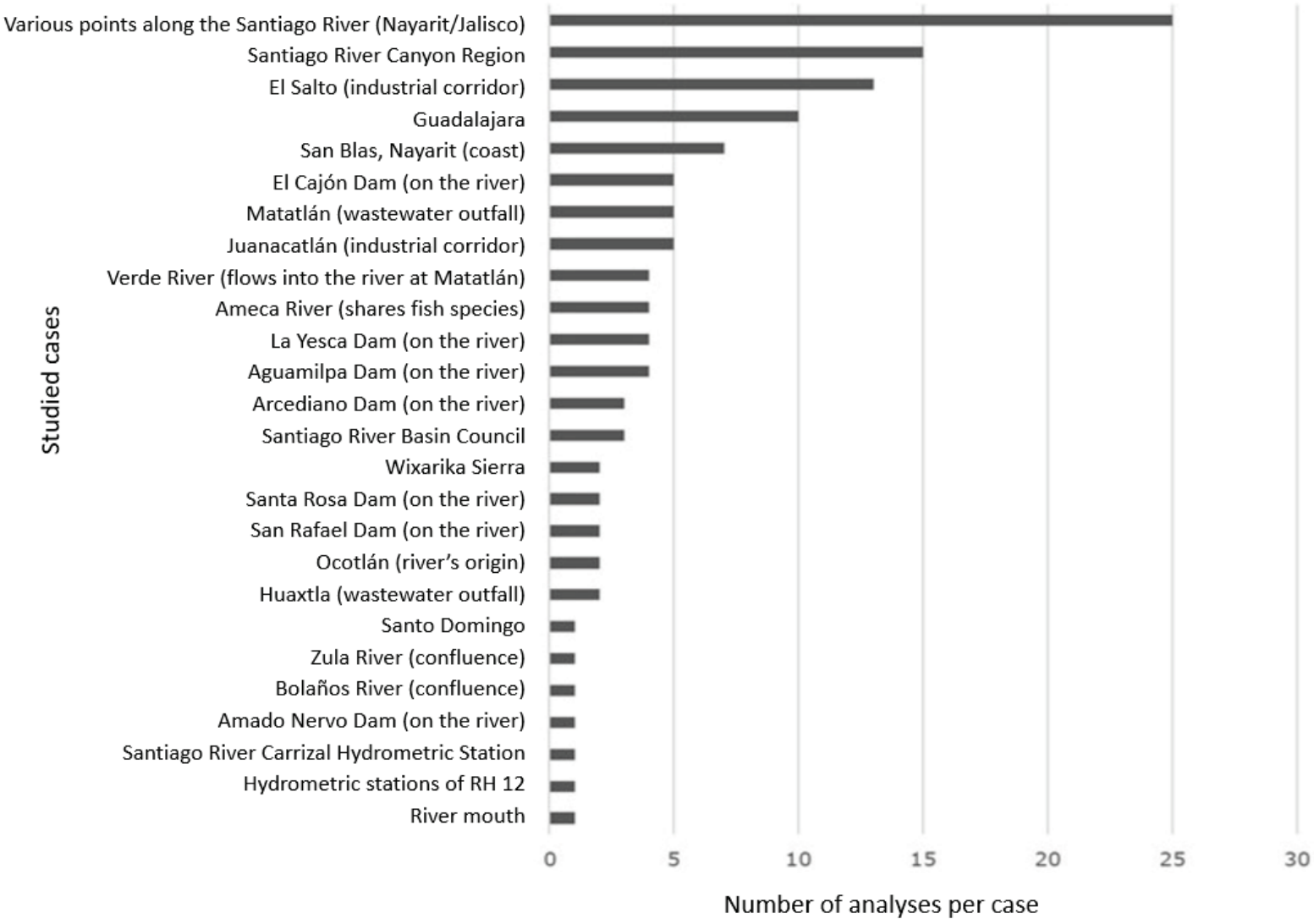

Figure 5. Case studies analyzed with direct influence on the Santiago River.

Of the 46 journals in which these studies were published, the Revista Mexicana de Biodiversidad (Mexican Journal of Biodiversity) of the National Autonomous University of Mexico (UNAM) recorded a total of seven publications, making it the journal that has published the most on the river; while the journal Sincronía of the University of Guadalajara

(UDG) recorded four publications. Other journals such as Agrociencia, El Cotidiano, Environmental Monitoring and Assessment, Espiral, among others affiliated with various institutions, recorded two scientific publications. However, there are many other journals from different international institutions that have published one scientific article (Figure 6 and Figure 7). This reflects the geographical scope, relevance, and interest that research on the Santiago River has had over the last 20 years.

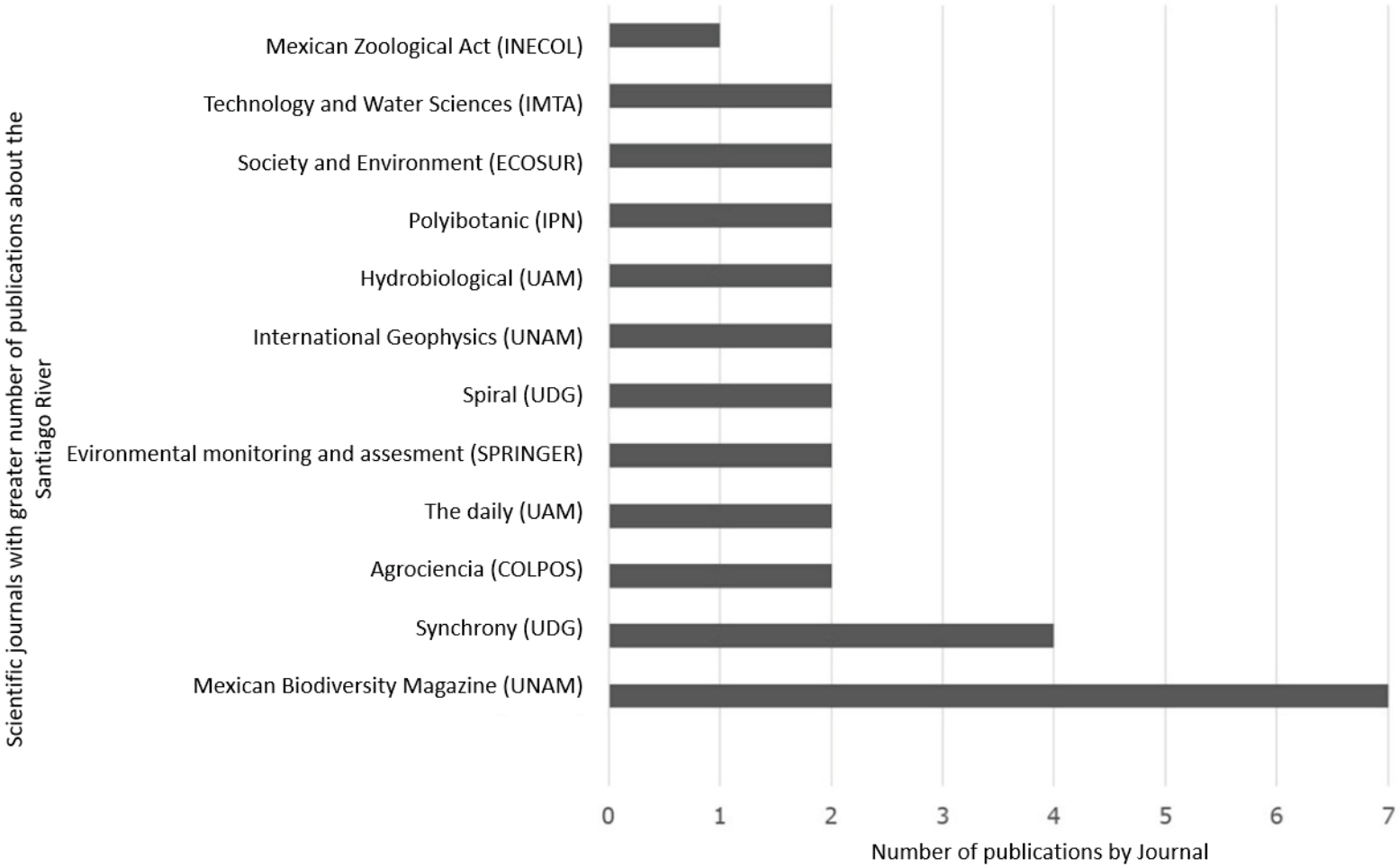

Figure 6. Journals with the highest number of scientific publications on the Santiago River.

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Figure 7. Journals with the highest number of scientific publications on the Santiago River.

With regard to the institutional characteristics of scientific publications, of the 29 affiliations identified, the most frequent was UNAM with 11 publications distributed across four journals, followed by UDG with eight publications in five different journals; then there were other institutions of international stature such as Springer with 5 publications in journals such as Environmental Monitoring and Assessment, Journal of Forestry Research, or Environmental Earth Sciences; there are also institutions such as the Universidad Autónoma Metropolitana (UAM), Elsevier, and Wiley with 4 different journals; finally, there are other

affiliations such as El Colegio de la Frontera Sur (Ecosur), the Colegio de Postgraduados (Colpos), the Instituto Mexicano de Tecnología del Agua (IMTA), the Instituto Politecnico Nacional (IPN), and the American Meteorological Society (AMS), among other institutions with one publication (Figure 8).

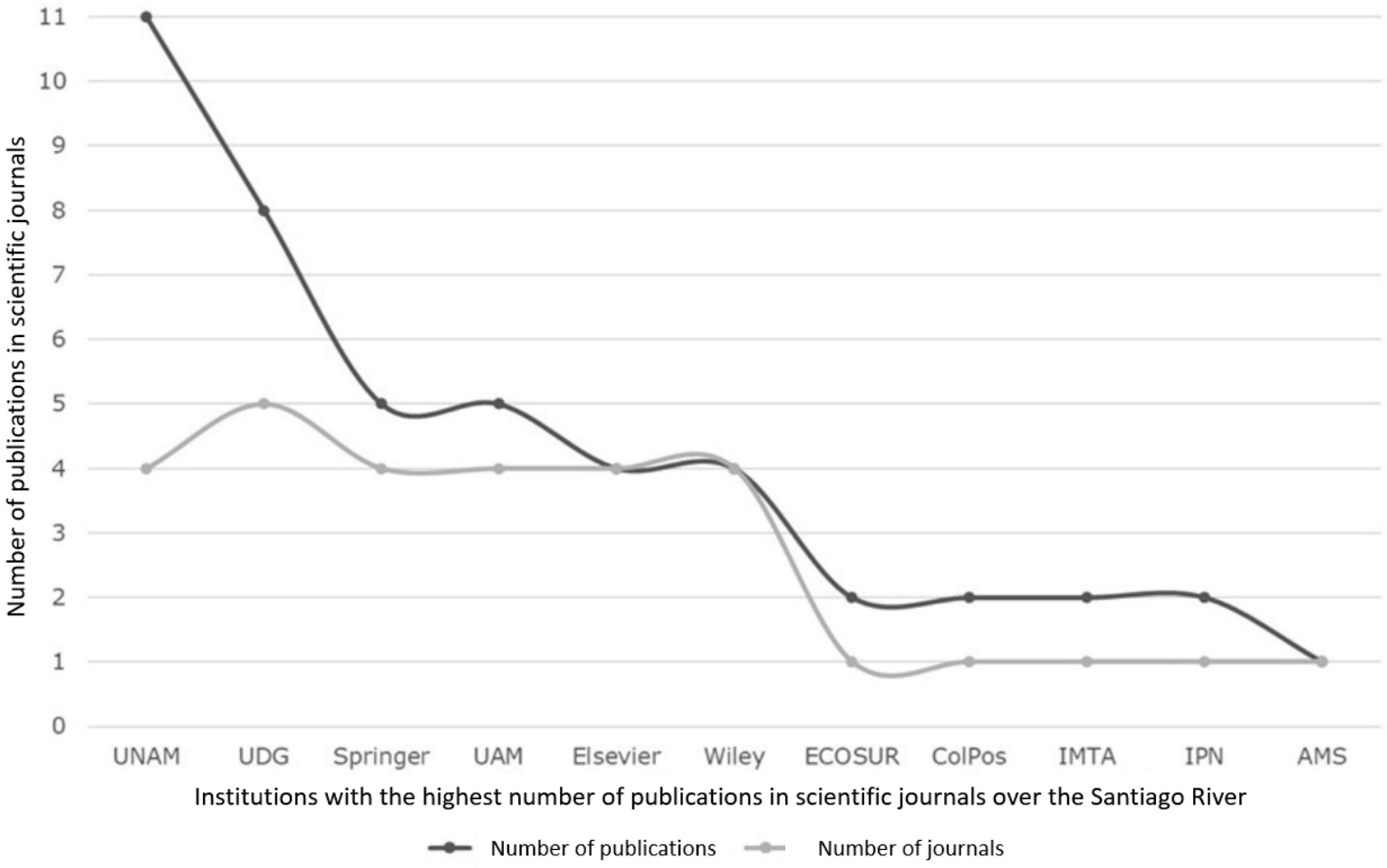

Figure 8. Institutional affiliations with the highest number of scientific publications.

With regard to the authors, Figure 9 represents in various colors the number of authors per country who have taken an interest in studying the Santiago River through the various topics mentioned above. It is observed that the country with the greatest interest in the river is undoubtedly Mexico, although the river has also been of interest to authors from the United States of America (USA), in second place, and from Spain, in third place. Meanwhile, authors from countries such as Russia are attracted by the hydrology of the river through the study of dams in the riverbed. Finally, it is worth mentioning that the river has also aroused the interest of authors from the United Kingdom, Germany, and Cuba.

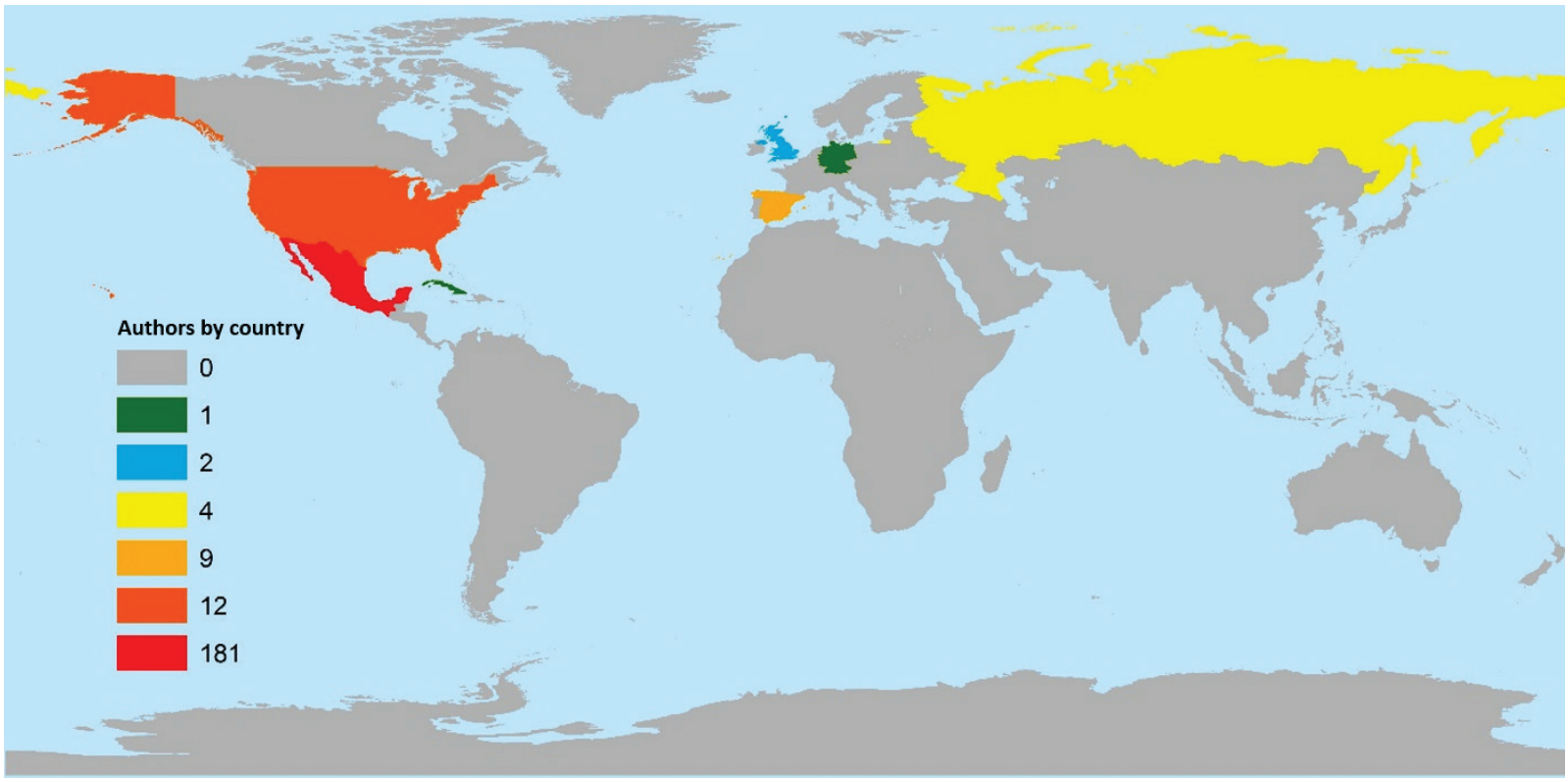

Figure 9. Number of authors with scientific publications by country.

On the other hand, since authors affiliated with Mexican institutions have been the most interested in studying the Santiago River, Figure 10 shows the Mexican states where the authors most interested in the subject are affiliated. It is observed that in the state of Jalisco there are 73 authors who have carried out this type of research, of which about 80 % (58 authors) have belonged to the UDG at the time of publication, while the rest were affiliated with institutions such as the Center for Research and Higher Studies in Social Anthropology of the West (Centro de Investigaciones y Estudios Superiores en Antropología Social de Occidente (CIESAS Occidente)), the University of the Valley of Mexico Campus Guadalajara, or the Autonomous University of Guadalajara. In second place is Mexico City with 39 authors, 85 % (33) of whom have been affiliated with the UNAM. In third place, are the states of Michoacán and Nayarit with authors affiliated with the Autonomous University of Nayarit and the Michoacán University of San Nicolás de Hidalgo (UMSNH).

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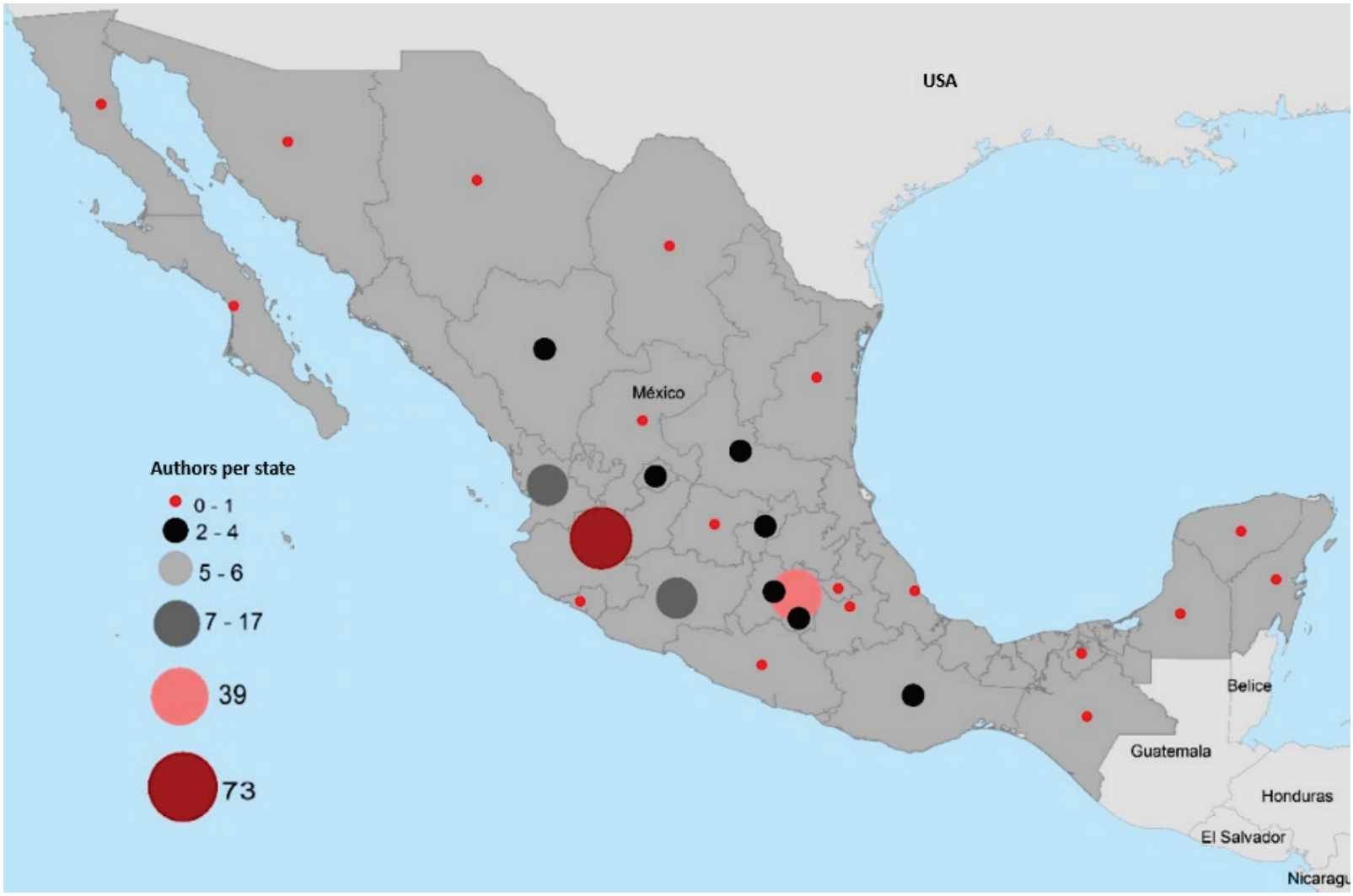

Figure 10. Number of authors with scientific publications by state.

In fourth place, are the states of Hidalgo, Sinaloa, and Nuevo León, with authors from the Autonomous University of the State of Hidalgo, the Technology Institute of Culiacán, or the Tecnológico de Monterrey. In fifth place, the states of San Luis Potosí, Aguascalientes, Durango, State of Mexico, Morelos, Oaxaca, and Querétaro, with institutions such as the Autonomous University of San Luis Potosí (UASLP), the Potosí Institute for Scientific and Technological Research (IPICYT), the IPN, the

Autonomous University of Aguascalientes, the Autonomous University of Querétaro, the Autonomous University of Durango, and the Center for Research in Geospatial Information Sciences (CentroGeo), among others. Finally, states such as Guanajuato, Yucatán, and Zacatecas have one author each in institutions such as the National Fisheries Institute, Yucatán, or the Autonomous University of Zacatecas; among many other institutions.

Another relevant finding in this research is that of the most cited authors in Table 2, where an author from the UMSNH stands out with 30 citations in the documents analyzed alone, it should be noted that this author is a biologist specializing in marine sciences and limnology, with a particular interest in fish species conservation. There are also authors from the National Museum of Natural Sciences in Madrid, the UNAM, the Center for Scientific Research and Higher Education (CICESE), the University of Wisconsin, the IPN, the Autonomous University of Nayarit, the Autonomous University of Querétaro, the University of Michigan, and the Center for Research in Food and Development (CIAD). All the authors from these institutions specialize in biology, biological-agricultural disciplines, geophysical exploration and applications, hydrological issues, and most focus on topics related to fish, specializing in aquaculture and environmental management, ichthyology, limnology, zoology, ichthyofauna, and biodiversity conservation of various types (see Table 2). However, all of them, through their topics of interest and research, argue the urgent need for the conservation and recovery of the Santiago River itself for the preservation of endemic and non-endemic biodiversity in the study area.

Table 2. Authors with the highest number of citations in the research analyzed.

No. of citations	Author	Institution
30	Omar Domínguez-Domínguez	UMSNH
15	Ignacio Doadrio	Museo Nacional de Ciencias Naturales, Madrid.
13	José Oscar Campos-Enríquez	UNAM
13	M. A. Alatorre-Zamora	CICESE
13	John Lyons	University of Wisconsin
12	Eugenia López-López	IPN
11	José I. Bojórquez-Serrano	Universidad Autónoma de Nayarit
10	Daniel Francisco Campos-Aranda	Universidad Autónoma de San Luis Potosí
10	Edmundo Díaz-Pardo	Universidad Autónoma de Querétaro
10	Arturo Ruiz-Luna	Centro de Investigación en Alimentación y Desarrollo
10	Robert Rush-Miller	University of Michigan
9	Juan Diego García-Paredes	Universidad Autónoma de Nayarit

With regard to research trends, Figure 11 and Figure 12 show that research on the Santiago River has had different scopes, some have been intended to make descriptions or diagnoses of the aforementioned topics; others delve into comparisons or research analyzing specific variables that affect the river, that is, they transcend diagnoses and descriptions; and

others have been aimed at projecting simulations over time or generating models to suggest improvements in river management. Clearly, the most common research have been those with diagnostic and analytical scope; however, it is necessary to promote research that suggests simulations or modeling, since they result from integrative and systemic approaches that involve a complex vision of the river's ecosystem dynamics, so that learning and knowledge of the system are more solid and realistic.

Figure 11 indicates that majority of the publications downloaded from Scopus have analytical and simulation scopes, only a small percentage have diagnostic scopes. While the Redalyc database is the opposite, the majority of the research has diagnostic and descriptive scope, in the first place; analytical scope, in the second place, and a small percentage of scientific production with simulation scope in the third place. Finally, the scope of Scielo research is entirely diagnostic. In this regard, it is important to clarify that of the total number of documents analyzed, 62.5 % are indexed in the Redalyc database, 31.25 % in Scopus, and only 6.25 % in Scielo.

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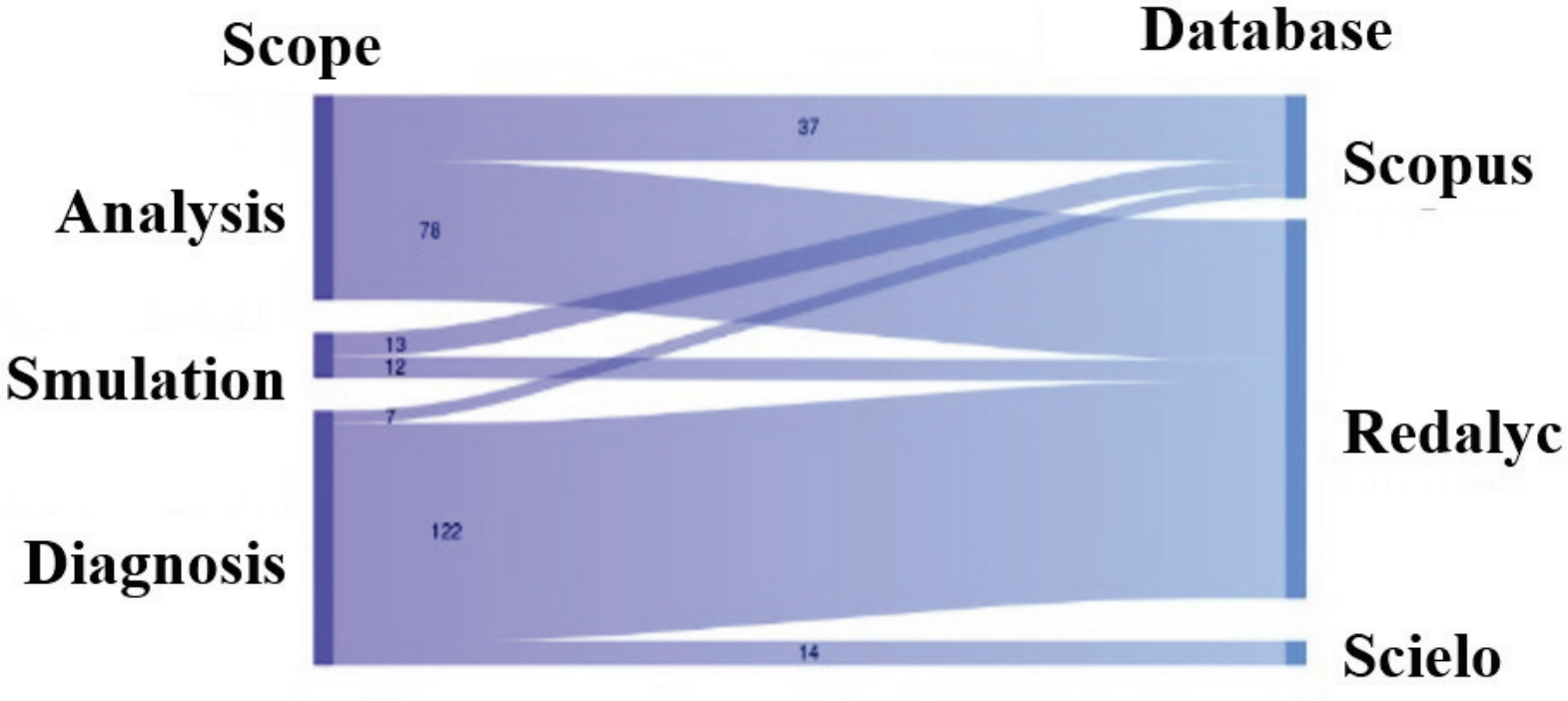

Figure 11. Scope of research according to the database from which the publication was downloaded.

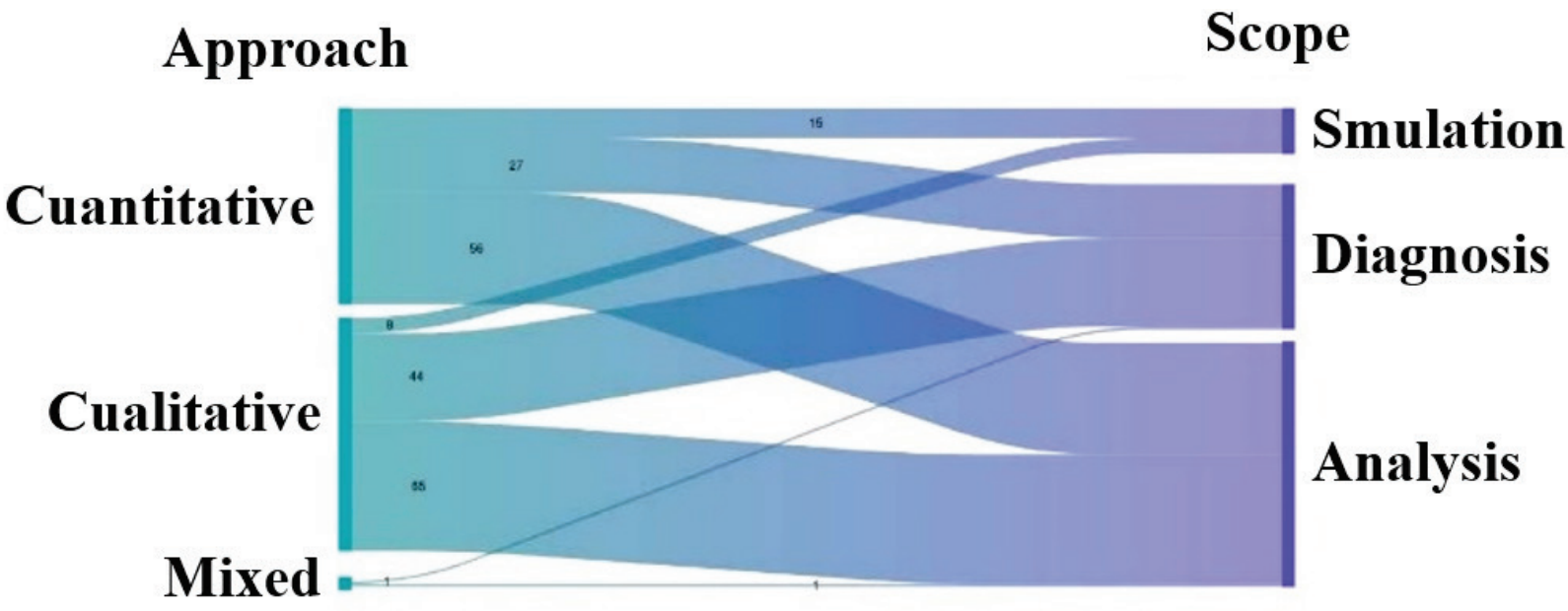

Figure 12. Research scope according to the methodological research approach.

Figure 12 shows that the percentages of research based on quantitative and qualitative approaches are very similar, while mixed approaches are less prominent. Likewise, their correlation shows the scope of research and reveals that qualitative and quantitative approaches generally have analytical and diagnostic scopes, while quantitative approaches generally have a simulation scope due to the nature of the data.

Figure 13 reveals the levels of correlation between the research scope and the research stages that have been prioritized in general terms for different scopes. Among the research projects that have proposed simulations or models of methodological and empirical incidence, the analytical stage has been a priority, supported mainly by mathematical, geostatistical and statistical, interpolation and regression analysis, water

quality analysis to estimate contamination risks, algorithm-based models to understand the operating policies and behavior of different reservoirs on the river, or remote sensing systems for erosion and river flooding. For research that has focused on diagnostics and descriptions or analysis, the three stages of research (data collection, analysis, and presentation) have had very similar levels of importance. Among the techniques that stand out for the presentation of results are graphic and illustrative techniques, although in diagnostics, most have been descriptive; while support for data collection and analysis using traditional methodological frameworks has been limited, this has facilitated the comprehensive development of techniques with the support of existing databases from official sources, surveys, interviews, mapping, indicators, and sampling, as well as monitoring and field trips.

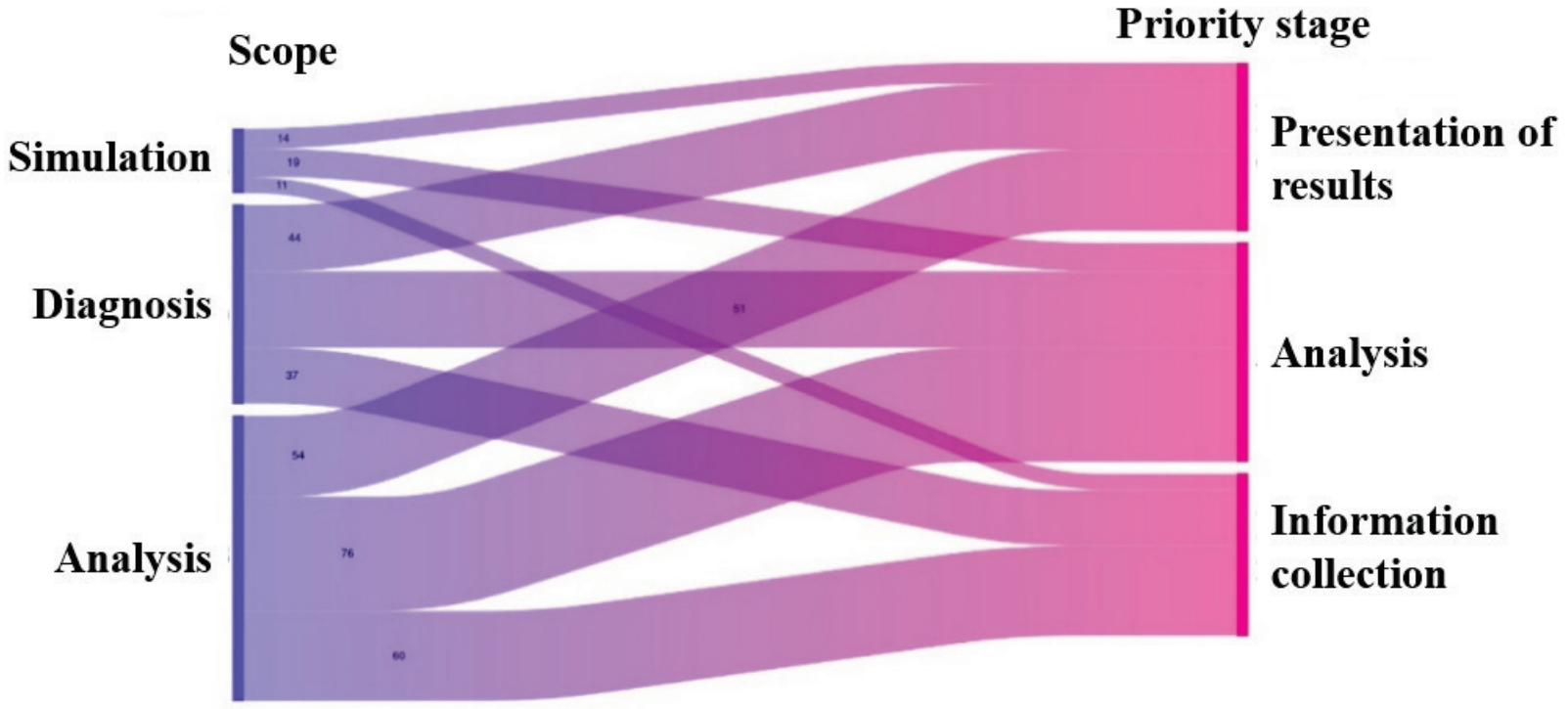

Figure 13. Importance of research stages for specific research scopes.

Furthermore, it should be noted that both research opportunities and the challenges or problems to be overcome are related, since a challenge to be overcome can be an opportunity for both research and implementation. Among the challenges most mentioned in the documents analyzed are contamination of the river by leachate from landfills, research and visibility of industrial waste in the riverbed, and lack of sanitation, as well as poor management, lack of monitoring, and low advocacy participation to improve management not only of the river but also at the basin level, since the Verde, Bolaños, and Zula rivers within the basin, flow into the Santiago River, which share very similar problems. Therefore, one of the main challenges is to seek comprehensive and participatory management of the basin, in addition to making visible and controlling those commercial, industrial, political, or even civil society actors who put the health of the river ecosystem and its related ecosystems at risk.

It is important to highlight the limited presence of social sciences in the research analyzed. However, it should be clarified that due to the nature of the documents analyzed, which were only scientific articles found in the Scopus, Redalyc, and Scielo databases, a low percentage of research from the social sciences was selected, since most publications in this academic sector are found in book chapters, reviews, theses, essays, reflections, or even entire books, to mention just a few, there are books entitled Environmental Situation of the Santiago-Guadalajara River Basin, Archaeology in the Santiago River, Jalisco. Posthumous Tribute to Archaeologist Carlos López Cruz, and The Sciences in Water Studies: Old Social Challenges and New Challenges (Bollo-Manent *et al*., 2017; Cabrero-García, 2016; Rojas-Ramírez, Torres-Rodríguez, & González-

Santana, 2018). However, there is research from the social sciences, but it did not enter our selection sample based on the methodology constructed. Therefore, it is necessary to review future trends and challenges in research with methodological samples that include books, theses, book chapters, and other types of publications.

Related to the limited presence of social science studies in this article, it is noted that biological sciences and earth sciences are prominent. Thus, we can identify windows of opportunity to develop interdisciplinary work and integrate various fields of research from the social sciences, exact sciences, earth sciences, biological sciences, health sciences, and even political science, public policy, and human rights. In addition to seeking proposals for policy implementation and improving the comprehensive management of the Santiago River as a result of interdisciplinary work.

Finally, it is important to highlight the need for integration by the riverside population, civil society, governmental and non-governmental organizations into transdisciplinary research work. Such integration would be conditional on collaborative work between disciplines, as it would support the implementation of mechanisms for constant participatory monitoring of river water quality and other issues that require constant observation by academia and the society involved. This type of situation, where various social actors and, above all, riverside inhabitants are integrated, would help to improve the implementation of public policies due to the appropriation of participatory work.

Conclusions and recommendations

It is suggested that future research take into account various aspects that translate into problems directly affecting the Santiago River, such as the pollution crisis, loss of aquatic biodiversity and its implications, regional inequalities in research coverage, fragmentation in the governance of the Santiago River, and proposed priority actions for integrated basin management.

With regard to the pollution crisis in the Santiago River, various studies document industrial discharges and the lack of adequate wastewater treatment, which has significantly deteriorated water quality and affected both human communities and biodiversity. In addition, the impact of this pollution on public health has led to a significant increase in respiratory and gastrointestinal diseases and certain types of cancer in local communities, not to mention that flora and fauna have suffered irreversible damage, with significant losses of endemic species that perform key ecological functions. It is necessary to undertake comprehensive research that addresses both the sources and consequences of pollution, considering the spatial and temporal variability of pollutants and their dispersion in the ecosystem. It is also essential to enforce environmental regulations and promote advanced water treatment technologies with the support of quality control programs, monitoring systems, and stricter penalties for industries that dump toxic waste. Intergovernmental coordination is therefore crucial for effective water resource management.

It is worth mentioning that the loss of aquatic biodiversity has altered essential ecological processes and biological cycles and interactions between species. Another cause for alarm is the reduction in

the economic activities of communities, such as artisanal fishing and tourism, as well as the impact on various ecosystem services provided by the Santiago River, including provisioning, cultural, support, and regulatory services. In this regard, research should focus on the involvement and integration of riparian communities in research processes to promote sustainable economic activities, such as ecotourism and regulated fishing, which alleviate pressure on the ecosystem. It is important to design comprehensive projects for the conservation of critical habitats and biodiversity, including incentives for sustainable practices and the ecological restoration of affected areas.

Research on the Santiago River is unevenly covered, with an excessive focus on urban and industrial areas, leaving significant gaps in knowledge about the impacts on other areas of the river and its tributaries. This uneven coverage limits decision-making and generates fragmented knowledge, preventing adequate assessment of hydrological interconnections and pollutant flows. Interdisciplinary and transdisciplinary research is essential to carry out integrative and comparative studies between different segments of the river in order to obtain a comprehensive view of the ecosystem and its problems. For adequate and sustainable planning, it is vital to create an environmental observatory not only for the river, but also for the basin, to centralize and coordinate data collection and analysis.

There is a strong fragmentation in the governance of the Santiago River due to a lack of coordination between local, state, and federal policies. Coupled with this, weak enforcement of regulations reinforces this fragmentation in the governance of the Santiago River and hinders effective water resource management. This fragmented approach perpetuates pollution problems and hinders biodiversity conservation and

the protection of critical habitats. In this regard, it is necessary to create a governance structure at the basin level that coordinates efforts among all levels of government and stakeholders to effectively address socio-environmental challenges.

Finally, the lack of effective community participation has limited the implementation of inclusive and sustainable policies. In addition, the absence of participatory monitoring and surveillance systems has restricted the ability to adequately manage environmental risks. Participatory action research allows for a deeper, evidence-based understanding of the basin's problems, integrating the perspectives and experiences of local communities, which supports the development of participatory action research models that involve local communities in identifying and solving environmental problems. There is an urgent need to design community monitoring and environmental education programs that train local communities, strengthen surveillance systems through accessible technologies, and create networks of local observers. Collaboration between academia, government, and civil society organizations will ensure a multidisciplinary and participatory approach to the integrated management of the Santiago River and its basin.

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