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FACULDADE DE ENGENHARIA SANITÁRIA E AMBIENTAL

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**UMA REVISÃO ABRANGENTE SOBRE OS IMPACTOS AMBIENTAIS DAS  
BARRAGENS BRASILEIRAS: PANORAMA E TENDÊNCIAS EMERGENTES**

***A COMPREHENSIVE REVIEW ON ENVIRONMENTAL IMPACTS OF  
BRAZILIAN DAMS: OVERVIEW AND EMERGING TRENDS***

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Trabalho de Conclusão de Curso  
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## RESUMO

Este estudo fornece uma visão geral, abordagens e tendências futuras de pesquisa sobre os impactos ambientais associados a barragens, sendo o primeiro a integrar análise bibliométrica e revisão sistemática sobre este tema no Brasil. A metodologia adotada inclui uma revisão sistemática seguindo o protocolo PRISMA para analisar diferentes abordagens presentes na literatura, bem como uma análise bibliométrica, que oferece uma visão panorâmica do tema e identifica tendências para pesquisas futuras. Os resultados apontam um crescimento exponencial das publicações, particularmente nos últimos cinco anos, refletindo uma correlação direta com os grandes desastres em barragens de mineração ocorridos no estado de Minas Gerais. Conseqüentemente, os estados, instituições e pesquisadores mais frequentemente abordados concentram-se majoritariamente na região Sudeste. As abordagens predominantes na literatura enfatizam as barragens hidrelétricas e os riscos ecológicos, especialmente no que se refere à biota. As tendências de pesquisa futuras sugerem um foco em metais pesados, barragens de mineração e na integração de índices de qualidade ambiental. Esse crescimento das publicações está associado aos desastres ambientais de Mariana (2015) e Brumadinho (2019), que intensificaram a preocupação com os impactos ecológicos das barragens de rejeitos de mineração. O estudo também identifica bacias hidrográficas-chave, em especial a do rio Doce, que tem sido central nas pesquisas pós-desastre. Estudos futuros devem ampliar a análise para incluir os riscos ecológicos de longo prazo dos rejeitos de mineração, integrando índices ambientais e aprimorando as abordagens regulatórias. Esta pesquisa destaca a necessidade de colaboração interdisciplinar para enfrentar os complexos desafios ambientais impostos pelas falhas de barragens no Brasil.

**Palavras-chave:** Barragens hidrelétricas; Desastres de mineração; Riscos ecológicos; Análise bibliométrica; Gestão de recursos hídricos.

## ABSTRACT

This study provides an overview, approaches, and future research trends on the environmental impacts associated with dams, being the first to integrate bibliometric analysis and a systematic review on this topic in Brazil. The adopted methodology includes a systematic review following the PRISMA protocol to analyze various approaches in the literature, as well as bibliometric analysis, which offers a panoramic view of the topic and identifies trends for future research. The results show exponential growth in publications, particularly in the last five years, reflecting a direct correlation with major mining dam disasters in the state of Minas Gerais. Consequently, the most frequently addressed states, affiliations, and researchers are mainly concentrated in the Southeast region. The predominant approaches in the literature emphasize hydroelectric dams and ecological risks, especially regarding biota. Future research trends suggest a focus on heavy metals, mining dams, and the integration of environmental quality indices. This growth in publications is linked to the environmental disasters in Mariana (2015) and Brumadinho (2019), which have led to increased concern over the ecological impacts of mining waste dams. The study also identifies key river basins, particularly the Doce River, which has been central to post-disaster research. Future studies should expand to include the long-term ecological risks of mining waste, while integrating environmental indices and improving regulatory approaches. This research highlights the need for interdisciplinary collaboration to address the complex environmental challenges posed by dam failures in Brazil.

**Keywords:** Hydropower dams; Mining disasters; Ecological risks; Bibliometric Analysis; Water Resources Management

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## 1. Introduction

According to Law No. 14.066/2020, which amends the National Policy on Dam Safety (PNSB), dams and associated structures are defined as constructions "inside or outside a permanent or temporary watercourse, in a valley or in an exhausted excavation with a dyke, for the purpose of containment or accumulation of liquid substances or mixtures of liquids and solids (...)" (Brazil 2020a, art. 2, n/a).

Currently, 23,977 dams are registered in the National Information System on Dam Safety (SNISB), categorized according to their main uses, namely: irrigation (38%), animal watering (21%), flow regulation (11%), water supply for human consumption (8%), electricity generation (5%), containment of mining waste or sediments (4%), recreation (2%), various industrial uses (2%), and other uses - such as drought control, flood defense, aquaculture, among others (9%) (ANA 2022).

However, it is known that the actual total number of dams in Brazil is much higher, as most of the small dams are not registered in the SNISB. Chaves et al. (2021) identified through remote sensing that in the state of Pará, Brazil, approximately only 10% of the dams were registered in the SNISB, representing many dams with no identification of their real situations.

Indeed, the emergence and spread of dams in Brazilian territory have been related to water supply and irrigation in certain regions (Silva et al. 2020), and to development associated with hydroelectricity (Klanovicz and Zarpelon 2022), or the mining industry (Freitas et al. 2022). However, it was only in the 1980s that environmental concerns began to be legally emphasized in the national territory, especially through the definition of environmental impact, the right to an ecologically balanced environment and the need for conservation of resources for future generations, guaranteed by the Federal Constitution (Brasil 1988, art. 225).

In Brazil, over the decades, concerns have persisted regarding the environmental effects in the surrounding areas of reservoirs. The transformations caused by dams in the physical and chemical patterns of rivers have significant impacts, such as modifications to natural ecosystems, including species extinction (Fearnside 2015), changes in fish community diversity (Hoque et al. 2022), flooding of floodplain forests (Resende 2019), emissions of polluting gases, such as carbon dioxide (CO<sub>2</sub>) and methane (CH<sub>4</sub>) (Fearnside 2016), sediment contamination (Sá et al. 2021), siltation and erosion (Chagas et al. 2022), among others. Additionally, Dias et al. (2018b), conducted a similar study regards hydropower reservoirs in Brazil, emphasizing, mostly hydrological aspects of

climate changes in this field. Hence, there is a growing number of studies addressing dam safety, aiming at risk reduction, and consequently, environmental impact mitigation (e.g., Rita et al. 2023).

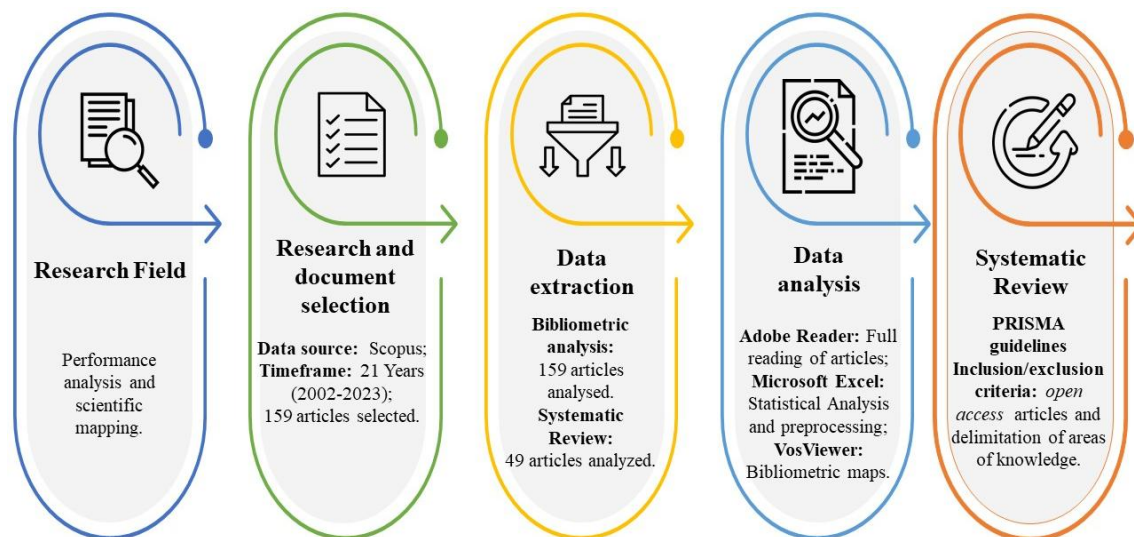
Furthermore, according to a report from the United Nations Environment Agency, Brazil stands out among the countries with the highest number of dam failures since 1985 (Roche et al. 2017), which points to an even more evident scenario of environmental impacts. Recently, Brazil has witnessed major disasters involving the ruptures of the Mariana and Brumadinho dams, occurring in 2015 and 2019, respectively, triggering numerous environmental impacts (Rotta et al. 2020; Sá et al. 2021). Amies et al. (2024), also highlight in their work the lack of studies surrounding dam safety and the importance of research in this field. Thus, discussions related to dams and their environmental impacts are still in their infancy, especially considering the last decades.

In this context, the present research is justified by the imminent need for a survey on the environmental impacts linked to dams in Brazil, aiming to identify trends in the literature, thereby enhancing understanding of the state of the art over the past 22 years and future perspectives on the topic. Therefore, this study aims to foster scientific debate on dam projects and the environment, providing support for environmental management and planning in areas with dams.

The hypotheses considered by this study are as follows: 1) The increase in publications on this topic is related to mining dams, especially the rupture of mining dams in the Southeast region; 2) The main approaches of the studies emphasize environmental contamination in the vicinity of dams.

## **2. Methodology**

This integrated study encompasses both bibliometric analysis and a systematic literature review. The bibliometric analysis provides a comprehensive visualization of studies conducted in a particular area of knowledge (Herrera-Franco et al. 2020). In addition to the bibliometric review, a systematic literature review was also conducted to identify the approaches of studies published in a specific area of knowledge. The systematic review consists of four stages: I) identification, II) selection, III) eligibility, and IV) inclusion. To achieve this, the methodological procedure was divided into five stages: I) research field, II) document search and selection, III) data extraction, IV) data analysis, and V) Systematic Review (Figure 1).



**Fig. 1** Flowchart illustrating methodological process

### 2.1 Research Field

The methodology was structured to evaluate the evolution of studies conducted in the selected research field, based on two main aspects: i) performance analysis and ii) scientific mapping, which are the most common parameters used to demonstrate the evolution, structuring and dynamics of the research field (Zupic and Cater 2015; Cobo et al. 2011a; Hallinger and Suriyankietkaew 2018).

Performance analysis is based on the main characteristics of scientific publications, such as: year of publication, journals, authors, universities, and other factors associated with scientific production (Río-Rama et al. 2020; Montalván-Burbano et al. 2020). Simultaneously, scientific mapping enables the graphical representation of other factors, such as research fields and subfields, and also identifies connections between them (Van Eck and Waltman 2014; Cobo et al. 2011b).

### 2.2 Document Search and Selection

The repository selected as the data source for this research was the Scopus database, chosen for its extensive collection of journals and recent publications (Shukla et al. 2019), with 1.7 billion cited references dating back to 1970 and ease of data acquisition (Harzing and Alakangas 2016; Hallinger and Suriyankietkaew 2018). The articles analyzed in this study were published between January 2003 and December 2023, totaling 21 years. This timeframe was chosen to enable the analysis of linear and exponential trends, requiring a minimum of one publication per year to conduct the analysis.

In the initial search phase, descriptors contained in titles, abstracts, and keywords related to the terms "dams" and "environment" such as "impacts" "risks" and

"consequences" were used, limited to the country "Brazil." Based on the chosen terms, 291 documents were obtained in the initial search. Subsequently, the documents underwent a selection process through exclusion criteria to limit the search to the document type (articles), language (English), and territory (Brazil), resulting in 159 articles selected for data extraction.

In this study, only peer-reviewed articles were included to ensure the quality of the review, as this type of document undergoes a rigorous peer review process (Herrera-Franco et al. 2021). The selection included articles published in English, due to the predominance of this language in scientific publications, as emphasized by Cisneros et al. (2018), and articles in Portuguese.

To limit the search and conduct it objectively to achieve the expected results of this research, boolean logical operators were used in conjunction with the following descriptors to conduct the search: "dam" AND "Brazil" AND "environment" AND ("impacts" OR "risks" OR "consequences"). A total of 159 scientific articles were obtained and used in the predefined bibliometric analysis.

In the search conducted to determine the quantity of studies in each Brazilian state, the same descriptors were used, with the addition of the name of each Brazilian state (AND "state name" after the descriptor "Brazil").

### *2.3 Data Extraction*

The bibliographic information of the 159 documents was downloaded into a comma-separated values (CSV) file, which can be used in various software focusing on mapping scientific productivity (Cobo et al. 2011b). The original content to be included in the download of this file consists of bibliographic data such as authors, title, year of publication, source title, author's affiliations, keywords, citation numbers and data, representing crucial information for bibliometric studies (Hallinger and Suriyankietkaew 2018).

### *2.4 Data Analysis*

The first stage of data analysis focused on statistical analysis and preprocessing of the metadata identified in Microsoft Excel software (Herrera-Franco et al. 2021), to obtain an analysis of the annual growth trend of the topic, country performance, authors, scientific journals and citation trends over the years, which are represented in tables and graphs. For the analysis of publication and citation trends, Price's Law (Price 1986) was used, which is attributed to the analysis of productivity in a particular research field and allows visualization of the development of publications through bibliometric productivity

indicators. Using Price's Law, Wu et al. (2023) and Veiga-del-Baño et al. (2023), presented the effectiveness of this method to evaluate productivity in a bibliometric analysis. The Price index was applied to demonstrate citation trends, which is obtained by dividing the number of publications in the last 5 years by the total number of citations, multiplied by 100, as expressed in Equation 1.

$$\text{Price's Index} = \frac{\text{number of citations less than 5 years old}}{\text{total number of citations}} * 100 \quad (1)$$

In the second stage, bibliometric maps were created. For this purpose, the VOSviewer software, developed by Van Eck and Waltman (Van Eck and Waltman 2010), was used, which is a tool capable of constructing and facilitating the creation of bibliometric networks (clustering solutions), using elements such as authors, journals, keywords, references, and other bibliographic characteristics (Montalván-Burbano et al. 2020). The application of the technique included the analysis of author citations, co-authorship and co-occurrence of author's keywords. The documents were registered in combination with each other, allowing the attribution of these words into similar groups, through clusters of different colors and interconnections (Van Eck and Waltman 2017).

### *2.5 Systematic Review: Data and Analysis*

In this stage, a systematic literature review was conducted. Data were extracted according to the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines (Moher et al. 2015), as per Ansari and Farzadkia (2022). Inclusion/exclusion criteria were applied to the previously selected articles. From the pre-selected articles, only those meeting the following criteria were selected: (1) open access articles and (2) articles related to the fields of "agricultural and biological sciences" and "environmental sciences".

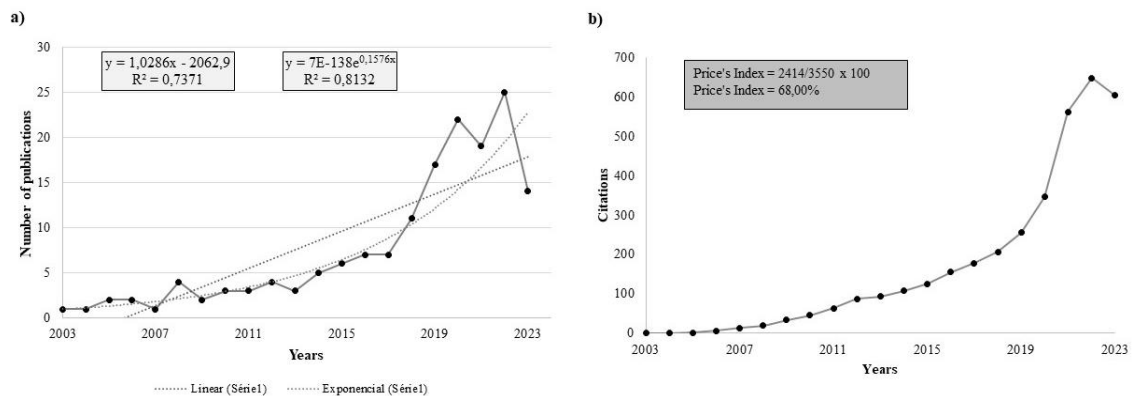
The articles meeting the selection criteria were downloaded from the Scopus database. After downloading, the articles were fully read to identify the required information. In this analysis, the following data were extracted: article titles, sources, references, approaches, types of dams studied and the hydrographic basin in which they are located. These data were compiled and processed in a spreadsheet using Excel.

## **3. Results**

### *3.1 Pattern of Publication Development*

The analysis of scientific production was demonstrated through the relationship between the quantity of publications produced per year during the analyzed time period. In total, 159 articles were considered for this research. Figure 2a allows for the

visualization of the development of these studies over the 21 years and Figure 2b presents the calculated Price's Index (68%) representing the citation trend analyzed.



**Fig. 2 a)** Development of quantity of publications per year from 2003 to 2023 **b)** Price's Index based and citations evolution over the years

Price's Law was used as a bibliometric indicator for productivity analysis, which showed an exponential growth between 2003 and 2023. In Figure 2a, two types of regression were analyzed (linear and exponential). Given the coefficient of determination ( $R^2$ ) of the equations, the exponential growth curve ( $R^2 = 0.8132$ ) showed a higher result than the linear value ( $R^2 = 0.7371$ ), confirming the trend of exponential growth of the analyzed data.

### 3.2 Pattern of Citation Evolution

In this stage, only citations from the year 2003 onward were evaluated. The analysis of the 159 articles included in this study identified a total of 3550 citations between 2003 and 2023, with 2,018 of these occurring in the last five years. As shown in Figure 2b, the period from 2003 to 2013 recorded relatively low publication numbers, with each year contributing fewer than 100 citations. Altogether, this period accounted for 362 citations, corresponding to 12.28% of the total.

In contrast, a marked increase in citations was observed over the past nine years, totaling 3,080 citations or 86.76% of the overall count. Notably, no citations were recorded in 2003 and 2004, but from 2005 onward, citation numbers began to rise, starting with just two citations (0.05%) that year.

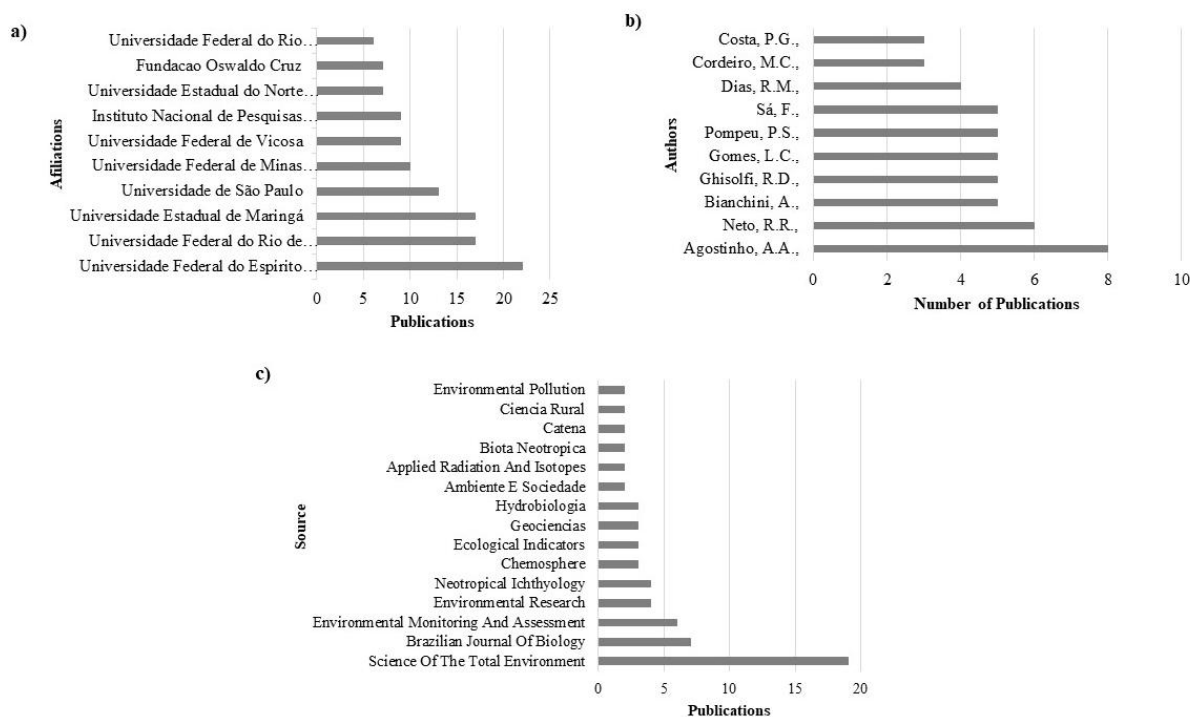
The highest citation counts were concentrated in the last three years. Specifically, 2021 accounted for 562 citations (15.83%), followed by 2022 with 648 citations (18.25%), and 2023 with 603 citations (16.98%), making 2022 the peak year. Combined, these three years represent 51.07% of the total citations. Based on these data, the Price

Index for the analysis was calculated at 68%, reflecting the predominance of recent literature.

Table 1 presents the top ten most cited articles in descending order. Leading the list is the work by Agostinho et al. (2008) with 595 citations, followed by Pelicice and Agostinho (2008) with 219, and Molica et al. (2005) with 143 citations. Additional prominent works include Oliveira et al. (2018) with 117 citations, Thompson et al. (2020) with 116, Silva et al. (2010) with 109, and Fearnside (2005) with 100 citations. Completing the ranking are Hallwass et al. (2013) with 99 citations, Araújo et al. (2009) with 92, and Mendes et al. (2019) with 84 citations.

### 3.3 Analysis of Publications by Institutions

Among the 142 institutions that published, the top 15 were considered above all others. In Figure 3a, it is possible to observe the Universidade Federal do Espírito Santo (UFES), the Universidade Federal do Rio de Janeiro (UFRJ), and the Universidade Estadual de Maringá (UEM) as the institutions that published the most on the research topic during the 22 years analyzed, with 22 publications (UFES, 13.93%) and 17 publications each (UFRJ and UEM, 10.69% each). It is worth noting the relevance of these top three institutions, responsible for 35.22% of the total share of publications.



**Fig. 3** a) Most productive Institutions based on number of publications b) Most productive authors and published papers analyzed c) Main source of publications in ascending order

In fourth place is the Universidade de São Paulo (USP) with 13 publications (8.17%), followed by the Universidade Federal de Minas Gerais (UFMG) with 10 publications (7.5%). Following the rankings, we observe the Universidade Federal de Viçosa (UFV) and the Instituto Nacional de Pesquisa da Amazônia (INPAP), which published nine articles each (5.6%). In eighth place is the Universidade Estadual do Norte Fluminense (UENF), followed by the Fundação Oswaldo Cruz (Fiocruz), each with seven publications (4.4%).

Rounding out the top 15 are the Universidade Federal do Rio Grande (FURG), the Universidade Federal do Pará (UFPA), the Universidade Federal do Paraná (UFPR), the Universidade Federal de Lavras (UFLA), and the Universidade Federal de Ouro Preto (UFOP), all with 6 publications each (3.7%), and the Universidade de Brasília (UNB) in the last position with 5 publications (3.14%).

### *3.4 Authorship Analysis of Studies*

To demonstrate the productivity of each author in this area, the number of publications during the analyzed period was verified, considering only the principal author of the articles among the 159 articles analyzed by this study, with emphasis on the top 15 (Figure 3b).

The author who produced the most articles was Agostinho, A. A., affiliated with the Universidade Estadual de Maringá, who was the principal author of eight articles (5.03%). In second place is the author Neto, R. R., affiliated with the Universidade do Espírito Santo, with six publications (3.7%), followed by Gomes, L. C., a faculty member at the Universidade Estadual de Maringá, responsible for authoring five articles (3.14%).

In fourth place, Pompeu, P. S. (Universidade Federal de Lavras), contributed with five publications (3.75%). Following this classification, Bianchini, A. (Universidade Federal do Rio Grande), Ghisolfi, R. D. (Universidade Federal do Espírito Santo), and Sá, F. (Universidade Federal do Espírito Santo), all contributed with five publications (3.14%), followed by Dias, R. M. (Universidade Estadual de Maringá) with four publications (2.51%).

Concluding the analysis, we observe the authors Cordeiro, M. C. (Universidade Federal do Rio de Janeiro), Costa, P. G. (Universidade Federal do Rio Grande), Fearnside, P. M. (Instituto Nacional de Pesquisas da Amazônia), Longuini, C. M. (Universidade Federal do Rio Grande do Norte), Loures, R. C. (Universidade Federal de Lavras), Pelicice, F. M. (Universidade Federal do Tocantins), and Rangel, T. P. (Universidade

Estadual do Norte Fluminense), with three publications each (1.8%). Together, these authors produced 13.20% of the explored works.

### *3.5 Analysis of Scientific Journal Productivity*

For this analysis, data from 88 different journals were considered, above which the 15 most productive were selected for graphical representation (Figure 3c). The most productive journal, *Science of the Total Environment*, was responsible for publishing 19 articles in this research (11.94%), followed by the national journal, *Brazilian Journal of Biology*, which accounted for seven articles (4.40%). Finishing the top 3, *Environmental Monitoring and Assessment* stands out with six publications (3.77%).

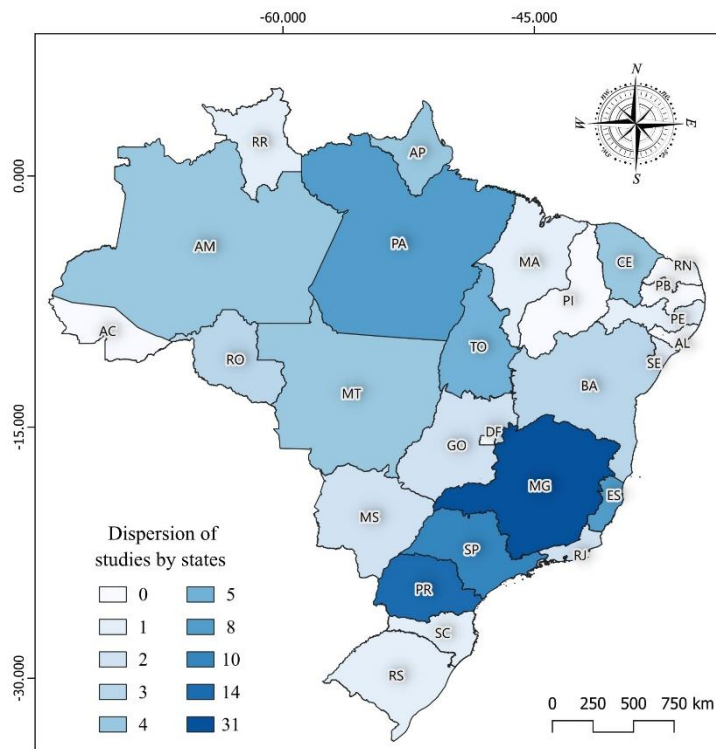
, Following the ranking *Neotropical Ichthyology and Environmental Research* each had four publications followed by *Chemosphere*, *Ecological Indicators*, *Geociências* and *Hydrobiologia* each responsible for publishing three articles (1.88%).

### *3.6 Analysis of the Quantity of Studies by States*

The studies considered a total of 110 publications, covering 69.18% of the evaluated articles, with only 30.81% not mentioning the states in the descriptors used for title, abstract and keywords. In this analysis, a disproportionate concentration of studies addressing the state of Minas Gerais was observed, totaling 31 studies on the topic in this state (28.18%).

Following the analysis, Paraná state was addressed in 14 articles (12.72%), and São Paulo with 10 articles (9.09%). For the states of Espírito Santo and Pará, eight studies were found for each (7.27%) and for Tocantins, five publications were observed (4.54%). Four articles (4.8%) were found for the states of Amazonas, Amapá, Ceará, and Mato Grosso (3.63%). Continuing along this line, three articles (2.72%) were verified for the states of Rondônia and Bahia. Addressed in two articles are the states of Goiás, Rio de Janeiro, and Mato Grosso do Sul (1.81%).

With the mention in only one article (0.9%), the states of Roraima, Maranhão, Sergipe, Santa Catarina, Pernambuco, and Rio Grande do Sul are discussed. Finally, concluding this analysis, the states of Acre, Piauí, Rio Grande do Norte, Alagoas, Paraíba and the Federal District are not discussed in the articles analyzed by this study (0%). (Figure 4).

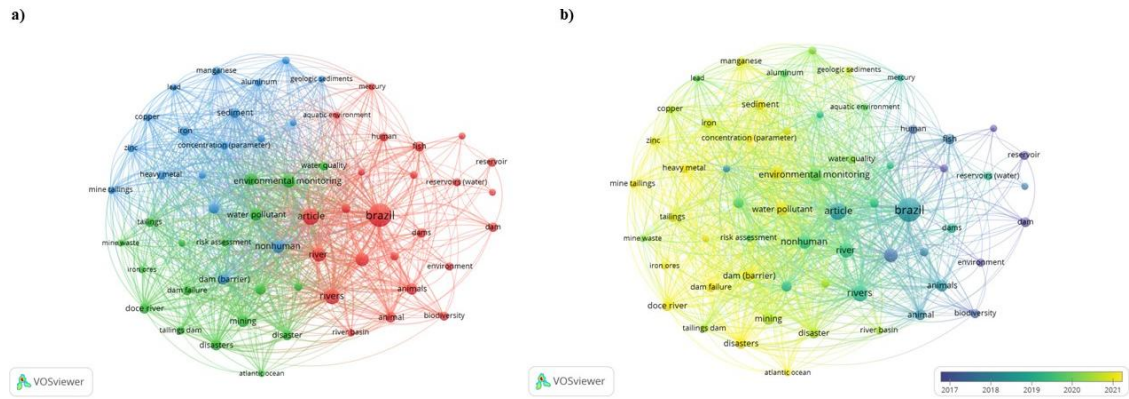


**Fig. 4** Illustrative Map of dispersion of studies approaching Brazilian states (verified by Excel)

### 3.7 Co-authorship and Co-occurrence of Keywords

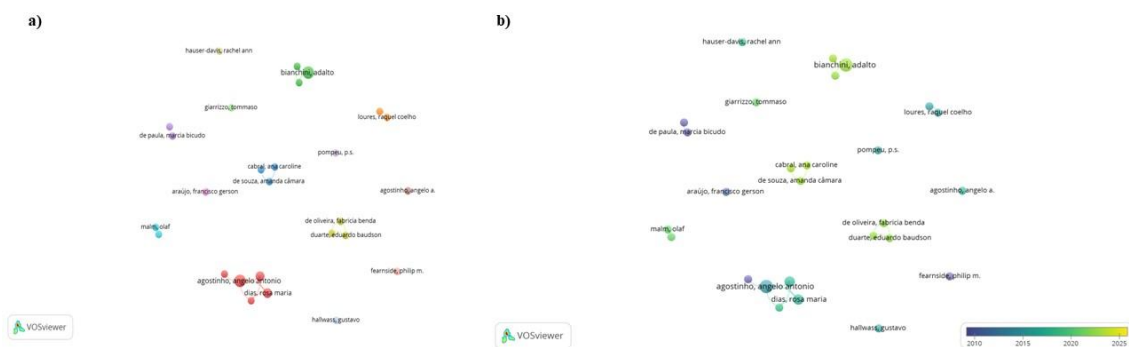
The analysis of keyword co-occurrence and co-authorship among publications was conducted using VOSviewer software. For the keyword co-occurrence analysis, a total of 2,184 keywords were found in the articles; however, only those with 10 or more occurrences were used for this research, resulting in 60 analyzed terms. The main keywords found, according to the link strength classification, include: Brazil, article, rivers, river, environmental monitoring, water pollutant, water pollutants chemicals, non-human, dam (barrier), and disasters.

The keywords were distributed into three related groups (Figure 5a). This analysis also demonstrates the evolution of keyword usage over the years. This visualization allows for the dispersion and popularization of terms such as Doce River, disasters, heavy metal, iron ores, mine tailings concentration (parameters), and tailings dam to be observed (Figure 5b).



**Fig. 5 a)** Network of keywords distribution **b)** Overlay visualization of keyword (verified by VOSviewer)

For the co-authorship analysis, the following parameters were established: documents with a maximum of 15 authors and additionally considering a minimum of two documents per author. After filtering the data, 21 authors were found within these criteria, and they were compiled into 14 clusters. In Figure 6a, the collaboration groups can be observed, with one group consisting of five authors, three groups with three authors each, three groups with two authors each and the remaining seven groups with only one author each. It is notable that there is no collaboration between the groups.



**Fig. 6 a)** Network of collaboration groups between authors **b)** Overlay visualization of co-authorship (verified by VOSviewer)

Figure 6b illustrates the trend of co-authorship over the analyzed period. It can be observed that five groups of authors, totaling 12 authors, published between the years 2020-2023. The remaining authors published before 2018.

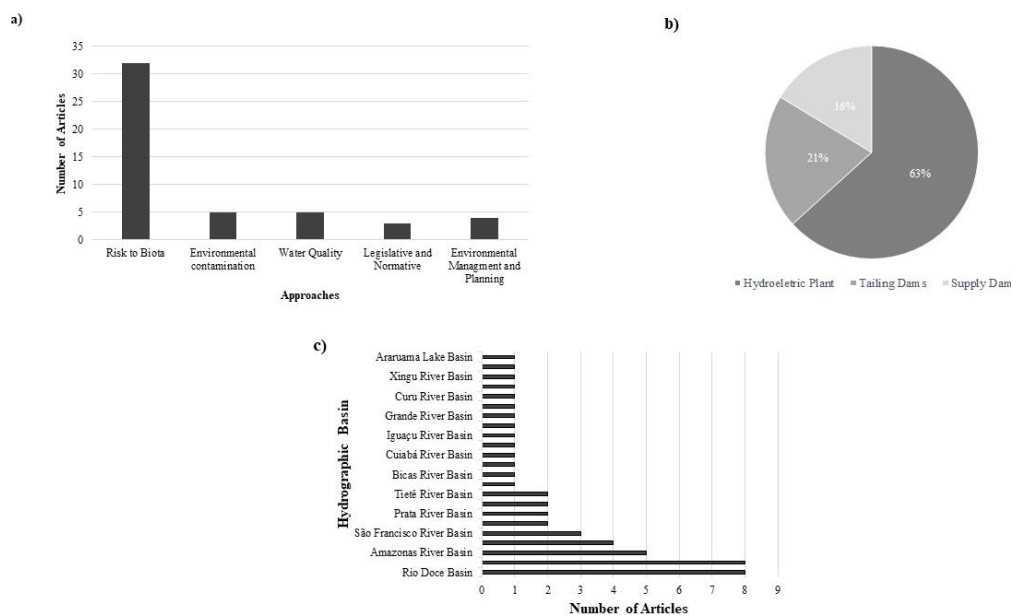
### 3.8 Systematic Review

In this stage, out of the 159 analyzed articles, 49 were selected after applying the exclusion/inclusion criteria. Table 2 presents the data of the studies (title, source, and

reference) used for this analysis, organized in ascending order from the oldest to the most recent.

### 3.8.1 Approaches

The most frequent approaches observed in these articles are related to risks to biota (63.26%), followed by studies related to environmental contamination (10.20%). Articles addressing topics related to water quality (10.20%), environmental management and planning (8.1%), and legislative and regulatory aspects (6.12%) were also identified, as illustrated in Figure 7a.



**Fig. 7 a)** Main approaches detected by the systematic review **b)** Concentration of types of dam addressed in studies **c)** Most cited Hydrographic Basins

### 3.8.2 Types of Dams

Among the types of dams addressed by the analyzed articles, hydroelectric power plants are the most cited in these studies (63.26%). In second place, studies mentioning tailings dams account for 20.40% of the results, while 16.32% deal with water supply dams (Figure 7b).

### 3.8.3 Watersheds

A total of 48 citations of watersheds and sub-watersheds were identified in the articles, with 23 being the total number of watersheds and sub-watersheds identified during the analysis. This value was due to the fact that some authors addressed more than one watershed in their studies. The two most cited watersheds were the Doce River Basin and the Paraná River Basin, each addressed in eight distinct studies. Next is the Amazon

River Basin, cited in five studies, and the Tocantins-Araguaia Basin, mentioned in four articles. The São Francisco River Basin is addressed in three articles.

The Jaguaribe River Basin, Paraguay River Basin, Tietê River Basin and Araguari River Basin, separately, were each covered in two articles. The following basins were addressed in only one of the analyzed articles: Carangola River Basin, Bicas River Basin, Pombas River Basin, Cuiabá River Basin, Turvo Sujo River Basin, Iguaçu River Basin, São Pedro River Basin, Grande River Basin, Curu River Basin, Paraíba do Sul River Basin, Xingu River Basin, Uruguai River Basin, Araruama Lake Basin and the Recôncavo Sul Basin (Figure 7c).

## **4. Discussion**

### *4.1 Advances in Scientific Production on Dam Impacts*

The results presented by this study highlight the evolution of research trends regarding environmental impacts related to dams in Brazil. Over the course of the 21 years analyzed, there was a noticeable exponential increase in publications, particularly in the last six years (2018-2023), which account for 68% of the publications included in this research.

To assess productivity trends in a specific research field, Price's Law was applied, allowing for the visualization of the evolution of academic works published on the selected theme (Price 1986). The Price index found in this study is 69.06%, indicating a growing trend in this area, as higher index values suggest more current references in the analyzed articles (Garcés-Ginarte et al. 2022). An exponential growth in publications within the analyzed context was observed in this study, suggesting that this theme will likely continue growing in the coming years.

The bibliometric research conducted by Carvalho et al. (2021), involving environmental studies in the Doce River basin before and after the mining dam collapse in Mariana, found that five years after this disaster, approximately twice as many articles were published than had been produced since 1969 in the context of articles related to agricultural and fishing activities in the Doce River basin. In line with this, Silva et al. (2022) also observed an increase in the number of publications related to impacts resulting from tailings dam collapses, with a concentration of publications between 2019 and 2020.

The systematic review identified that the main research approaches developed by the articles are related to environmental sciences, emphasizing topics such as risks to biota, environmental contamination, water quality, environmental management and planning, as well as legislative and regulatory frameworks, respectively, in this order of

recurrence. These risks are often addressed in different types of damming, as perceived by the systematic review, demonstrating a greater number of approaches for hydroelectric plants, mining tailings dams, and water supply dams, respectively.

Co-authorship analysis enables the visualization of collaboration networks among authors, who are responsible for the development of knowledge in a particular area (Jiang et al. 2017). In growing scientific fields, this analysis is useful for understanding how different authors collaborate with one another (Donthu et al. 2021). In this regard, it is interesting to note that four of the fifteen most productive authors frequently collaborate within the same research group. Similar results were described by Veiga-del-Baño et al. (2023), suggesting that frequent collaborations may contribute to higher author productivity.

For the keyword co-occurrence analysis, only keywords with 10 or more occurrences were selected, resulting in a total of 52 identified terms. Among the most prominent keywords were: brazil, rivers, river, environmental monitoring, non-human, water pollutant, water pollutants chemicals, dam (barrier), and mining.

In the temporal analysis of keyword usage, an increase in the use of terms such as Doce River, disasters, heavy metal, concentration (parameters), and tailings dam was observed. The growing use of keywords is primarily related to studies on environmental disaster scenarios, such as the accidents in Brumadinho and Mariana, as research on the consequences of mining waste contamination has increased. These keywords also reflect the evolving trend in research focused on environmental impacts associated with dams. As reported by Carvalho et al. (2021) and Jankowsky et al. (2021), a drastic shift occurred in the research landscape regarding the types of studies conducted in the Doce River Basin following the 2015 disaster.

#### *4.2 Mining Dam Disasters and Their Influence on the Scientific and Regulatory Landscape*

Few annual publications related to the theme of this research were found between 2003 and 2017. Significant increases in studies on environmental impacts related to dams were only observed from 2018 onwards. This phenomenon is possibly linked to the mining dam collapse events that occurred in the country. On November 5, 2015, the Fundão dam in Mariana, Minas Gerais, collapsed, releasing 43 million cubic meters of iron-rich tailings into the Doce River, one of the largest hydrographic basins in the country (Queiroz et al. 2021). This event was one of the largest tailings dam failures ever recorded

globally and the worst environmental disaster in the history of mining in Brazil (Carmo et al. 2017), resulting in the loss of 19 lives and causing extensive ecological damage, including soil and water pollution (Bernardino et al. 2019; Gabriel et al. 2020), and a consequent loss of aquatic fauna (Lima et al. 2020).

A second disaster occurred on January 25, 2019, involving the collapse of an iron ore mining tailings dam ("Dam B1"), located at the Córrego do Feijão mine, in the municipality of Brumadinho, also in the state of Minas Gerais (Vergilio et al. 2020). This event resulted in the release of approximately 12 million cubic meters of tailings, which reached the company's administrative area and part of the nearby communities, leading to the death of 244 people and the disappearance of 26 (Porsani et al. 2019).

Considering the magnitude of these disasters, significant changes in the regulatory framework were made to promote dam safety through legislative and regulatory measures (Silva et al. 2023). Law No. 14,066/2020, amending Law No. 12,334/2010, explicitly prohibits the construction or raising of upstream dams due to the inherent risks of this method and its relationship with previous incidents. Similarly, National Mining Agency (ANM) Resolution No. 95/2022, amending ANM Resolution No. 130/2023, reinforces new methods of inspection and safety for mining dams. Decree No. 1,310/2022 regulates the provisions of Law No. 12,334/2010, aiming to ensure compliance with the legislation to mitigate the probability of incidents, accidents or disasters and to minimize their consequences.

The growing trend of publications could be highly related to the Mariana and Brumadinho disasters, which also contributed to boosting improvements in regulations and legislation related to dam safety, especially in terms of inspection, monitoring and safety planning (De Paiva et al. 2024). Additionally, it's also worth mentioning that, according to Nava et al. (2021), scientific production regarding small dam has not contributed significantly to sustainable policies that could be applied to small dams, which creates a gap in updated information since the number of small dams is growing exponentially in Brazil (Chaves et al. 2021).

In this perspective, there is a lack of legislative approaches related to dam safety, particularly regarding the updating and proposal of measures to better classify projects according to risk categories and proposing remediation measures for extreme situations. In line with this, Carmo et al. (2017), emphasize that the large proportion of disasters, along with ineffective measures to retain tailings released by mining dams, are responsible for triggering irreversible environmental damage.

Consistent with the legislative framework, according to Carmo et al. (2017), there was also a setback in the process, such as budget cuts to regulatory agencies and relaxation of law, revealing weakness in Brazilian legislation. In the study conducted by De Paiva et al. (2024), the authors identified that both Fundão and Brumadinho dam projects were approved with during the licensing process despite several weaknesses, including a lack of up-to-date and in-depth information for risk assessments. According to the authors, the environmental licenses of these projects would not have been possible under current Brazilian legislation (De Paiva et al. 2024).

Recent bibliometric studies conducted in other countries also point to an increase in scientific output related to dam safety, particularly in response to major disasters involving tailings dams. For instance, Wu et al. (2022) identified a significant rise in publications after high-profile failures, especially in research topics such as risk management, remote monitoring, and structural modeling. Their analysis classified the international literature into distinct stages, with a rapid increase in publications following catastrophic events, such as the Wenchuan earthquake in China. Similarly, Islam and Murakami (2021), in a global-scale review of mine tailings dam failures between 1915 and 2020, observed that publication trends tend to intensify after accidents, particularly in countries with emerging economies, where institutional frameworks for dam oversight may still be under development. These international findings are consistent with the trend observed in Brazil, where scientific production increased significantly after the Mariana and Brumadinho dam failures.

#### *4.3 The Doce River Basin as a Symbol of Environmental and Scientific Impacts*

In addition, the results obtained from the systematic review regarding the main river basins and sub-basins identified during the analysis, the Doce River basin was the most cited. The accident involving the collapse of the mining tailings dam in the Doce River basin resulted in changes in physical and chemical variables in the affected aquatic environments due to contamination, and furthermore, the release of these contaminants directly affected the biota and the functioning of these ecosystems (Silva et al. 2022).

As reported by Freitas et al. (2019) and Silva et al. (2019) in their studies, after the release of these tailings, there was contamination of water bodies, soil and air, directly impacting agricultural activities, triggering flooding in some areas, and causing adverse situations for the biota. In Brazil, CONAMA 357/2005 has been the main standard used for comparing contaminant concentrations in relation to reference values, especially in

relation to total dissolved solids and water turbidity (e.g., Thompson et al. 2020; Kutter et al. 2023).

Omachi et al. (2018) reported that the large volume of sediment loading led to the siltation of affected water bodies. Furthermore, according to Thompson et al. (2020), there was also a change in water temperature and a reduction in dissolved oxygen concentrations. After the Mariana dam collapse, there was significant water and sediment contamination, with higher pollutant concentrations observed in the impacted areas (Freitas et al. 2019; Quadra et al. 2019). The concentrations of Fe, Al and Mn observed in the main impacted areas were between 5,000 and 23,000 times higher than in non-impacted areas, thus exceeding reference levels (Quadra et al. 2019).

Vergilio et al. (2020), reported that water and sediments became toxic to organisms at different trophic levels, such as algae, microcrustaceans and fish. The tailings plume released after the dam collapse reached the coastal region 17 days after the accident. Subsequently, particulate matter was reported in coral reefs (Francini-Filho et al. 2019). Bonecker et al. (2019) also noted some larval fish with reddish sediment adhered to their bodies, as well as two other species that had damaged digestive systems.

The study by Gabriel et al. (2021), showed that the collapse of the Fundão dam can be considered one of the most significant environmental disasters involving dams, considering the volume of released tailings and the socio-environmental impacts generated, when compared to other mining dam disasters. Furthermore, the estuary continues to be impacted by tailings contamination, representing major impacts on biota and human health (Queiroz et al. 2021; Sá et al. 2021). Given the importance of the Doce River basin for the diversity of the Brazilian ecosystem and the disaster involving the collapse of the Fundão dam, this basin has gained considerable prominence in scientific studies.

Based in the analyses conducted in these studies, it was possible to observe a concentration of research related to impacts on biota in areas surrounding dams. This factor highlights a trend in studies that prioritize the analysis of environmental impacts in areas previously affected by disasters related to mining ventures (e.g., Dias et al. 2018a; Polignano and Lemos 2020). Nevertheless, this same perspective has been applied to dams in hydroelectric ventures, which affect physical and natural systems (geomorphological processes, characteristics of the aquatic environment, and impacts on biological communities), as highlighted by Serra and Oliveira (2020).

#### *4.4 Economic Repercussions of Disasters and Institutional Failures*

Besides the major environmental impacts reported, other documents have revealed different perspectives on the impacts. A study conducted by Niquito et al. (2021) demonstrated that after the collapse of the Fundão dam, a negative impact of -6,81% on the total GDP was observed. Additionally, Gonzalez et al. (2021), reported a loss of US\$5.28 billion throughout the Doce River Basin as an economic impact after the accident. It is important to mention that in Minas Gerais, mineral exploration represents the majority of the state's economy, and in the recent decades, a large expansion of mines has been observed (Rezende 2016), revealing the significant economic impact caused by this accident. This same perspective would justify the prominence of institutions like UFES and UFMG (1st and 5th positions) and the prominence of authors Neto, R. R., Ghisolfi, R. D., and Sá, F. (2nd, 4th, and 7th positions), considering that many of these studies encompass territories of Minas Gerais and Espírito Santo (1st and 4th places), often associated with disasters in the Doce River basin and the resulting environmental impacts (Gaeta et al. 2022; Gabriel et al. 2020; Holz et al. 2020; Nogueira et al. 2021; Sá et al. 2021).

In addition, the Federal University of Rio de Janeiro (UFRJ; 2nd place) and the University of São Paulo (USP; 4th place) justify their rankings as they are among the top Brazilian universities according to the Center for World University Rankings (CWUR 2023), which considers, among other criteria, the research performance (total number of works, high-quality publications, influence, and citations).

The journals that published the most articles in the selected research area were: *Science of the Total Environment*, *Brazilian Journal of Biology*, *Neotropical Ichthyology* and *Environmental Monitoring and Assessment*. These journals focus on environmental sciences, biological sciences, botany and zoology, reflecting the research approaches observed in the published studies. According to Carvalho et al. (2021), who conducted a review of environmental studies in the Doce River Basin, out of the 278 articles analyzed, 113 addressed biota-related topics.

#### *4.5 Regional and Institutional Approaches in Academic Production*

On the other side, the prominence of UEM (3rd place) suggests a relation with research conducted in the state of Paraná (2nd position), which was addressed in 8.8% of the analyzed articles. Affiliated with this institution, authors like Agostinho, A. A., and Gomes, L. C. (1st and 5th place), stand out as the most productive in the field, together

contributing to 8.17% of the analyzed articles. The volume of publications may be related to the hydroelectric potential existing in the state, considering that Paraná has large-scale ventures such as Itaipu Binacional, in addition to the potential of Small Hydroelectric Plants (PCHs) and Hydraulic Generating Stations (CGHs) (Wegner et al. 2020).

Among the five most addressed states in studies, besides Minas Gerais, Paraná, and Espírito Santo, we observe the states of Pará and Tocantins (5th and 6th place). Except for the state of Espírito Santo, the other states possibly receive prominence due to the significant potential available for energy generation. Simultaneously, the systematic review also identified the prominence of the Paraná, Amazon, and Tocantins-Araguaia River Basins in the studies' approaches. It is important to highlight that such basins constitute fundamental pillars for the Brazilian energy sector, concentrating a large number of hydroelectric plants that supply the country with electric power (EPE 2023).

#### *4.6 Hydroelectric Dams and Their Socioenvironmental Effects*

Although hydroelectric plants represent important pillars of national economic development, the damming of rivers, by interrupting their natural flow regime, can lead to far-reaching consequences, such as altering natural hydrological dynamics, biological reproduction, and biodiversity distribution, as well as disrupting ecosystem service dynamics in these aquatic systems (Agostinho et al. 2008; Nilsson et al. 2005).

According to the study conducted by Alho (2020), in the Amazon region where the Belo Monte Hydroelectric Plant was implemented on the Xingu River, in the state of Pará, a proliferation of disease vector species, such as malaria and leishmaniasis, was observed. In the same study, the author also mentions the case of Amazon turtles (*Podocnemis*), which were severely impacted by environmental imbalance in the region, as this species has a highly complex reproductive behavior that depends on the seasonality of river flow, making it highly sensitive to environmental changes.

A study by Lopes et al. (2024), reveals that the implementation of Belo Monte Plant, combined with the occurrence of a El-Niño drought, resulted in decrease of fish consumption in riverine communities, suggesting an environmental impact caused by the project. Additionally, Calvi et al. (2020), recorded that Belo Monte Dam caused an exodus of rural workers, who opted for urban jobs, leading to a decline in rural labor. Instead of strengthening local production, actually provoked less market integration, giving place to agricultural commodities (Calvi et al. 2020).

Subsequently, Castro-diaz et al. (2024) conducted an experiment that revealed that residents in this region suffered economic (such as loss of income) and issues related to energy access (the interviewee's electricity does not come from Belo Monte, but from other power plants, which leads to limited access to drinking water). Similarly, Mayer et al. (2022), conducted a study in another Amazonian Dam located in Madeira River Basin and concluded that due to the displacement or resettlement necessary for the dam implementation, many people suffered significant economic losses, as inhabitants lost their income or had to change jobs.

The construction of the Itaipu Hydroelectric Plant on the Paraná River, located between Brazil and Paraguay, has contributed to the loss of fauna and flora in the local Atlantic Forest. Additionally, during the formation of the Itaipu reservoir, about 30,000 animals were relocated to a protected area; however, many did not survive due to inability to adapt to the new habitat (Ziober and Zanirato 2014; Alho 2020). The most productive author in this field of study was Agostinho, A. A., who, in several articles analyzed by the systematic review, highlighted the risks to biota, especially in fish affected by dam construction (Agostinho et al. 2012; Agostinho et al. 2008; Pelicice and Agostinho 2007).

Regarding the Itaipu project, Campos and Brandão (2023), reported that the governmental aspects surrounding its implementation reflect a tendency to favor certain economic groups and also led to the violation of civil rights among subaltern classes during its execution. Furthermore, according to Nogueira and Barros (2024), the Itaipu project represents a convergence of political power and economic interest. The study conducted by Dias and Castelano (2024), revealed that approximately 40,000 people were affected during the expropriation process for the construction of Itaipu reservoir, highlighting the violent nature of this historical event in Brazil.

#### *4.7 The São Francisco River Basin and Conflicts Arising from Water Diversion Projects*

Due to the large number of dams implemented in Brazilian territory, there is a need for studies that adopt a predictive approach regarding dam breaches or the leakage of contaminant materials. It is essential to foster research to investigate potential environmental impacts, so that effective action plans can be developed for mitigation and accident prevention (Garcia et al. 2024).

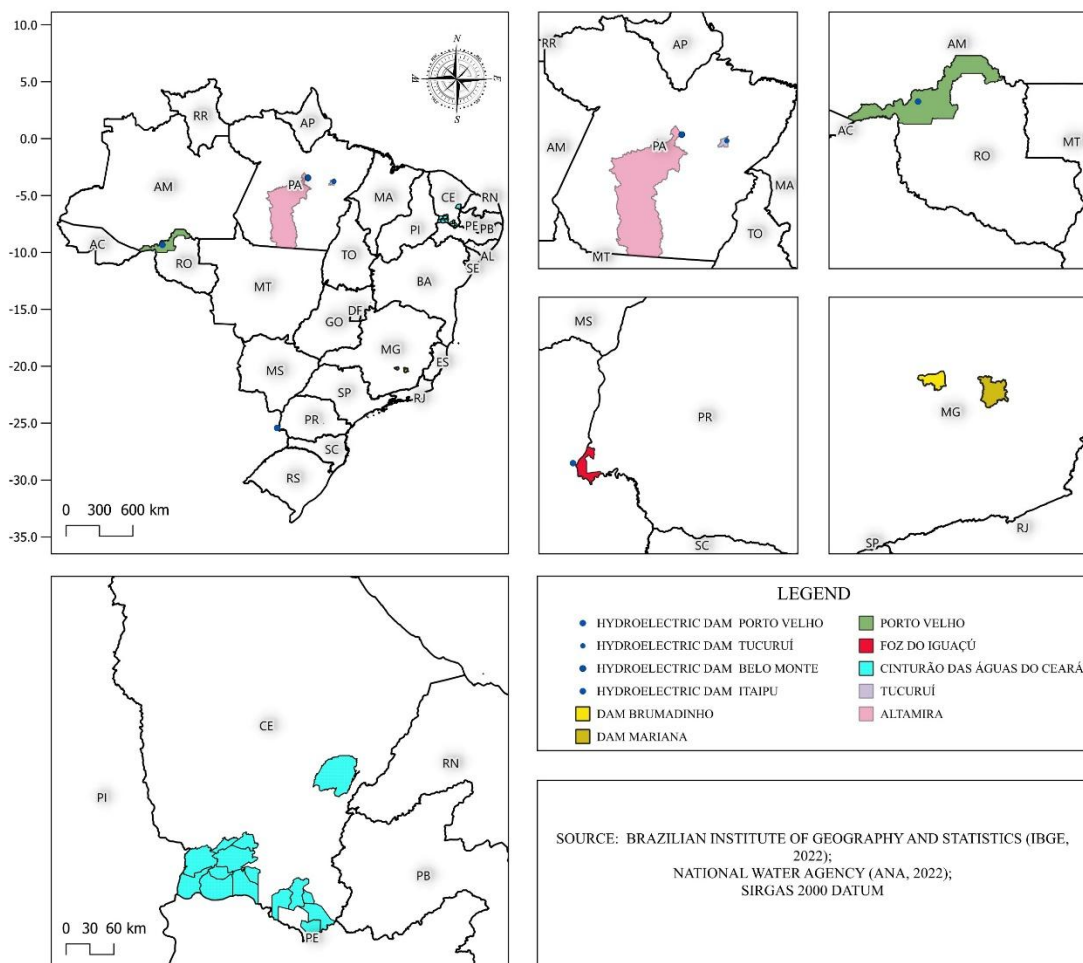
According to the data obtained from the systematic review, another noteworthy river basin was the São Francisco basin. Due to its hydroelectric potential, the São Francisco River hosts power generation plants that supply electricity to parts of the

Southeast and Northeast regions of the country. It also serves as a water supply source, playing an important role in irrigation (Costa et al. 2021).

When it comes to studies about this basin, it's also important to highlight the São Francisco River Transposition, which is one of the largest water infrastructure projects in Latin America (Brazil 2020b). In the state of Ceará, the hydraulic project called Cinturão das Águas do Ceará (CAC) aims to transpose the waters of the São Francisco River to the main hydrographic basins of Ceará (Arrais and Bezerra 2022).

According to the study conducted by Arrais and Bezerra (2022), there is a concentration of studies related to the Cinturão das Águas in Ceará that mainly focus on the social consequences of the project's implementation, highlighting conflicts triggered by the installation of the CAC and psychological effects resulting from the expropriation of the local population. Additionally, Barbosa et al. (2015) highlight the high risk of soil collapsibility in one section of the project, which could cause leaks along the canal.

In São Francisco Basin, many problems were triggered by dam implementation, such as environmental conflicts due to land use changes, community displacement, and environmental degradation (Junior et al. 2024). Following this, Campos and Serapião (2022), reported that these projects caused physical and mental health issues in the population living in regions affected by dam projects in São Francisco Basin, along with loss of territoriality and others economic problems.



**Fig. 8** Map showing the location of the main dams discussed in the study and their location.

#### 4.8 Trends and Updates in Dam safety

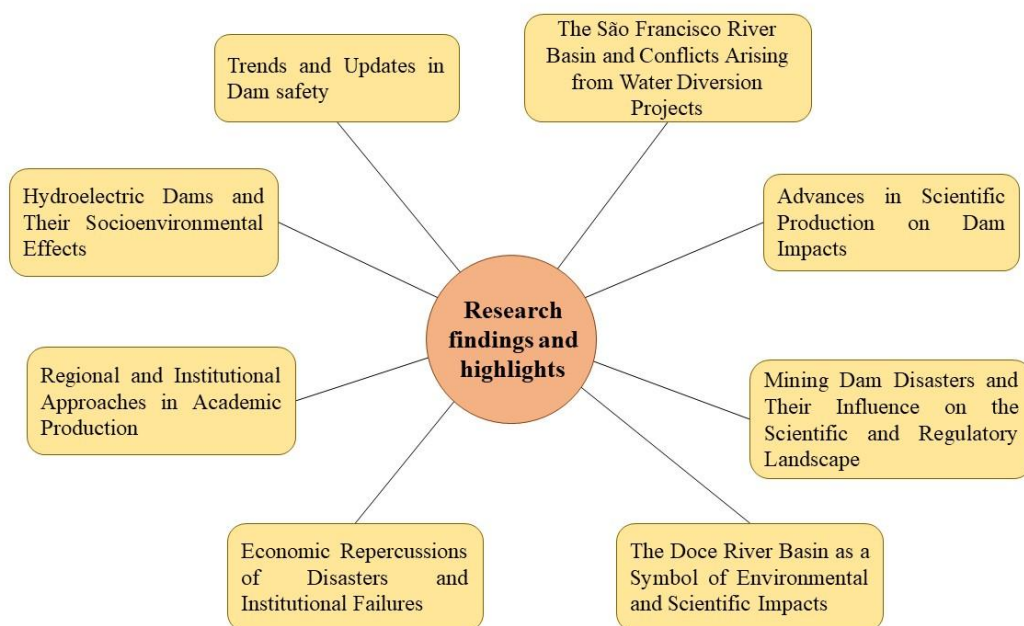
After the Brumadinho collapse, the National Dam Safety Policy (Brasil 2010a) was modified by Law N° 14.066, assigning mining companies the responsibility for mitigation, prevention and compensation of environmental impacts resulting from mining activities. The law also mandates the implementation of a contingency plan for each project, along with an environmental recovery plan for impacted areas. Guimarães et al. (2022), highlight that the Emergency Action Plan (EAP) required by both international and national law is insufficient, as it requires only minimum content related to environmental impacts.

In this regard, an additional perspective is provided by Silva et al. (2021), who argue that dam safety management can be improved by maintaining accurate data on dam projects, starting from the licensing process through construction and operation. Furthermore, considering past accidents in similar projects and utilizing prior information could offer better insights for dam management (Silva et al. 2021). Additionally, for

effective risk and disaster management, environmental, social and public health aspects should be considered fundamental pillars (Guimarães et al. 2022).

There are some emerging technologies related to dam safety that can significantly contribute to improvements in risk management. In this context, Suwatthikul et al. (2021), successfully conducted an experiment in Thailand using Dam Safety Remote Monitoring System (DS-RMS), which monitors dam behavior, reservoir operation, earthquakes, expert system assessments, and public communication. The system proved to be a fast and reliable tool for monitoring and evaluation for hydroelectric dams. Lei et al. (2022), also employed remote sensing for flood disaster monitoring and emergency assessment, using a combined method involving satellites, unmanned aerial vehicles, and field measurement technologies. They achieved an accuracy of 98%, and the system was able to provide information on flood evolution, disaster progression, and emergency rescue operations.

Additionally, Sang et al. (2022), applied an Extended Cloud Model (ECM) combined with the Extended Analytic Hierarchy Process (EAHP) for a concrete panel rockfill dam, demonstrating that the model is reliable for safety warning indicators and also more flexible and easier to be used compared to other methods. Han et al. (2022), applied an expert system integrated with online safety monitoring system for hydropower in China. This system can identify data anomalies and detect possible structural changes in dams, thus providing critical support for safety monitoring and management.



**Fig. 9** Topics addressed in the discussion

## **5. Conclusion**

The study found that dams used for hydroelectric power generation (hydroelectric plants) are the most frequently addressed in the literature. However, the trend of exponential growth in the theme, especially over the last five years, is closely linked to accidents involving mining dam failures. Multiple lines of evidence reinforce this relationship (e.g., the predominance of studies focused on the Doce River Basin; the prominence of research in the states of Minas Gerais and Espírito Santo; and visibility of researchers affiliated with UFES and UFMG). Additionally, the recent emerge of terms such as "disaster", "heavy metals" and "tailings dam" directly alludes to these disasters, demonstrating trends for future research directions.

This research also found that the main approaches are based on analysis of risks to biota, demonstrating a persistent concern regarding impacts on living organisms. Consequently, many of the secondary approaches identified in this study are complementary to support this analysis (e.g., environmental contamination, water quality, and environmental management and planning). Furthermore, it is likely that many of the biota-related risks reported are related to areas surrounding hydroelectric plants, considering that they constitute the main type of dams addressed in studies and that studies related to mining dams are relatively recent in the temporal scale.

The initial results of this research should guide future studies among researchers, environmentalists, and regulators, and also be useful in identifying potential collaborators for further investigations. Upcoming studies should aim to highlight emerging trends in research on disasters associated with metallic contaminants and ecological risks, using integrated indices. To fill existing gaps, future studies could examine a broader temporal scale, including searches restricted to specific regions of Brazil, thereby facilitating state and municipal initiatives.

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## 7. Interest Statement

No potential conflict of interest was reported by the author(s).

## 8. Data availability

The data that support the findings of this study are available from the corresponding author, Ana Cristina Cavalcante Selfe, upon reasonable request.

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**ANEXO I – SUSTAINABLE WATER RESOURCES MANAGEMENT (Qualis A4 – Engenharias I)**

**Date:** 02 Sep 2025  
**To:** "Ana Cristina Cavalcante Selfe" ana.selfe@tucurui.ufpa.br  
**From:** "Sustainable Water Resources Management (SWAM)" kamatchi.natarajan@springer.com  
**Subject:** Your Submission SWAM-D-24-00379R2

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Dear Ms Cavalcante Selfe,

We are pleased to inform you that your manuscript, "A COMPREHENSIVE REVIEW ON ENVIRONMENTAL IMPACTS OF BRAZILIAN DAMS: OVERVIEW AND EMERGING TRENDS", has been accepted for publication in Sustainable Water Resources Management.

You will receive an e-mail in due course regarding the production process. You will have an opportunity to review your final proof as part of the typesetting process. Please be sure to make all necessary editing on the galley proofs.

The online publication of your manuscript is not a precursor to a final publication. It is a permanent, unalterable record and is fully citable and recognized by international library standards. No further revisions can be made after your manuscript is published online except by errata sheet.

Please remember to quote the manuscript number, SWAM-D-24-00379R2, whenever inquiring about your manuscript.

With kind regards,  
Alper ELCI, PhD  
Editor-in-Chief  
Sustainable Water Resources Management