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Water losses in water distribution systems: a brief bibliometric analysis

Perdas hídricas em sistemas de distribuição de água: uma breve análise bibliométrica

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Resumo
A aplicação da análise bibliométrica permite visualizar tendências em uma determinada área de estudo. Neste sentido, a pesquisa visa analisar a evolução do conhecimento científico acerca da temática das perdas em sistemas de distribuição de água a partir da análise bibliométrica. A busca foi realizada na base Scopus no período de 1978 a 11 de março de 2024, totalizando 158 artigos. Os principais resultados indicam que os anos de 2022 e 2023 se destacaram em termos de quantidade de publicações. Dentre os resultados, China e Estados Unidos lideraram em número de publicações, com 66 e 55, respectivamente. Mais de 70 termos foram identificados com cinco ou mais ocorrências, com "*water distribution systems*", "*water distribution networks*", "*leak detection*" e "*water supply*" destacando-se como os termos mais estudados. Esses temas emergiram como os principais focos de interesse na amostra, caracterizando-se como os *Motor Themes*. Embora as soluções tecnológicas sejam amplamente estudadas, há pouca análise sobre sua viabilidade e implementação em contextos com infraestrutura precária ou recursos limitados.
Palavras-chave: abastecimento de água, vazamento, modelos, gestão de perdas, sistema de distribuição de água.

Abstract
The application of bibliometric analysis makes it possible to visualize trends in a given area of study. In this sense, the research aims to analyze the evolution of scientific knowledge on the topic of losses in water distribution systems based on bibliometric analysis. The search was carried out on the Scopus database from 1978 to March 11, 2024, totaling 158 articles. The main results indicate that the years 2022 and 2023 stood out in terms of the number of publications. Among the results, China and the United States led the way in terms of several publications, with 66 and 55, respectively. More than 70 terms were identified with five or more occurrences, with "water distribution systems", "water distribution networks", "leak detection" and "water supply" standing out as the most studied terms. These themes emerged as the main focuses of interest in the sample, characterizing them as Motor Themes. Although technological solutions are widely studied, there is little analysis of their feasibility and implementation in contexts with poor infrastructure or limited resources.
Keywords: water supply, leakage, models, loss management, water distribution system.

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1 Introduction

Water resources have undergone significant changes in their composition and availability, predominantly attributable to human activities, especially since the onset of the First Industrial Revolution. Factors such as accelerated industrialization, exponential population growth, large-scale urbanization, climate change, depletion of natural resources, water scarcity, and environmental pollution (soil, water, and air) are key elements driving global awareness of environmental issues (Hawken, Lovins & Lovins, 2007; Amaral et al., 2023).

Water distribution losses are categorized by the discrepancy between the amount of water produced and that effectively measured at consumption points. According to Farouk, Rahman, and Romali (2023), the amount of water produced and lost before reaching the final consumer significantly affects water sustainability. This difference can arise at any stage from the source to delivery to the final consumer. Such losses are divided into two distinct groups: physical losses, which occur due to leaks, and non-physical losses, resulting from administrative failures, commercial irregularities, water theft, and measurement inaccuracies (Kusterko et al., 2018).

The World Bank Report indicates that global water losses are significant, with over 32 billion m³ of treated water lost due to leaks in distribution networks. Additionally, another 16 billion m³ of water delivered to the population is not billed due to measurement issues and theft. The estimated total cost of these distribution losses for sanitation companies is around US$14 billion per year (Kingdom, Liemberger & Marin, 2006).

Beyond the effects of climate change and water resource scarcity, this resource management has been hampered, often due to high levels of not billed water loss in water supply companies (Liemberger & Wyatt, 2018).

The challenge already faced in the distribution and conservation of water resources intensifies due to the lack of adequate sanitation, with water distribution losses being one of the main challenges. These losses indicate a critical aspect of sanitation, considering the availability of water for human consumption and the efficiency of supply systems (Guedes et al., 2023).

Globally, there is significant inefficiency in water distribution, with expert estimates indicating that between 30% and 40% of water is lost in the distribution network. These losses, attributed to outdated infrastructure, leaks, and a variety of other causes, tend to differ depending on the region and country (Tundisi & Matsumura-Tundisi, 2020).

The metric used for comparison in water loss analysis is the Total Revenue Loss Index (TRLI). In 2021, Brazil recorded 40.9% for TRLI, while countries such as "Cameroon (40.0%), Tanzania (37.0%), Ethiopia (29%), China (21%), and the United States (14%) had lower values compared to Brazil" (ITB, 2023, p. 4). These data highlight the urgency of reducing water supply system losses in Brazil, particularly considering that it has higher rates than some African countries. However, it is important to note that in many of these African countries, supply network coverage is lower, which may contribute to lower water loss levels.

Reducing losses in water supply systems is seen as a fundamental strategy in the decision-making process of companies, especially in the current competitive scenario. Investments in controlling and reducing these losses offer advantages in various areas, such as: economic, technological, socio-cultural, and environmental (Kusterko et al., 2018).

A study conducted by Santi, Cetrullo and Malheiros (2021) highlights 54 practices aimed at loss control in 42 water supply companies in municipalities within the Piracicaba, Capivari, and Jundiaí River Basins which shows a direct relationship between company performance and the number of water loss control practices adopted, and differences in the number of practices adopted may be influenced by technical-operational, planning and management factors.

To understand the topic under study, scientific production on the subject must be investigated, as it allows for the explanation of trends and knowledge domains. A tool for observing the focuses and movements, regarding the scientific production of a given subject, occurs with bibliometric analysis, which has quantitative and qualitative aspects. Bibliometric analysis is an important technique for evaluating the extent and nature of generated knowledge, regardless of being scientific (Marques, Maculam & Souza, 2023). This analysis enables detailed monitoring of a scientific field by delineating research areas and its evolution and mapping the cognitive structure of the field (Andrade & Queiroz, 2023).

Therefore, the main objective of this research was to quantify the studies being conducted on the topic of losses in water distribution systems and analyze which methods are being used to mitigate these losses.

2 Methodological procedures

This research aims to identify the state of the art regarding water loss in distribution systems at both national and international levels. In this regard, the study is characterized as applied, descriptive, and mixed-methods (qualitative and quantitative). Its applied nature is reflected in the pursuit of practical solutions to real-world problems related to water losses in distribution systems, aiming to contribute effectively to resource management and conservation. Regarding its descriptive approach, Gil (2019) states that the primary objective is to describe the characteristics of a given phenomenon or population or to establish relationships between variables.

The Scopus database (Elsevier) was chosen due to its international recognition (Singh et al., 2021). Initially, an exploratory search was conducted to identify the most appropriate keywords. The main search was then carried out using the Boolean operators "AND" and "AND NOT" as follows: "water management" AND "water supply" AND "loss" AND NOT "irrigation", covering scientific articles published from 1970 to March 11, 2024 resulting in 914 articles. The search was carried out only with documents in the English language, and only scientific articles were selected from the range of documents obtained.

However, it was necessary to refine the search to better align with the study's objective, that is, water losses in distribution systems. A second search was conducted on March 11, 2024, using the same database and the following keywords combined with Boolean operators: "water distribution systems" AND "loss" AND "leak" AND NOT "irrigation" AND NOT "agriculture". The "AND NOT" operator was used to exclude documents containing the terms "irrigation" and "agriculture," as water losses in these contexts are not considered in this research. This refined search resulted in 158 articles. It is important to note that no time restriction was imposed on the search, allowing for the inclusion of all relevant scientific literature indexed in Scopus.

By utilizing keywords and computational tools, it is possible to quantify and qualify academic outputs on the subject and highlight the main contributions to science and their interconnections. Keywords represent a central focus of contemporary bibliometric analysis (Urbizagástegui-Alvarado, 2022). This enables the identification of scientific advancements and the most influential journals, authors, regions, and educational institutions on a given topic (Kaffash & Nguyen; Zhu, 2021).

After defining the search for keywords with their respective operators, all documents from the Scopus platform were obtained. Then, using the Bibliometrix tool, some results were achieved for the main bibliometric indicators.

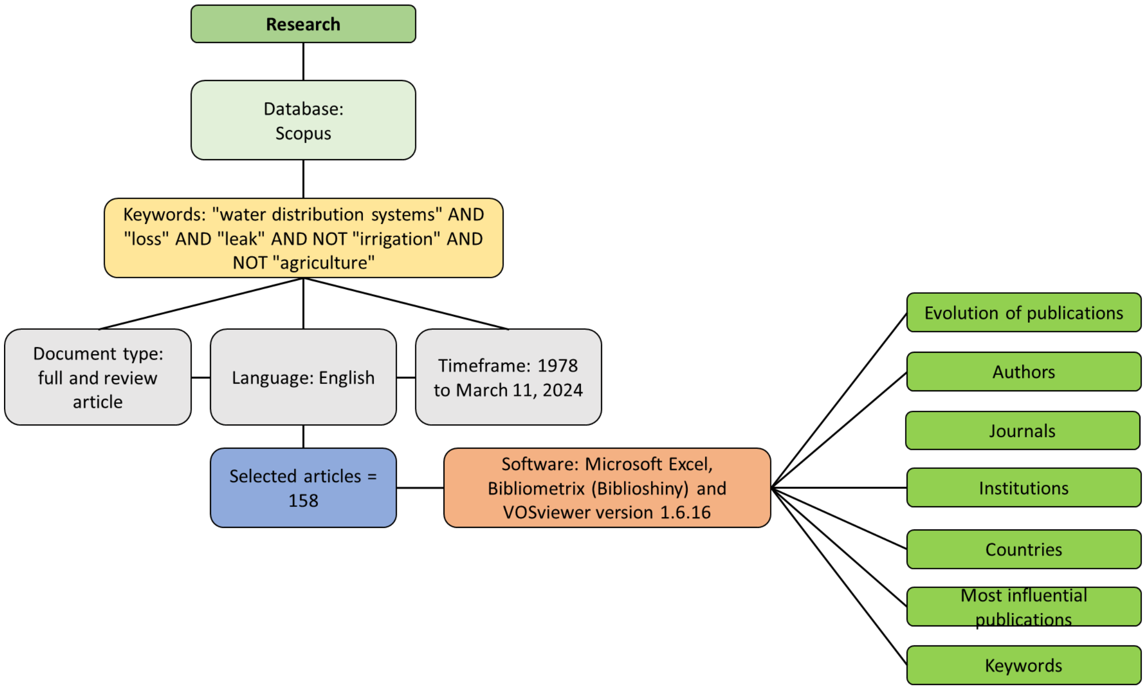
Bibliometrix, as an extension of the R software, and its integration with the Biblioshiny package, provide a comprehensive range of functions specific to bibliometric analysis. This tool offers a suitable approach for investigating scientific production and facilitates detailed and comprehensive analyses (Aria & Cuccurullo, 2017; Moreira, Guimarães & Tsunoda, 2020).

For constructing keyword co-occurrence networks, the VOSviewer software (version 1.6.20) was used. Additionally, procedures such as data tabulation, conversion, and compilation of the data obtained were performed using Microsoft Excel.

Bibliometric research consists of "examining the production of articles in a given field of knowledge, mapping academic communities, and identifying researcher networks and their motivations" (Chueke & Amatucci, 2015, p. 2). For a clearer visualization of the research process, the study framework is presented in Figure 1.

Figure 1

Research Framework



Source: Prepared by the authors (2024).

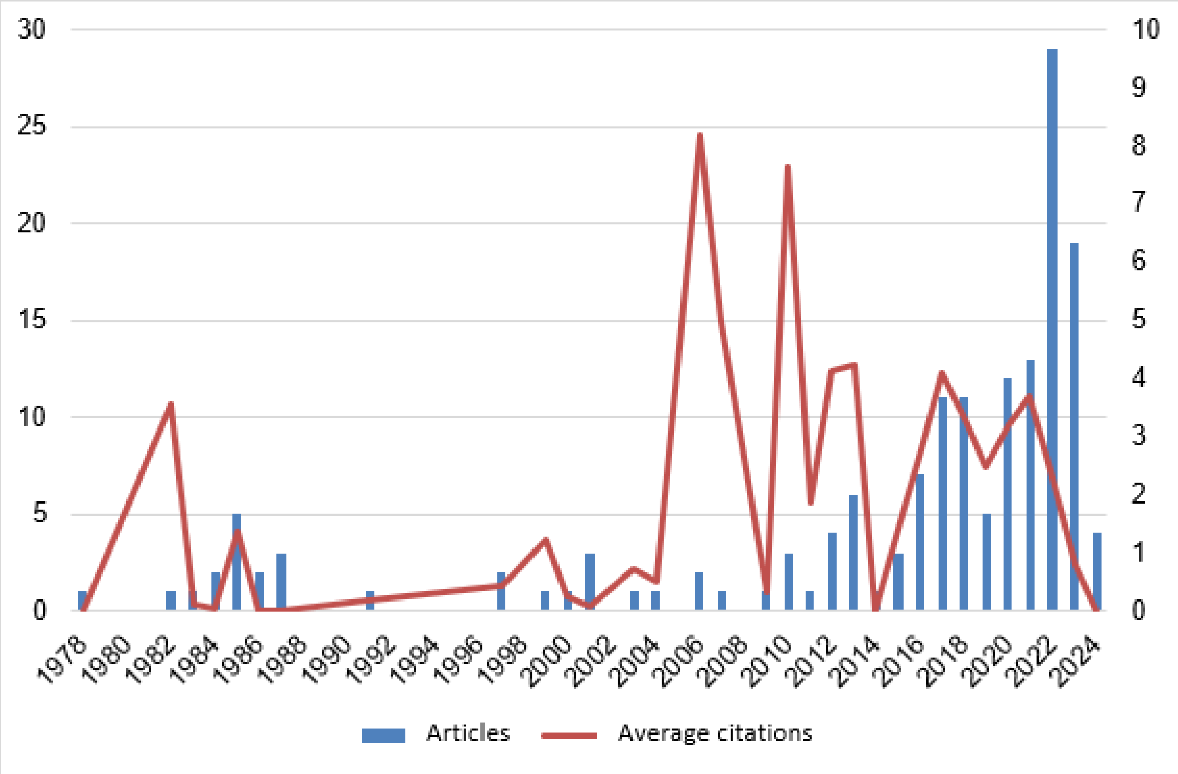
3 Results

The bibliometric analysis conducted for the period from 1978 to March 11, 2024, resulted in the following aspects: the number of published articles, the countries with the highest publication rates, the main universities conducting research, the leading scientific journals from these universities, the keyword co-occurrence network, and the thematic map.

Figure 2 illustrates the number of articles published between 1978 and March 11, 2024, on the studied topic.

Figure 2

Number of articles published between 1978 and March 2024



Source: Prepared by the authors using Biblioshiny (2024).

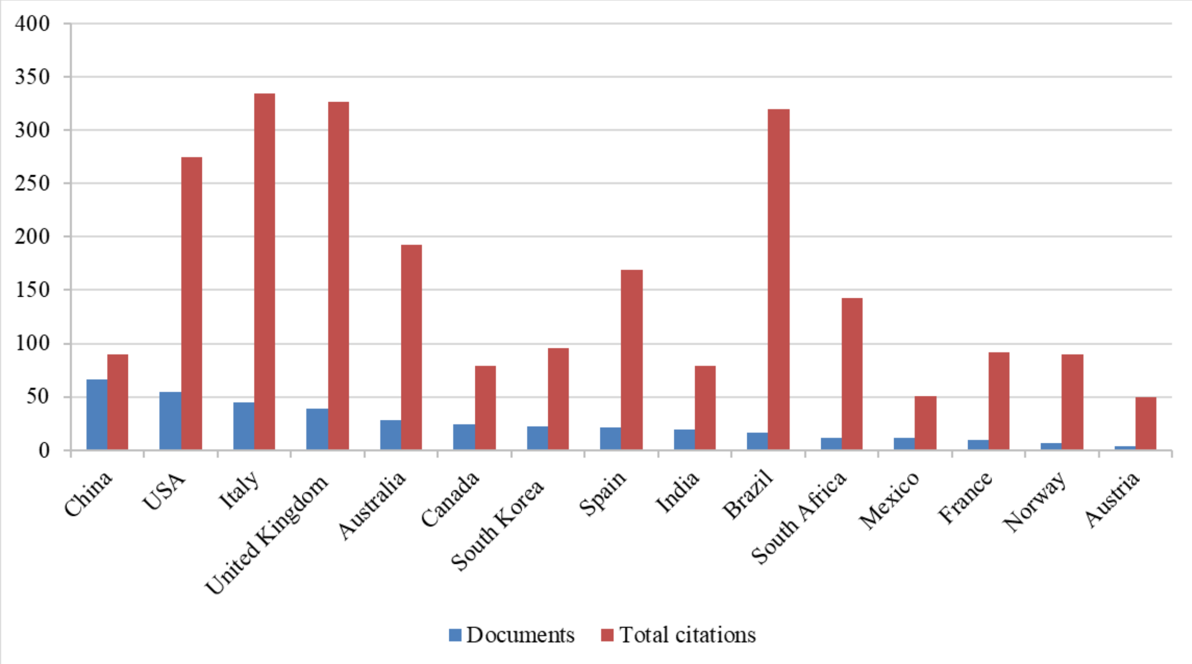
From 1978 to 2016, the number of published articles ranged from 0 to 7 per year, however, between 2017 and March 2024, this number accounted for 66.67% of the publications, demonstrating the growing prominence and research interest in this period. The peak of publications occurred in 2022, with 29 articles. The first published article was authored by Kurkjian (1978) and describes how butterfly valves can be used in various ways to achieve a piping system that operates the pressure drops smoothly and without leaks.

The average number of citations per year on this topic mostly ranged between 0 and 5 citations per year, the highest annual citation averages were recorded in 2006 with 8.16 and 2010 with 7.64. It is important to note that more recent articles tend to have fewer citations, as there is a necessary period for their integration and recognition in academic literature.

Regarding geographical distribution, 37 countries have published articles on this topic. Figure 3 presents the top fifteen countries with the highest number of publications and their respective citation counts.

Figure 3

Number of articles published in the 15 leading countries



Source: Prepared by the authors using Biblioshiny (2024).

The following countries have the highest number of publications in descending order: China (66), the United States (55), Italy (45), the United Kingdom (39), and Australia (28). In terms of citations, the leading countries are Italy (334), the United Kingdom (327), Brazil (320), the United States (275), and Australia (193).

The ten most frequent universities that conducted research on the subject, along with their respective countries, are listed in Table 1.

Table 1

Number of articles published by the top 10 universities

Contry	University	Articles
Australia	University of Adelaide	15
China	Zhejiang University	15
United Kingdom	University of Sheffield	12
Italy	University of Perugia	10
Spain	Universitat Politècnica de València	9
Italy	University of Brescia	9
United State	Clemenson University	8
China	The Hong Kong Polytechnic University	8
South Africa	Tshwane University of Technology	8
Thailand	National Electronics and Computer Technology Center	7

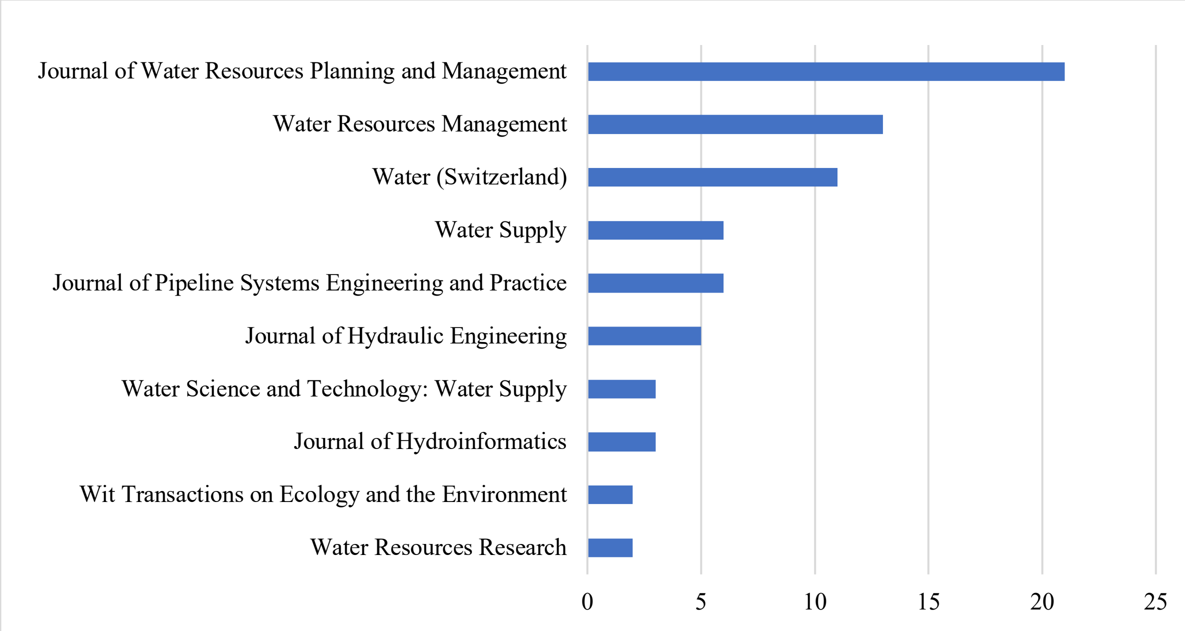
Source: Prepared by the authors using Biblioshiny (2024).

The ten leading universities in this field account for 26% of the total documents, with the University of Adelaide (15) in Australia, Zhejiang University (15) in China, and the University of Sheffield (12) in the United Kingdom.

Publications from these ten universities are distributed across 80 scientific journals, with the top ten shown in Figure 4.

Figure 4

Number of articles published in the top 10 journals



Source: Prepared by the authors using Biblioshiny (2024).

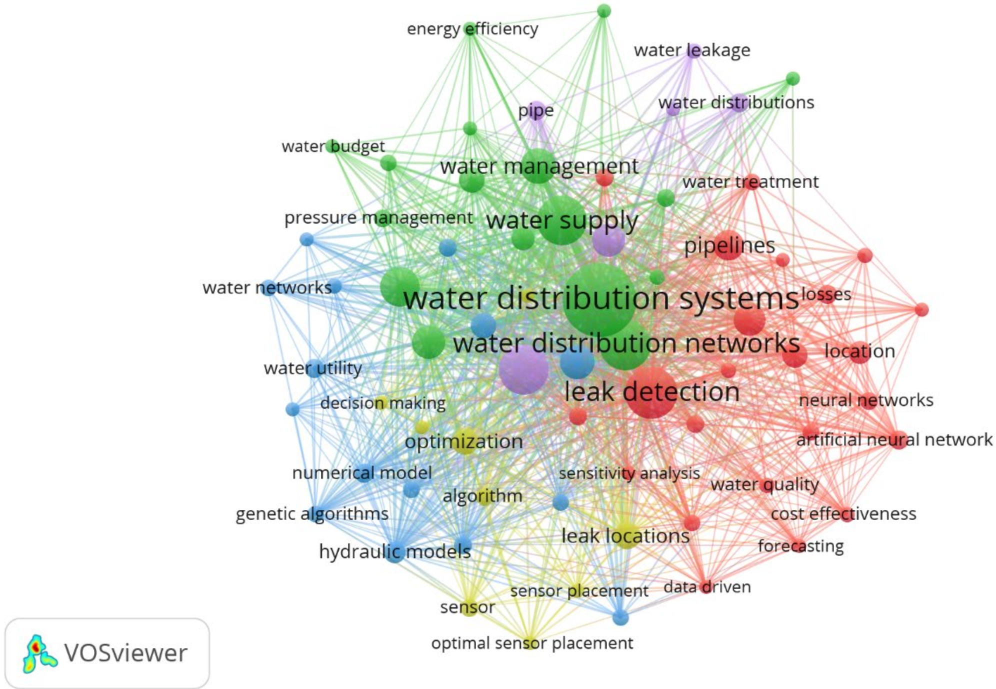
As shown in Figure 4, among the ten selected journals, the Journal of Water Resources Planning and Management had the highest number of publications, totaling 21 articles over the analyzed period.

For this study, the VOSviewer software was used, as described by Van Eck and Waltman (2023), to create a keyword co-occurrence network. This technique identified 1,551 recurring terms. A more detailed analysis was conducted by refining the selection criteria to include only terms with at least five occurrences. Additionally, vocabulary normalization was performed (grouping repeated or synonymous terms and excluding inappropriate terms), leading to the identification of 70 key terms.

The keyword co-occurrence network resulted in five clusters, comprising 70 nodes connected by 1,274 edges, as shown in Figure 5.

Figure 5

Keyword co-occurrence network



Note: Keywords with a minimum of five occurrences were considered.
Source: Prepared by the authors using VOSviewer (2024).

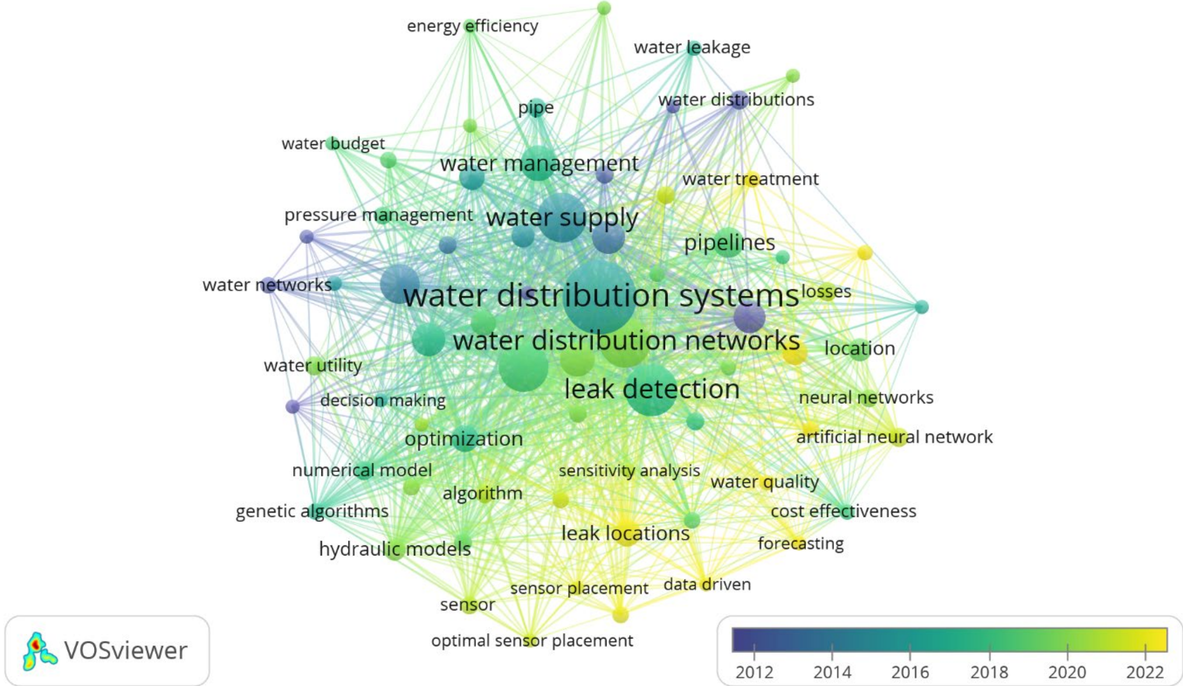
In the VOSviewer software, the term co-occurrence network analysis resulted in five distinct clusters, identified by the following colors: red (23 items), green (17 items), blue (17 items), yellow (9 items), and purple (6 items). The sphere diameter in the visualization is proportional to the number of occurrences of the associated term, indicating that larger spheres represent terms with higher frequencies. Additionally, the thickness of the lines connecting these spheres reflects the strength of the relationship between the terms, with thicker lines denoting stronger connections. The most frequent terms in each cluster are:

- The red cluster corresponds to the terms: "leak detection", "water pipelines", "pipelines", "machine learning" and "location".
- The green cluster corresponds to the terms: "water distribution systems", "water distribution networks", "water supply", "water losses" and "water management".
- The blue cluster corresponds to the terms: "detection method", "water resources", "hydraulic models", "numerical model" and "water utility".
- The yellow cluster corresponds to the terms: "leak locations" and "optimization".
- The purple cluster corresponds to the terms: "leakage" and "leakage (fluid)".

In Figure 6 it is possible to verify the keyword incidence network in the period from 1978 to March 2024.

Figure 6

Keyword incidence network, 1978 to March 2024 period



Source: Prepared by the authors using VOSviewer (2024).

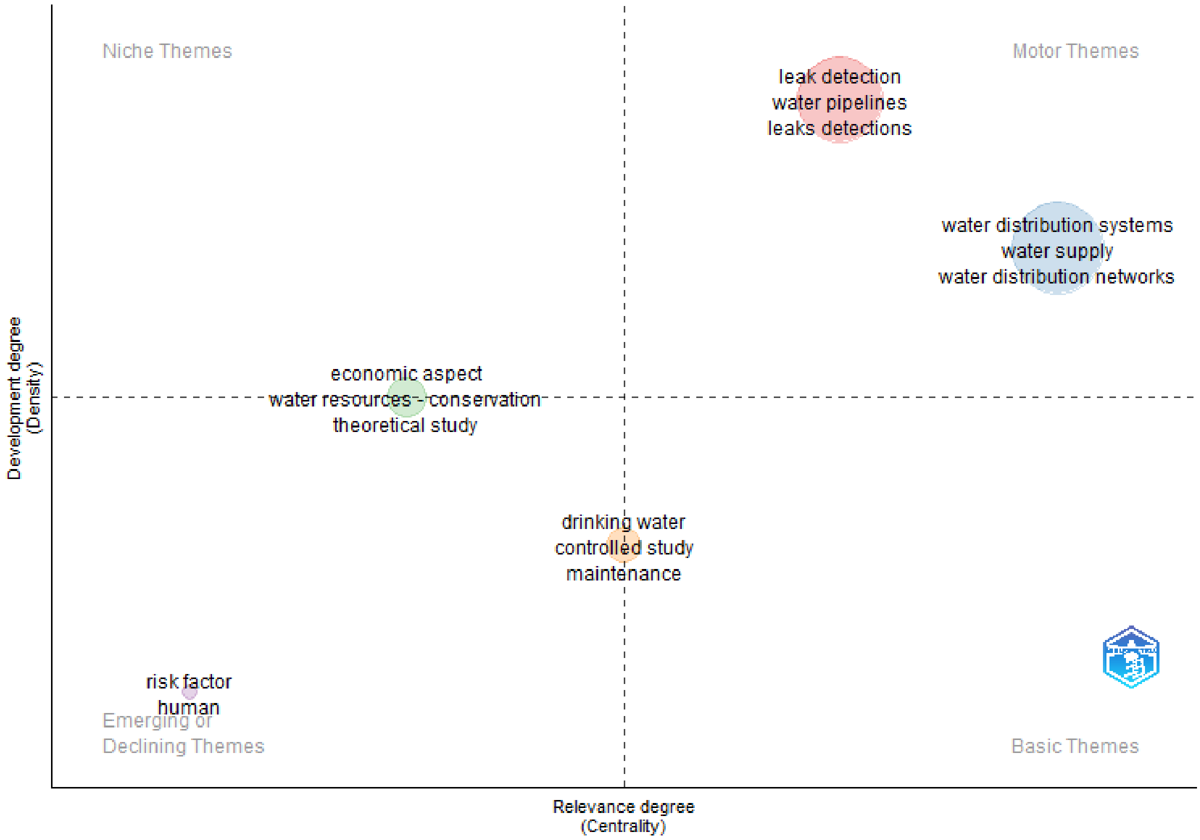
From Figure 6, it is possible to identify when the discussion on this topic began and which initial terms were used—water supply and distribution losses in dark blue color. This analysis can indicate the trajectory of the discussion on this topic, leak detection, water quality, and water treatment (yellow).

The topic of water losses in distribution systems proves to be highly relevant and necessary, supporting the significance of the present research. Between 2011 and 2012, the research was strongly linked to water supply and the provision of this essential resource to the population. In recent years, the focus has shifted toward water losses in distribution systems, reflecting the changing in concerns. This shift occurs because, as a growing portion of the global population gains access to water, the challenges now concentrate on distribution efficiency, loss reduction, and on the supply system optimization.

Additionally, this analysis is reinforced by the thematic map. Such map presents a matrix of topics related to water distribution systems, arranged according to two main axes: degree of development (density) and relative importance of the topics (centrality). The topics are classified into four quadrants, as illustrated in Figure 7.

Figure 7

Thematic map



Source: Prepared by the authors using Biblioshiny (2024).

- Niche Themes: These topics are less developed and less central, potentially representing emerging or highly specific areas. It can be seen that in this quadrant the Niche Themes ("economic aspect", "water resources conservation" and "theoretical study") intersect with the Emerging or Declining Themes.
- Emerging or Declining Themes: In this quadrant are arranged themes with low density but high centrality, indicating that, although they are not widely developed, they are of increasing importance or in the process of declining in the field of study. Themes such as "risk factor" and "human" may be related to new research on human risks in the context of water management.
- Basic Themes: These are well-developed topics with lower centrality. They form the foundation of knowledge in the field, but may not be at the forefront of current research. In this study, "drinking water", "controlled study" and "maintenance" themes are considered fundamental to understanding and managing water distribution systems.
- Motor Themes: These topics have both high density and high centrality, representing key areas of research and development in the field. It can be observed in the map that the themes "leak detection", "water pipelines", "leaks detections"; "water distribution systems", "water supply" and "water distribution networks" are examples of Motor Themes, highlighting their central role in advancing efficient water resource management.

In order to verify the authors who published the most on the topic, Table 2 was constructed.

Table 2

Distribution of top 10 authors

Author	Country	Article	Citacions
Narasimhan, S.	United States	6	43
Firat, M.	Turkey	5	21
Boxall, J.	United Kingdom	4	50
Abid, M.	Tunisia	3	3
Beck, S. B. M.	United Kingdom	3	59
Brunone, B.	Italy	3	35
Butterfield, J. D.	United Kingdom	3	59
Collins, R. P.	United Kingdom	3	59
Lambert, M. F.	Australia	3	39
Li, J.	China	3	3

Source: Prepared by the authors using Biblioshiny (2024).

A total of 466 authors were identified in the analyzed scientific production. Among the top ten authors: 16.67% of articles are linked to the United States, 13.88% to Turkey, and 36.11% to the United Kingdom.

Italy and Australia articles account for 8.33% each country. The most prolific authors are Narasimhan, S. (6 articles), Firat, M. (5), and Boxall, J. (4). Notably, authors Beck, S. B. M. (3), Butterfield, J. D. (3), and Collins, R. P. (3) co-authored the same three articles. However, the most cited articles do not belong to any of the authors who published the most on this subject (Table 3).

Table 3

Most Cited Articles

Author/Year	Title	Article	Citacions
Araujo, Ramos and Coelho (2006)	Pressure control for leakage minimisation in water distribution systems management	Water Resources Management	281
Germanopoulos (1985)	A technical note on the inclusion of pressure dependent demand and leakage terms in water supply network models	Civil Engineering Systems	244
Mounce, Boxall and Machell (2010)	Development and verification of an online artificial intelligence system for detection of bursts and other abnormal flows	Journal of Water Resources Planning and Management	191
Clark Stafford and Goodrich (1982)	Water distribution systems: a spatial and cost evaluation.	Journal of Water Resources Planning and Management	153
Wu Sage and Turtle (2010)	Pressure-dependent leak detection model and its application to a district water system	Journal of Water Resources Planning and Management	153
Britton, O'halloran and Stewart (2013)	Smart metering: Enabler for rapid and effective post meter leakage identification and water loss management	Journal of Cleaner Production	150
Fontana, Giugni and Portolano (2012)	Losses Reduction and Energy Production in Water Distribution Networks	Journal of Water Resources Planning and Management	140
Adedeji et al. (2017)	Towards Achieving a Reliable Leakage Detection and Localization Algorithm for Application in Water Piping Networks: An Overview	Ieee Access	126
Nygård et al. (2007)	Breaks and maintenance work in the water distribution systems and gastrointestinal illness: A cohort study	International Journal of Epidemiology	90

Farah and Shahrour (2017)	Leakage Detection Using Smart Water System: Combination of Water Balance and Automated Minimum Night Flow	Water Resources Management	66

Source: Prepared by the authors using Biblioshiny (2024).

4 Discussion

As previously observed, the study covered the period from 1978 to March 2024, highlighting a significant increase in the number of publications starting in 2016 (Figure 2). This growth can be attributed, in part, to the implementation of the 2030 Agenda in 2015, reflecting the increasing importance of global environmental concerns. The peak of scientific publications on the topic was recorded in 2022.

The search resulted in 4,625 references and identified 466 authors involved. The annual growth rate was calculated at 3.06%. Additionally, international collaboration was significant, representing 17.72% of identified co-authorships. The Journal of Water Resources Planning and Management emerged as the leading journal in this field, with major contributions from Clark, Stafford and Goodrich (1982), Mounce, Boxall and Machell (2010), Wu, Sage and Turtle (2010), Fontana, Giugni and Portolano (2012).

One of the first approaches identified to address the problem of water losses was mathematical modeling. An example is the study conducted by Germanopoulos (1985), which employed a network simulation model to analyze the relationship between pressure and leakage flow. This study enabled more realistic results by assuming fixed nodal consumptions independent of network pressures. However, the author concluded that these fixed nodal consumptions are not valid in situations where the distribution system operates with failures or below-normal pressures.

Losses in water distribution systems represent a serious global issue, leading to economic, environmental, and social problems, as well as potential health risks. Nygård et al. (2007), while evaluating maintenance interruptions in Norway's water distribution system, observed that these interruptions were associated with an increased risk of gastrointestinal diseases. Rapid detection and localization of leaks in water distribution systems are crucial, as they not only prevent economic losses but also mitigate environmental issues (Benítez et al., 2012; Shiddiqi, Cardell-Oliver; Datta, 2020; Kafle; Fong; Narasimham, 2022; Blázquez-García et al., 2021; Li, Zheng; Lu, 2022; Basnet et al., 2023) and prevent serious health risks (Avila et al., 2021; Kafle, Fong and Narasimham, 2022).

The application of Artificial Intelligence (AI) and mathematical models to determine the optimal placement of sensors in water distribution pipelines can assist in detecting leaks and preventing unbilled water losses. Yu et al. (2023) clarify that data collection through sensors is relevant due to its potential application in real-time monitoring systems for leak detection.

The development and implementation of AI-based systems and Neural Networks have played a crucial role in leak detection and localization in water distribution systems. Mounce, Boxall and Machell (2010) are pioneers in this field, using neural networks and AI to create an online system capable of identifying leaks and abnormal flows. This advancement in water loss management not only demonstrated the effectiveness of these technologies in leak detection but also significantly improved the operational efficiency of water distribution networks.

Moreover, recent studies by Pérez et al. (2021), Bohorquez et al. (2022), Vanijjirattikhan et al. (2022), Basnet et al. (2023) and Yu et al. (2023) have reinforced the importance of AI and Neural Networks in this context. Yu et al. (2023), for example, highlight the application of mathematical models to determine the optimal position of sensors in water distribution systems, thus complementing the approach of Mounce, Boxall and Machell (2010). Data collection through sensors has proven to be crucial for real-time monitoring and efficient leak detection, contributing to a more effective and agile management of water distribution networks.

Araujo, Ramos and Coelho (2006), as well as Fontana, Giugni and Portolano (2012), with the application of Genetic Algorithms sought an optimized solution for pressure control and valve management in the water distribution system and, consequently reducing losses. The application of Genetic Algorithms for leak detection was carried out by Ayad et al. (2021), Wu, Sage and Turtle (2010), Farley, Mounce and Boxall (2013), and Steffelbauer and Fuchs-Hanusch (2016).

Water distribution system losses can be caused by excessive pressure (Freitas et al., 2022). In this regard, Araujo, Ramos and Coelho (2006), and Fontana, Giugni and Portolano (2012), recommend minimizing pressure in the distribution system after valve selection. However, pressure reduction makes leak detection in water distribution systems more challenging (Al-Washali et al., 2019).

Britton, O'Halloran and Stewart (2013) conducted research on implementing smart metering technology in Hervey Bay, Australia. This automated technology allowed for the efficient identification and management of post-meter leaks, highlighting its effectiveness in reducing water losses, improving operational efficiency, and promoting sustainability in the water supply sector. In parallel, Farah and Shahrour (2017) conducted a complementary study at the University of Lille, France, where they applied smart water systems to mitigate unbilled water losses and detect unreported leaks. By using an advanced water balance methodology and hydraulic sensors, they achieved a 36% reduction in losses, clearly illustrating the benefits of these systems in the effective management of water resources and in the waste minimization.

Clark, Stafford and Goodrich (1982) conducted a comprehensive analysis of the challenges faced in maintaining and replacing water distribution systems, considering the impacts of water quality on system costs. They emphasized the importance of establishing effective programs to ensure reliability and minimize costs, using statistical models and analyses to examine the relationship between infrastructure and population growth. They concluded that careful planning is essential to ensure economic efficiency and system reliability.

On the other hand, Adedeji et al. (2017) focused on developing an algorithm for accurate leak detection in water pipeline networks. By implementing pressure sensors and wireless communication, they demonstrated the feasibility of leak detection, significantly contributing to the efficiency of water pipeline networks. These efforts aimed to reduce water losses and improve overall water distribution efficiency.

Several authors use mathematical modeling as a tool to interpret and simulate a water distribution system. The development of new models and the appropriate use of technology favor the construction of more efficient and replicable models worldwide.

As a research gap, it is notable that most studies focus on technological solutions such as mathematical modeling, AI, and sensors for leak detection. However, few studies investigate institutional, political, and economic barriers that hinder the implementation of these technologies and the effective reduction of water losses.

Although various studies explore technological solutions to optimize distribution systems, there is a gap in the analysis of the feasibility and implementation of these solutions in different contexts, especially in countries with precarious infrastructure or financial constraints.

5 Concluding Remarks

This investigation provides insights into how research on water losses in distribution systems has evolved over approximately 46 years. From 1978 to 2015, the number of publications on the subject was relatively modest, with absence of publications in various periods. Starting in 2016, there was an increase in scientific journal publications, peaking in 2022. China led in the number of studies, while Italy had the highest citation count.

The analysis of results indicates that certain topics emerge as central and fundamental for advancing efficient water resource management. The identified themes like "Motor Themes”, "leak detection", "water pipelines", "leak detection systems", "water distribution systems", "water supply" and "water distribution networks", stand out not only for their frequency but also for their strategic importance in water distribution management.

Considering the problems of water distribution systems in relation to water pipes, which generally suffer from the effects of time, in addition to operational difficulties, since many water-carrying pipes are underground, it is expected that numerous studies will focus on the use of mathematical and/or statistical models supported by AI techniques to detect water leaks and, consequently, reduce water losses.

Thus, it becomes essential to utilize sensors, AI, and models to control pressure in water distribution systems to prevent potential leaks of water, thereby mitigating the loss of such valuable resource and ensuring the well-being of the population.

Additionally, it is crucial to highlight that the context of climate change imposes additional pressure on water resource management. With the increasing frequency and intensity of extreme weather events (droughts, heavy rainfall, water stress, among others), the need to efficiently preserve and manage water becomes even more urgent.

Water pipelines, already susceptible to deterioration, are subjected to additional stress due to changing environmental conditions. Therefore, it is imperative that research continues to explore innovative approaches, such as mathematical models, AI techniques, and advanced sensors, to detect and mitigate leaks in water distribution systems.

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References

Adedeji, K. B., Abe, B. T., Hamam, Y., & Abu-Mahfouz, A. M. (2017). Towards achieving a reliable leakage detection and localization algorithm for application in water piping networks: An overview. *IEEE Access*, 5, 20272-20285. https://doi.org/10.1109/ACCESS.2017.2752802

AL-Washali, T., Sharma, S., AL-Nozaily, F., Haidera, M., & Kennedy, M. (2019). Modelling the Leakage Rate and Reduction Using Minimum Night Flow Analysis in an Intermittent Supply System. *Water*, 11(48). https://doi.org/10.3390/w11010048

Amaral, P. S., Zanatta, F., Meireles, G. B., Mendes, J. P., Meireles, S. P. A., & Mariosa, D. F. (2023). Fundamentos e consequências éticas da aplicação dos princípios de universalização, sustentabilidade e segurança hídrica contidos no marco regulatório do saneamento no Brasil. *Gestão & Regionalidade*, 39, e20237565. https://doi.org/10.13037/gr.vol39.e20237565

Andrade, F. M., & Queiroz, A. P. de. (2023). Publicações de autoria feminina no boletim paulista de geografia (1949-2018): análise da participação e das palavras-chave. *RA'EGA - O Espaço Geográfico em Análise*, 56, 121-139. http://dx.doi.org/10.5380/raega.v56i0.84267

Araujo, L. S., Ramos, H., & Coelho, S. T. (2006). Pressure Control for Leakage Minimisation in Water Distribution Systems Management. *Water Resources Management*, 20, 133-149. https://doi.org/10.1007/s11269-006-4635-3

Aria, M., & Cuccurullo, C. (2017). bibliometrix: An R-tool for comprehensive science mapping analysis. *Journal of Informetrics*, 11(4), 959-975. https://doi.org/10.1016/j.joi.2017.08.007

Ávila, C. A. M., Sánchez-Romero, F. J., López-Jiménez, P. A., & Sánchez, M. P. (2021). Leakage Management and Pipe System Efficiency. Its Influence in the Improvement of the Efficiency Indexes. *Water*, 13(14), e1909. https://doi.org/10.3390/w13141909

Ayad, A., Khalifa, A., Fawy, M., & Moawad, A. (2021). An integrated approach for non-revenue water reduction in water distribution networks based on field activities, optimisation, and GIS applications. *Ain Shams Engineering Journal*, 12(4), 3509-3520. https://doi.org/10.1016/j.asej.2021.04.007

Basnet, L., Brill, D., Ranjithan, R., & Mahinthakumar, K. (2023). Supervised Machine Learning Approaches for Leak Localization in Water Distribution Systems: Impact of Complexities of Leak Characteristics. *Journal of Water Resources Planning and Management*, 149(8). https://doi.org/10.1061/JWRMD5.WRENG-6047

Benítez, J., Delgado-Galván, X., Izquierdo, J., & Pérez-García, R. (2012). Improving consistency in AHP decision-making processes. *Applied Mathematics and Computation*, 219 (5), 2432-2441. https://doi.org/10.1016/j.amc.2012.08.079

Blázquez-García, A., Conde, A., Mori, U., & Lozano, J. A. (2021). Water leak detection using self-supervised time series classification. *Information Sciences*, 574, 528-541. https://doi.org/10.1016/j.ins.2021.06.015

Bohorquez, J., Lambert, M. F., Alexander, B., Simpson, A. R., & Abbott, D. (2022). Stochastic Resonance Enhancement for Leak Detection in Pipelines Using Fluid Transients and Convolutional Neural Networks. *Journal of Water Resources Planning and Management*, 148(3). https://doi.org/10.1061/(ASCE)WR.1943-5452.0001504

Britton, T., O'halloran, K., & Stewart, R. A. (2013). Smart metering: enabler for rapid and effective post meter leakage identification and water loss management. *Journal of Cleaner Production*, 54, 166-176. https://doi.org/10.1016/j.jclepro.2013.05.018

Chueke, G. V., & Amatucci, M. (2015). O que é bibliometria? Uma introdução ao Fórum. *InternexT*, 10(2), 1-5. https://doi.org/10.18568/1980-4865.1021-5

Clark, R. M., Stafford, C. L., & Goodrich, J. A. (1982). Water distribution systems: A spatial and cost evaluation. *Journal of the Water Resources Planning and Management Division*, 108(3), 243-256. https://doi.org/10.1061/JWRDDC.0000257

Farah, E., & Shahrour, I. (2017). Leakage detection using smart water system: Combination of water balance and automated minimum night flow. *Water Resources Management*, 31, 4821-4833. https://doi.org/10.1007/s11269-017-1780-9

Farley, B., Mounce, S. R., & Boxall, J. B. (2013). Development and Field Validation of a Burst Localization Methodology. *Journal of Water Resources Planning and Management*, 139(6), 706-733. https://doi.org/10.1061/(ASCE)WR.1943-5452.0000290

Farouk, A. M., Rahman, R. A., & Romali, N. S. (2023). Non-revenue water reduction strategies: systematic review. *Smart and Sustainable Built Environment*, 12(1), 181-199. https://doi.org/10.1108/SASBE-04-2021-0071

Fontana, N., Giugni, M., & Portolano, D. (2012). Losses reduction and energy production in water-distribution networks. *Journal of Water Resources Planning and Management*, 138(3), 237-244. https://doi.org/10.1061/(ASCE)WR.1943-5452.0000179

Freitas, C. L. de, Silva, F. G. B. da, Silva, A. T. Y. L., & Barbedo, M.D.G. (2022). Analysis of a real water distribution system in Southern Minas Gerais using geographical information system. *Engenharia Sanitária Ambiental*, 27(1), 31-39. https://doi.org/10.1590/S1413-415220200380

Germanopoulos, G. (1985). A technical note on the inclusion of pressure dependent demand and leakage terms in water supply network models, Civil Engineering Systems, 2(3), 171-179. https://doi.org/10.1080/02630258508970401

Gil, A. C. (2019). *Métodos e técnicas de pesquisa social*. 7. ed. São Paulo: Atlas.

Guedes, W. P., Sugahara, C. R., Ferreira, D. H. L., & Branchi, B. A. (2023). Indicadores de saneamento básico: uma aplicação da Análise Fatorial para os municípios das Bacias Hidrográficas dos Rios Piracicaba, Capivari e Jundiaí. *Interações*, 24(1), 261–179. https://doi.org/10.20435/inter.v24i1.3722

Hawken, P., Lovins, A., & Lovins, H. (2007). *Capitalismo Natural:* criando a próxima revolução industrial. São Paulo: Cultrix.

ITB. Instituto Trata Brasil (2023). *Água perdida no país poderia abastecer todas as 17,9 milhões de pessoas que residem nas favelas do Brasil por cerca de um ano e meio*. GO Associados. Available in: https://tratabrasil.org.br/wp-content/uploads/2023/06/Press-Release-Estudo-de-Perdas-2023.pdf. Accessed: 01 fev. 2024.

Kaffash, S., Nguyen, A. T., & Zhu, J. (2021). Big data algorithms and applications in intelligent transportation system: A review and bibliometric analysis. *International Journal of Production Economics*, 231, e107868. https://doi.org/10.1016/j.ijpe.2020.107868

Kafle, M.D., Fong, S., & Narasimham, S. (2022). Active acoustic leak detection and localization in a plastic pipe using time delay estimation. *Applied Acoustics*, 187, e108482. https://doi.org/10.1016/j.apacoust.2021.108482

Kingdom, B., Liemberger, R., & Marin, P. (2006). *The Challenge of Reducing Non-Revenue Water (NRW) in Developing Countries*. How the Private Sector Can 11 Help: A Look at Performance-Based Service Contracting. World Bank Discussion Paper Number 8. Washington D.C.

Kurkjian, G. (1978). Proper butterfly valve application avoids costly repairs. *Water Sewage Works*, 125(6), 84-89.

Kusterko, S., Ensslin, S. R., Ensslin, L., & Chaves, L. C. (2018). Gestão de perdas em sistemas de abastecimento de água: uma abordagem construtivista. *Eng Sanit Ambient*, 23(3), 615-626. https://doi.org/10.1590/S1413-41522018156436.

Li, J., Zheng, W., & Lu, C. (2022). An Accurate Leakage Localization Method for Water Supply Network Based on Deep Learning Network. *Water Resources Management: An International Journal*, 36 (7), 2309-2325. https://doi.org/10.1007/s11269-022-03144-x.

Liemberger, R., & Wyatt, A. (2018). Quantifying the global non-revenue water problem. *Water Science & Technology Water Supply*. https://doi.org/10.2166/ws.2018.129.

Marques, F. B., Maculan, B. C. M. S., & Souza, R. R. (2023). A bibliometria na pós-graduação brasileira: uma revisão interativa da literatura. *Transinformação*, 35, e227089. https://doi.org/10.1590/2318-0889202335e227089.

Moreira, P. S. C., Guimarães, A. J. R., & Tsunoda, D. F. (2020). Qual ferramenta bibliométrica escolher? um estudo comparativo entre softwares. *P2P & Inovação*, 6(2), Ed. Especial, 140-158. https://doi.org/10.21721/p2p.2020v6n2.p140-158.

Mounce, S. R., Boxall, J. B., & Machell, J. (2010). Development and verification of an online artificial intelligence system for detection of bursts and other abnormal flows. *Journal of Water Resources Planning and Management*, 136(3), 309-318. https://doi.org/10.1061/(ASCE)WR.1943-5452.0000030.

Nygård, K., Teverdal, A., Wahl, E., & Aavitsland, P. (2007). Breaks and maintenance work in the water distribution systems and gastrointestinal illness: a cohort study. *International journal of epidemiology*, 36 (4), 873-880. https://doi.org/10.1093/ije/dym029

Pérez-Pérez, E. J., López-Estrada, F. R., Valencia-Palomo, G., Torres, L.; Puig, V., & Mina-Antonio, J. D. (2021). Leak diagnosis in pipelines using a combined artificial neural network approach. *Control Engineering Practice*, 107, e104677. https://doi.org/10.1016/j.conengprac.2020.104677

Santi, A. D. de, Cetrullo, T. B., & Malheiros, T. F. (2021). Water loss control practices in developing countries: a case study of a Brazilian region. *Water Supply*, 212. https://doi.org/10.2166/ws.2020.351

Singh, V. K., Singh, P., Karmakar, M., Leta, J., & Mayr, P. (2021). The journal coverage of Web of Science, Scopus and Dimensions: A comparative analysis. *Scientometrics*, 126(6), 5113–5142.

Shiddiqi, A. M., Cardell-Oliver, R., & Datta, A., (2020). An Advanced Sensor Placement Strategy for Small Leaks Quantification Using Lean Graphs. *Water,* 12(12), e3439. https://doi.org/10.3390/w12123439.

Steffelbauer, D. B., & Fuchs-Hanusch, D. (2016). Efficient Sensor Placement for Leak Localization Considering Uncertainties. *Water Resour Manage*, 30, 5517–5533. https://doi.org/10.1007/s11269-016-1504-6

Tundisi, J. G. (2008). Recursos hídricos no futuro: problemas e soluções. *Estudos Avançados*, 22(63), 7-16. https://doi.org/10.1590/S0103-40142008000200002.

Tundisi, J. G., & Matsumura-Tundisi, T. (2020). *A água*. Scienza: São Carlos.

Urbizagástegui-Alvarado, R. (2022). *Bibliometria brasileira:* análise de copalavras. *Transinformação*, 34, e220004. https://doi.org/10.1590/2318-0889202234e220004.

Van Eck, N. J., & Waltman, L. (2023). *VOSviewer Manual*. Manual for VOSviewer version 1.6.20. Universiteit Leiden.

Vanijjirattikhan, R., Khomsay, S., Kitbutrawat, N., Khomsay, K., Supakchukul, U.; Udomsuk, S., Suwatthikul, J., Oumtrakul, N., & Anusart, K. (2022). AI-based acoustic leak detection in water distribution systems. *Results in Engineering*, 15, e100557. https://doi.org/10.1016/j.rineng.2022.10055

Wu, Z.Y., Sage, P., & Turtle, D. (2010). Pressure-dependent leak detection model and its application to a district water system. *Journal of Water Resources Planning and Management*, 136(1), 116-128. https://doi.org/10.1061/(ASCE)0733-9496(2010)136:1(116).

Yu, T., Chen, X., Yan, W., Xu, Z., & Ye, M. (2023). Leak detection in water distribution system. *Mechanical Systems and Signal Processing*, 185(15), e109810. https://doi.org/10.1016/j.ymssp.2022.109810.