

Global Research Trends on Seawater Intrusion in Coastal Aquifers: A Bibliometric Analysis

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ABSTRACT

Coastal aquifers are essential sources of freshwater for domestic, agricultural, and industrial use in many regions worldwide. However, these critical resources are increasingly threatened by seawater intrusion, a hydrogeological process exacerbated by excessive groundwater extraction, population growth, and climate change. A comprehensive understanding of the dynamics and research evolution of this phenomenon is vital to support the sustainable management of coastal water resources. This study presents a bibliometric analysis of global research on seawater intrusion in coastal aquifers from 2014 to 2024. Data were retrieved from the Scopus database and analysed using the Bibliometrix package in R, complemented by visualization techniques developed in Python. The analysis examines publication trends, identifies influential authors, institutions, and journals, explores international collaboration networks, and maps the thematic evolution of research topics. By applying key bibliometric indicators and established laws such as those of Bradford and Lotka, the study provides an integrated perspective on the structure, dynamics, and development of this research field.

The findings contribute to a deeper understanding of global scientific efforts addressing seawater intrusion and offer insights to guide future research, technological innovation, and policy initiatives for the sustainable management of coastal groundwater resources.

KEYWORDS: Seawater intrusion; Coastal aquifers; Groundwater salinization; Bibliometric analysis.

I. INTRODUCTION

Coastal aquifers are crucial sources of freshwater that sustain domestic, agricultural, and industrial demands for millions of people worldwide. However, these natural reservoirs are increasingly threatened by a critical hydrogeological process known as seawater intrusion[1]. This phenomenon occurs when the hydraulic pressure of saline seawater exceeds that of continental freshwater, driving the saltwater front inland. As a result, groundwater becomes salinized, drinking water quality deteriorates, and agricultural productivity declines, undermining the sustainability of water resources in many coastal regions[2].

Under natural conditions, a dynamic equilibrium exists between freshwater and seawater, where freshwater gradually flows toward the sea, preventing saltwater encroachment. This delicate balance, described by the Ghyben–Herzberg principle, depends on density and pressure differences between the two fluids[3][4]. However, various anthropogenic and climatic pressures increasingly disrupt this equilibrium. Excessive groundwater extraction, population growth, urban expansion, and intensive agriculture lower groundwater levels, facilitating the inland advance of saline water. Meanwhile, climate change, through sea-level rise, altered precipitation patterns, and more frequent droughts, further exacerbates the problem[5].

The consequences of seawater intrusion are both environmental and socio-economic. Environmentally, it leads to aquifer contamination, soil salinization, and the degradation of coastal ecosystems. Socio-economically, it reduces access to potable water, increases treatment costs,

and threatens food and livelihood security[6]. These impacts are particularly severe in arid and semi-arid regions such as North Africa, the Middle East, and South Asia, where dependence on groundwater is high and renewable freshwater resources are limited[7].

Scientific efforts to understand and manage seawater intrusion have evolved significantly over the past several decades. Early studies from the 1960s relied primarily on conceptual models and field observations, providing foundational insights into coastal aquifer behaviour. In contrast, recent advances in numerical modelling[8], [9], using tools such as SEAWAT, SUTRA, and MODFLOW-SWI2, have enabled high-resolution simulations of groundwater flow and salt transport[10]. Emerging technologies, including remote sensing, isotopic analysis, and applied geophysics, have greatly enhanced monitoring capabilities, while modern approaches integrating artificial intelligence, machine learning, and spatial analysis have improved predictive accuracy and vulnerability assessments[11].

A range of strategies has been proposed to mitigate seawater intrusion. Traditional measures include artificial recharge, freshwater injection, and hydraulic barriers designed to restore natural pressure gradients. Other engineering-based solutions involve optimized pumping regimes, impermeable subsurface barriers, and managed aquifer recharge using treated wastewater[12]. In addition, nature-based approaches, such as wetland restoration and the establishment of coastal vegetation belts, offer sustainable and adaptive alternatives that enhance the natural resilience of coastal systems against salinization.

Over the past two decades, research interest in seawater intrusion has expanded rapidly, reflecting a growing global awareness of coastal aquifers’ significance to water security and climate change adaptation. Nevertheless, existing scientific knowledge remains dispersed across multiple disciplines, including hydrogeology, environmental engineering, and geochemistry[13].

Against this backdrop, the present study conducts a comprehensive bibliometric analysis to map the global research landscape on seawater intrusion in coastal aquifers from 2014 to 2024. Following Pritchard’s (1969) definition of bibliometrics as the application of statistical and mathematical methods to the analysis of scientific literature[14], data were retrieved from the Scopus database and analyzed using Biblioshiny, the graphical interface of the Bibliometrix package in R[15]. To complement the analysis, additional visualization and data-processing techniques were implemented in Python[16][17], enhancing the exploration of publication networks and thematic structures. The analysis quantifies publication and citation patterns, visualizes international collaboration networks, and identifies thematic structures and emerging research fronts. Specifically, this study:

- traces the temporal evolution of scientific output on seawater intrusion,
- identifies the most active authors, institutions, and countries,
- analyzes keyword co-occurrence to delineate core research themes and emerging trends, and
- outlines potential directions for future investigation.

By offering a comprehensive, data-driven overview of the global research landscape, this study enhances understanding of the intellectual structure and thematic development of seawater intrusion research, providing valuable insights for scholars, practitioners, and policymakers engaged in coastal groundwater management.

Section 2 presents the methodology used in this study. Section 3 discusses the results and analysis, while Section 4 provides the conclusion and directions for future work.

II. METHODOLOGY

This study employs a bibliometric approach to evaluate global scientific research on seawater intrusion in coastal aquifers. Its primary objective is to identify research trends, collaboration networks, thematic structures, and influential contributors, while assessing the overall scientific performance of the field. Bibliometric analysis applies quantitative and statistical methods to measure research productivity, impact, and intellectual structure within a scientific domain. Positioned at the intersection of scientometrics and informetrics, it provides a systematic framework for mapping and quantifying the evolution and dynamics of research activity. The Scopus database was selected as the data source owing to its extensive multidisciplinary coverage and comprehensive indexing of environmental and water-related publications.

A. Data Source and Search Strategy

Data were retrieved from the **Scopus** database on **August 15, 2025**, using the following search query applied to titles, abstracts, and keywords (*TITLE-ABS-KEY*):

(“seawater intrusion” OR “saltwater intrusion”)

The search covered the period **2014-2024**, encompassing a decade of scientific publications on seawater intrusion. All document types available in Scopus were included, such as journal articles, conference papers, book chapters, reviews, and books, and no language restrictions were applied, ensuring a comprehensive and representative corpus of global research.

The complete metadata were exported in CSV format and included information such as titles, authors, affiliations, publication sources, publication years, abstracts, keywords, and citation counts. These data formed the foundation for subsequent bibliometric processing and analysis.

B. Data Cleaning and Preparation

Before analysis, a systematic process of data cleaning and metadata verification was conducted to ensure the coherence, completeness, and reliability of the bibliographic corpus. This preprocessing was carried out directly on the CSV file exported from Scopus prior to its import into Bibliometrix.

The cleaning process involved reviewing each essential column in the dataset (authors, affiliations, sources, titles, abstracts, and keywords) to identify missing or inconsistent values.

The main steps were as follows:

- **Verification and completion of missing fields:** Incomplete metadata were manually corrected whenever possible, particularly for titles and publication sources.
- **Normalization of author names and institutional affiliations:** A standardized format was applied to prevent duplication caused by typographical variations, name order, or capitalization inconsistencies.
- **Removal of duplicates:** Duplicate records were identified and deleted based on DOI matching and title similarity.

In addition, a selective exclusion procedure was implemented according to the type of analysis:

- Records lacking author or affiliation information were excluded from analyses related to author productivity or institutional collaboration.
- Documents missing a title, abstract, or keywords were excluded only from thematic and keyword co-occurrence analyses.
- Other records, even if partially incomplete, were retained when they contained sufficient information for broader analyses, such as overall publication volume.

This targeted cleaning protocol resulted in a consistent and reliable dataset tailored to each bibliometric analysis category, performance, collaboration, and thematic analysis. The prepared corpus thus provides a robust foundation for

modelling and visualizing scientific trends in seawater intrusion research.

C. Bibliometric Analysis: Tools and Techniques

The bibliometric analysis was conducted using the Bibliometrix package in R (version 4.3.1) through its graphical interface, Biblioshiny (version 4.2.0). These open-source tools enable comprehensive bibliometric workflows, encompassing both performance analysis and scientific mapping. To improve the visual clarity and resolution of figures, all graphical outputs were refined and reproduced using Python.

The following analyses were performed:

- **Performance analysis:** Measurement of publication output by year, author, institution, country, and source.
- **Citation and impact analysis:** Evaluation of total citations, average citations per document, and the *h*-index to assess research influence.
- **Collaboration network mapping:** Visualization of co-authorship patterns and institutional partnerships to explore international research connections.
- **Keyword and thematic analysis:** Examination of both Author Keywords and Keywords Plus to identify core research themes, conceptual relationships, and emerging topics.
- **Application of bibliometric laws:** Implementation of Bradford’s Law to evaluate the concentration of publications by source and Lotka’s Law to model author productivity distributions.
- **Geographical and visual analyses:** Generation of maps, word clouds, and trend visualizations to illustrate spatial and thematic patterns across the literature.

All analytical procedures and visualization steps followed the methodological framework proposed by [15] ensuring transparency, reproducibility, and alignment with established bibliometric standards.

III. RESULTS AND DISCUSSION

A. Data Overview

A preliminary examination of the dataset provides an overview of the bibliographic corpus analyzed in this study. The dataset retrieved from the Scopus database covers the period 2014–2024, encompassing 4,333 documents published across 1,143 different sources, including journals, books, and conference proceedings. This reflects a dynamic and steadily expanding body of scientific literature on seawater intrusion, characterized by an annual growth rate of 11.57%.

Each document has received an average of **17.95 citations**, indicating a moderate to high level of scholarly engagement and recognition within the research community. This suggests that the topic maintains strong academic relevance and cross-disciplinary visibility within the environmental and hydrological sciences.

The dataset includes contributions from 12,571 authors, representing a broad and diverse research community. Among these, 178 publications were single-authored, confirming that the field is largely collaborative. Co-authorship analysis indicates that most publications are

produced by multidisciplinary and international teams integrating expertise in hydrogeology, geochemistry, environmental engineering, and computational modeling.

The descriptive statistics characterize seawater intrusion research as a rapidly growing, collaborative, and highly visible field, establishing a quantitative foundation for the subsequent analyses of publication trends, institutional performance, and thematic development.

B. Temporal Evolution of Scientific Output

Figure 1 illustrates the steady increase in the proportion of publications addressing seawater intrusion between 2014 and 2024. In 2014, these studies represented approximately 4.5% of the total scientific output, whereas by 2024 they accounted for nearly 13.4%, almost tripling over the decade. This upward trend reflects a growing scientific interest in seawater intrusion and emphasizes the increasing relevance of groundwater salinization and climate change impacts on coastal regions.

The most pronounced growth occurred after 2018, when the share of publications rose sharply from 5.8% to 8.9%, marking a distinct turning point in research dynamics. Thereafter, the proportion continued to rise steadily, reaching 10.6% in 2020, 11.5% in 2022, and peaking at 13.4% in 2024. This consistent upward pattern indicates both the expansion of the research field and the progressive consolidation of a specialized scientific community focused on this topic. The evolution of publication percentages demonstrates an increasing global awareness of the risks associated with seawater intrusion and underscores the urgency of developing adaptation measures and sustainable groundwater management strategies for vulnerable coastal regions.

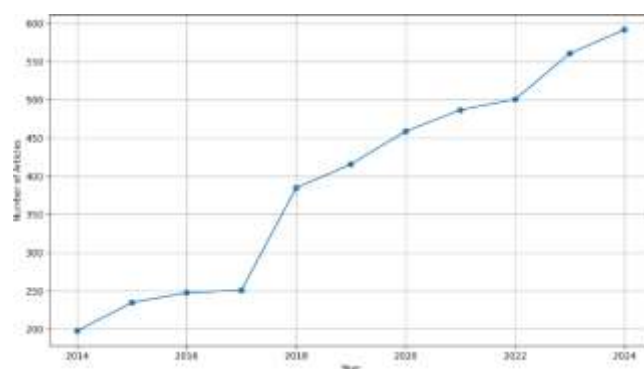


Figure 1 Annual trend of publications on seawater intrusion (2014– 2024)

C. Language of Publication

The analysis reveals that English overwhelmingly dominates as the primary language of publication, with 4,122 papers, representing most of the research on seawater intrusion. **Table 1** summarizes the identified publication languages and their corresponding percentages. This strong dominance underscores the global role of English as the lingua franca of scientific communication, facilitating international collaboration and the broad dissemination of research findings.

In contrast, other languages such as Chinese (161 papers) and Spanish (15 papers) occur with much lower frequencies, reflecting regionally focused research communities operating primarily within their linguistic domains. A smaller number

of publications in French (11), Korean (10), and German (7) also indicate contributions from diverse regions, though these remain marginal compared to English outputs.

Publications in languages such as Turkish, Russian, Portuguese, Persian, Italian, and Japanese, each contributing only three to four papers, demonstrate a limited yet geographically varied engagement with the topic. The appearance of isolated studies in Indonesian, Croatian, and Bosnian (one each) further indicates that the issue of seawater intrusion has attracted attention across a wide range of research contexts, even in regions with emerging scientific capacity.

In summary, the linguistic distribution of publications highlights the pronounced concentration of scientific output in English, reaffirming its central role in global knowledge exchange. At the same time, the presence of contributions in multiple other languages points to the progressive internationalization and geographical diversification of research on seawater intrusion.

Table 1 Identified Languages in Selected Publications.

Langue	Number of papers
English	4,122
Chinese	161
Spanish	15
French	11
Korean	10
German	7
Turkish	4
Russian	3
Portuguese	3
Persian	3
Italian	3
Japanese	3
Indonesian	1
Croatian	1
Bosnian	1

D. Document Types

Table 2 lists the identified source types in the selected studies. As it can be noticed most publications are research articles, accounting for 3,544 documents, which highlights that peer-reviewed journal papers remain the primary medium for disseminating scientific knowledge on seawater intrusion. This dominance reflects the maturity of the field and the preference for publishing comprehensive, data-driven studies in scholarly outlets.

The second most represented category is conference papers (411), followed by book chapters (192). This suggests that academic conferences and edited volumes play a complementary yet significant role in sharing preliminary findings, methodological developments, and regional case studies. The presence of reviews (114) further indicates an increasing effort to synthesize accumulated knowledge and identify research trends within the field.

Other document types, such as conference reviews, notes, editorials, letters, errata, and data papers, are comparatively rare, each contributing marginally to the total output. These formats primarily serve to clarify, correct, or briefly communicate findings. The small number of retracted papers

(4) demonstrates a generally reliable body of research, while the single short survey suggests limited use of this format within the discipline.

The distribution of document types demonstrates a clear emphasis on formal, peer-reviewed scientific publications, reflecting the methodological rigor and credibility that characterize research on seawater intrusion.

Table 2 Publication Types of Selected Papers.

Document Types	Count
Article	3544
Conference paper	411
Book chapter	192
Review	114
Conference review	24
Erratum	12
Book	8
Editorial	8
Note	7
Letter	5
Retracted	4
Data paper	3
Short survey	1

E. Sources of Publication

Table 3 lists the ten most productive publication sources on seawater intrusion in coastal aquifers between 2014 and 2024. The analysis of publication sources indicates that research on seawater intrusion is primarily disseminated through a limited number of highly specialized scientific journals, mainly within the disciplines of hydrology, geology, and environmental sciences. The leading journals account for a substantial share of the total publications, reflecting their central role in consolidating hydrological knowledge and advancing the understanding of saline intrusion processes.

The journal *Water (Switzerland)* ranks first, publishing 203 articles, followed by the *Journal of Hydrology* with 175 and *Environmental Earth Sciences* with 147. Together, these three outlets account for approximately 12% of all indexed publications, underscoring their dominant role in the field. Their prominence reflects both their disciplinary focus and their accessibility, with *Water* offering open-access visibility and *Journal of Hydrology* serving as a cornerstone outlet for groundwater research.

Several high-impact environmental and multidisciplinary journals also contribute significantly to the literature. *Science of the Total Environment* (136 articles) and *Environmental Science and Pollution Research* (88 articles) demonstrate that seawater intrusion research extends beyond hydrogeology to address issues of environmental pollution, sustainability, and integrated water resource management.

Conference proceedings, particularly the *IOP Conference Series: Earth and Environmental Science* (79 papers), highlight the importance of academic exchanges and scientific meetings in promoting the rapid dissemination of emerging findings and methodological developments. Other specialized sources, including *Water Resources Research* (73), *Hydrogeology Journal* (65), *Groundwater for Sustainable Development* (62), and *Environmental Monitoring and Assessment* (57), play complementary roles by providing outlets for applied and interdisciplinary studies related to saline intrusion and groundwater sustainability.

Overall, the distribution of publications suggests that research on seawater intrusion is highly concentrated within a few core scientific journals, while still maintaining broader diffusion across environmental and hydrological outlets.

Table 3 Source Venues and Publication Counts.

Sources	Count	Type
Water (switzerland)	203	Journal
Journal of Hydrology	175	Journal
Environmental Earth Sciences	147	Journal
Science of the Total Environment	136	Journal
Environmental Science and Pollution Research	88	Journal
IOP conference series: Earth and Environmental Science	79	Conference
Water Resources Research	73	Journal
Hydrogeology Journal	65	Journal
Groundwater for Sustainable Development	62	Journal
Environmental Monitoring and Assessment	57	Journal

F. Bradford’s Law

The application of Bradford’s Law to the dataset reveals a typical concentration–dispersion pattern of scientific productivity across publication sources. Figure X shows that the literature on seawater intrusion is unevenly distributed among sources, forming three distinct Bradford zones.

Zone 1, or the core zone, comprises a small number of journals that publish the largest share of articles on the topic. These highly productive journals act as the principal outlets for research dissemination and constitute the core knowledge base of the field.

Zone 2 includes a moderate number of sources contributing a smaller, though still substantial, portion of the total publications. These journals often address related subtopics such as groundwater dynamics, environmental management, and coastal hydrology, thereby broadening the disciplinary scope of seawater intrusion research.

Zone 3 encompasses a large number of sources that each publish relatively few articles. This long tail of less productive journals reflects the dispersion of research interest across multiple scientific disciplines, including environmental engineering, earth sciences, and climate-related studies.

The Bradford distribution confirms that a small nucleus of journals accounts for a disproportionate number of publications, while many peripheral journals contribute more sparsely. This pattern highlights the maturity and specialization of the research field.

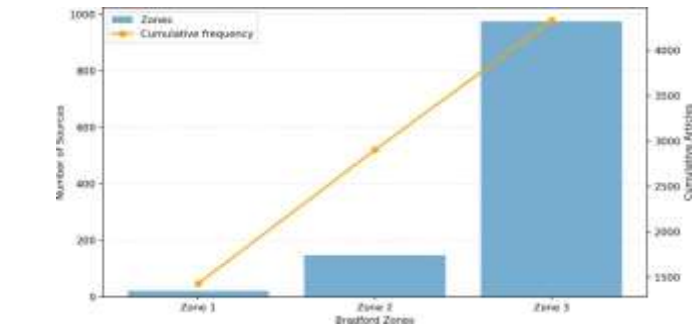


Figure 2 Distribution of Relevant Sources According to Bradford’s Law.

G. Institutional Analysis

Table 4 lists the ten most prolific institutions publishing research on seawater intrusion in coastal aquifers between 2014 and 2024. The bibliometric analysis reveals a strong dominance of Chinese universities and research centers, which collectively account for the majority of publications in this field. This concentration underscores China’s leading role in global research on coastal hydrogeology and groundwater salinization.

The most productive institutions include major national universities and research academies, each contributing between approximately 120 and 460 articles, reflecting their sustained and large-scale engagement in seawater intrusion research. This strong representation highlights both significant national investment in environmental and water-related sciences and the presence of an extensive domestic collaboration network.

Notably, Florida International University (United States) appears among the top contributors, indicating active international participation and the presence of global expertise addressing seawater intrusion, particularly in regions affected by coastal aquifer challenges.

Beyond the top ten, the dataset comprises 2,855 distinct institutional affiliations, suggesting that while a limited number of institutions dominate publication output, a wide range of universities, research institutes, and governmental organizations worldwide contribute to the topic. This broad participation underscores the global relevance and interdisciplinary nature of seawater intrusion research, spanning hydrology, geology, climate science, and sustainable water management.

The distribution of institutional affiliations demonstrates both a concentrated core of highly productive Chinese institutions and a diverse international research landscape. This pattern reflects the strategic importance of seawater intrusion as a shared global environmental challenge.

Table 4 Top Ten Prolific Institutions.

Affiliation	Articles
Hohai University	458
Ocean University of China	199
China University of Geosciences	190
Sun Yat-Sen University	168
Fujian Normal University	133
East China Normal University	130
University of Chinese Academy of Sciences	128
Florida International University	127
First Institute of Oceanography	121

H. Author Analysis

Table 5 lists the ten most productive and influential authors contributing to seawater intrusion research between 2014 and 2024. The bibliometric analysis of author productivity and impact reveals a highly specialized and internationally diverse group of leading researchers who have significantly advanced understanding of this topic. Among the 11,430 identified authors, the top ten stand out for their notable publication output (NP), high total citation counts (TC), and strong h-index values, reflecting both productivity and sustained scholarly influence.

The most influential authors exhibit H-index values ranging from 13 to 20, with total citations exceeding 1,000 for the most cited contributors. This distribution indicates that a relatively small group of experts has played a pivotal role in shaping the theoretical, numerical, and applied frameworks used to study and manage seawater intrusion processes. Their research contributions often encompass hydrogeological modeling, groundwater–saltwater interaction analysis, and the development of management strategies for coastal aquifers.

Several of these leading researchers are affiliated with the top-performing institutions identified earlier, highlighting a strong correlation between institutional productivity and author prominence. This alignment suggests that scientific excellence in this domain tends to cluster within well-established academic environments characterized by active international collaboration and multidisciplinary expertise. Although the top ten authors represent less than 0.1% of the total contributor base, their collective citation impact, often exceeding several thousand citations, positions them as the intellectual core of the seawater intrusion research community.

The author productivity distribution follows a classical bibliometric pattern, where a small group of highly productive and influential scholars drives the field’s conceptual and methodological direction, while a broader base of contributors sustains knowledge diversity, fosters interdisciplinary collaboration, and supports continued scientific expansion.

Table 5 Top 10 Prolific Authors.

Author	H-index	TC	NP
Lu Chunhui	16	760	41
Zheng Xilai	19	964	40
Datta B.	17	724	36
Werner Adrian D.	20	1328	35
Zheng Tianyuan	17	881	34
Abd-Elaty Ismail	15	621	34
Walther Marc	20	1015	31
Wu Jichun	16	735	31
Ahmed Ashraf Awadelkarim Widaa	13	636	27
Senapathi Venkatramanan	14	572	26

I. Lotka’s Law

The application of Lotka’s Law to the dataset of authors studying seawater intrusion reveals a characteristic inverse

relationship between author productivity and publication frequency. Figure 3 shows that the observed data (blue points) align closely with the theoretical Lotka distribution (red line), indicating that the field follows the expected bibliometric pattern, where a small number of authors produce a large share of publications, while most contribute only one or a few papers.

The fitted model parameters ($c = 0.769$ and $n = 2.594$) confirm that the observed distribution is consistent with Lotka’s empirical findings, in which n typically approximates 2. This alignment suggests that the productivity structure of the seawater intrusion research community is both balanced and mature, reflecting an established and collaborative scientific field.

Specifically, the exponent $n = 2.594$ indicates a slightly steeper decline than the theoretical value ($n = 2$), meaning that although a few prolific authors dominate the publication output, there remains a broad base of occasional contributors enriching the field’s diversity. Such a distribution implies a robust research ecosystem, supported by both a concentrated group of core experts driving major scientific advances and a wide periphery of researchers contributing complementary insights and case-specific studies.

The Lotka distribution confirms that seawater intrusion research follows a classical bibliometric pattern of scientific productivity, characterized by a small nucleus of highly active authors and a large number of contributors with lower publication frequency. This pattern reflects a healthy and evolving research landscape, where sustained expertise coexists with continuous new participation.

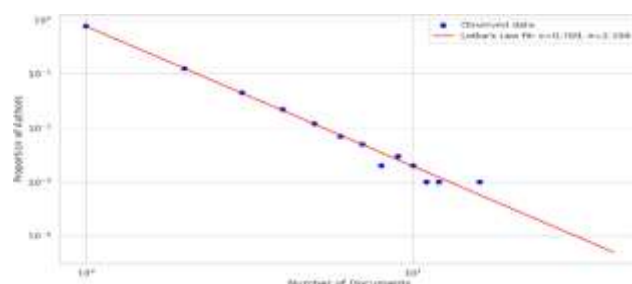


Figure 3 Author productivity distribution with fitted Lotka’s Law model

J. Geographical Distribution of Publications

The global distribution of publications on seawater intrusion reveals a highly internationalized research landscape, with contributions originating from nearly every continent. Figure 4 shows that China, the United States, India, and Australia serve as the principal research hubs, reflecting both their extensive coastal regions and well-developed research infrastructures in groundwater and environmental sciences.

A second tier of countries, including Iran, Spain, Italy, the United Kingdom, Germany, and France, demonstrates strong regional engagement, often through collaborative projects and applied studies focusing on local aquifer systems and coastal water resource management. Their active participation underscores the multidisciplinary and policy-oriented nature of seawater intrusion research.

Meanwhile, countries such as Saudi Arabia, Turkey, the Netherlands, Canada, and Japan exhibit emerging or moderate research activity, contributing valuable insights

through case-specific investigations and international partnerships. Their involvement highlights growing global awareness of seawater intrusion as both an environmental and socio-economic issue.

In summary, the spatial distribution of publications indicates a balance between scientific concentration and geographical diffusion. A limited number of countries function as central research leaders, while numerous others contribute incrementally, reflecting the truly global and collaborative character of seawater intrusion research.

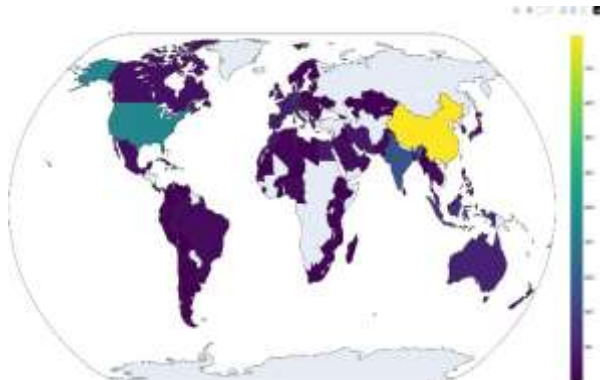


Figure 4 Geographical Distribution of Publications.

K. Thematic Analysis

Figure 5 presents a word cloud summarizing the most frequently occurring keywords in the literature on seawater intrusion, illustrating the dominant themes and conceptual structure of the research field. The prominence of terms such as “water,” “groundwater,” “aquifer,” “coastal,” and “intrusion” underscores the field’s primary focus understanding groundwater flow and salinization processes in coastal aquifer systems. These keywords reflect the hydrogeological foundation of the topic and highlight the dynamic interaction between seawater and freshwater resources.

Additional terms, including “salinity,” “pollutant,” “quality,” and “management,” reveal increasing research attention toward water quality degradation, pollution control, and sustainable resource management. The recurrence of “climate change” and “sea-level rise” further emphasizes the growing recognition of global environmental pressures that exacerbate seawater intrusion, particularly in vulnerable coastal regions.

Keywords such as “hydrogeology,” “geochemistry,” “numerical,” “model,” and “monitoring” demonstrate the methodological diversity of the field, encompassing numerical modeling, hydrochemical analysis, and environmental monitoring. The inclusion of “resource,” “supply,” and “management” highlights the applied dimension of the research, linking scientific inquiry to the practical challenges of groundwater sustainability.

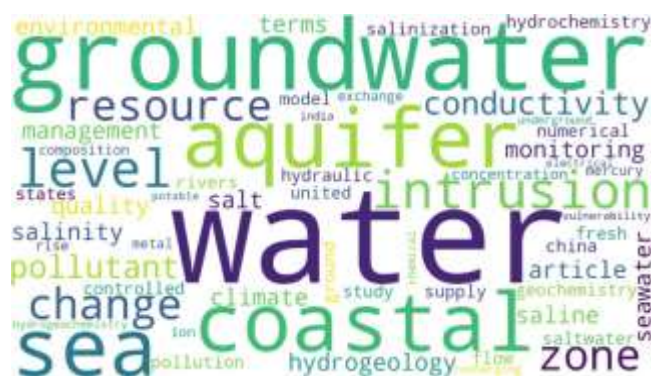


Figure 5 Word Cloud.

IV. CONCLUSION AND FUTURE WORK

This bibliometric study analyzed global research on seawater intrusion in coastal aquifers from 2014–2024, revealing a rapidly expanding and increasingly interdisciplinary field. Publication growth, international collaboration, and strong leadership by Chinese institutions reflect the field’s maturity and global relevance.

The concentration of articles in specialized journals (Bradford's Law) and the author productivity pattern (Lotka's Law) indicate a structured and balanced research ecosystem dominated by a core group of prolific contributors. Prevailing keywords emphasize groundwater salinization, numerical modelling, and management strategies, highlighting the focus on understanding and mitigating seawater intrusion.

Future research should advance integrated modelling, remote sensing, and machine learning applications; strengthen links between hydrogeological and socio-economic assessments; and promote open data sharing and transboundary collaboration to improve adaptive management in vulnerable coastal zones.

Seawater intrusion research now stands as a consolidated yet evolving field, essential for global water security and climate resilience.

REFERENCES

1. Q. Su, R. D. Kambale, J. H. Tzeng, G. L. Amy, D. Ladner, and R. Karthikeyan, "The growing trend of saltwater intrusion and its impact on coastal agriculture: Challenges and opportunities," *Sci. Total Environ.*, vol. 966, no. January, p. 178701, 2025, doi: 10.1016/j.scitotenv.2025.178701.
2. M. I. Hossain, A. S. Reza, S. M. Shafiuzzaman, M. S. U. Islam, and M. A. Rahman, "The effects of seawater intrusion on sustainable coastal areas: A comprehensive study on Bagerhat district, Bangladesh," *Reg. Stud. Mar. Sci.*, vol. 82, no. January, p. 104038, 2025, doi: 10.1016/j.rsma.2025.104038.
3. K. Maas, "Influence of climate change on a Ghijben-Herzberg lens," *J. Hydrol.*, vol. 347, no. 1–2, pp. 223–228, 2007, doi: 10.1016/j.jhydrol.2007.09.020.
4. H. L. Vacher, "Dupuit-Ghyben-Herzberg analysis of strip-island lenses," no. April, pp. 580–592, 1988.
5. Z. Luo *et al.*, "Approximate analytical solutions for assessing the effects of unsaturated flow on seawater extent in thin unconfined coastal aquifers," *Adv.*

- Water Resour.*, vol. 160, no. December 2021, p. 104104, 2022, doi: 10.1016/j.advwatres.2021.104104.
6. N. O. C. Victor, E. Ileberi, L. O. Daniel, and I. S. Sinneh, *Climate change impact on coastal groundwater salinity along the African Coast: With model prediction of economic cost*, no. May. 2025. doi: 10.4018/979-8-3693-6829-9.ch012.
7. R. Dong, Y. Cai, X. Chen, C. Wang, and A. Lian, “Ecological Risk Assessment of Saltwater Intrusion and Urban Ecosystem Management in Shenzhen City,” *Land*, vol. 13, no. 9, pp. 1–16, 2024, doi: 10.3390/land13091338.
8. I. Medarhri, M. Farhloul, K. Najib, S. Slimani, and Zine, “Mixed finite element method of a seawater intrusion problem in confined aquifers,” *E3S Web Conf.*, vol. 314, 2021, doi: 10.1051/e3sconf/202131405004.
9. S. Slimani, M. Farhloul, I. Medarhri, K. Najib, and Zine, “Mixed formulation of a stationary seawater intrusion problem in confined aquifers,” *Numer. Algorithms*, vol. 91, no. 2, pp. 651–669, 2022, doi: 10.1007/s11075-022-01277-z.
10. D. Ji, J. Xue, W. Wang, J. Ma, and Z. Wang, “Assessment of seawater intrusion in coastal aquifers by modified CCME-WQI Indicators: Decadal dynamics in North Jiaozhou Bay, China,” *Ecol. Indic.*, vol. 175, no. May, p. 113591, 2025, doi: 10.1016/j.ecolind.2025.113591.
11. T. Cao, D. Han, and X. Song, “Past, present, and future of global seawater intrusion research: A bibliometric analysis,” *J. Hydrol.*, vol. 603, no. PA, p. 126844, 2021, doi: 10.1016/j.jhydrol.2021.126844.
12. S. Saad, A. A. Javadi, H. F. Abd-Elhamid, and R. Farmani, “Mitigating seawater intrusion in coastal aquifers: Novel approach with treated wastewater injection and groundwater circulation,” *J. Hydrol.*, vol. 626, no. PA, p. 130139, 2023, doi: 10.1016/j.jhydrol.2023.130139.
13. A. Kassem, A. Sefelnasr, A. A. Ebraheem, and M. Sherif, “Seawater intrusion physical models: A bibliometric analysis and review of mitigation strategies,” *J. Hydrol.*, vol. 634, no. December 2023, p. 131135, 2024, doi: 10.1016/j.jhydrol.2024.131135.
14. N. Donthu, S. Kumar, D. Mukherjee, N. Pandey, and W. M. Lim, “How to conduct a bibliometric analysis: An overview and guidelines,” *J. Bus. Res.*, vol. 133, no. May, pp. 285–296, 2021, doi: 10.1016/j.jbusres.2021.04.070.
15. M. Aria and C. Cuccurullo, “bibliometrix: An R-tool for comprehensive science mapping analysis,” *J. Informetr.*, vol. 11, no. 4, pp. 959–975, 2017, doi: 10.1016/j.joi.2017.08.007.
16. J. D. Hunter, “Matplotlib: A 2D graphics environment,” *Comput. Sci. Eng.*, vol. 9, no. 3, pp. 90–95, 2007, doi: 10.1109/MCSE.2007.55.
17. J. Zerhouni, M. Hosni, and I. Medarhri, “Artificial Intelligence in Hydrogen Energy: A Comprehensive Bibliometric Analysis,” *Int. Conf. Artif. Intell. Appl. Innov. Ethics, AI2E 2025*, pp. 1–6, 2025, doi: 10.1109/AI2E64943.2025.10982927.