

*Review Article*

## **A Bibliometric Review of Remote Sensing Applications in Water Surge Risk Mapping for Waterfall Areas**

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### **ABSTRACT**

Waterfall areas are now in the gold rush era in research in different fields, including ecology and hydrology. There is a critical lack of studies on using remote sensing to detect and map water surges in waterfall areas, particularly in tropical regions, including Malaysia. Thus, this study sheds light on exploring the key research trends on remote sensing applications to detect and map water surges in waterfall areas globally in the past five years, providing insights to guide future research efforts in this critical but underrepresented field. Bibliometric analysis included defining search criteria and keywords, retrieving relevant bibliographic records from the Web of Science database, and conducting a comprehensive analysis of the data among 667 peer-reviewed articles was revealed that there is an immense need to investigate water surge risk in waterfall areas simultaneously as a broader environmental application. Critical visualisation was provided by generated network maps using VOSviewer. The study reveals a global and regional lack of research on using remote sensing to map water surges in waterfall areas. This work emphasises the critical need for targeted research in this niche field, offering actionable insights for advancing Sustainable Development Goals (SDGs) and disaster preparedness in regions prone to water surges.

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### **INTRODUCTION**

Freshwater supplies are the most valuable resource for sustaining life on earth; freshwater comprises rivers, snow, waterfalls, underground aquifers and all

other bodies of surface water. These sources of freshwater are subject to an increasingly large amount of stress throughout the world because they have both spatial and temporal disparities (Bănăduc et al., 2022). There is also relatively little general knowledge about the availability of freshwater resources in various areas, especially those where there are waterfalls and/or limited amounts of deep groundwater reserves. As a result of a lack of knowledge about the quality and quantity of available freshwater resources during periods of extreme water scarcity and/or abundance may cause significant negative impacts from drought to excessive water surges/flooding. Often, the hydrological extremes that occur will have devastating impacts upon both local and regional communities, resulting in substantial harm to the environmental, economic and social structures of a community (Wang & Xie, 2018). Therefore, it is crucially important to adequately monitor and manage the risk of water surges and droughts. Advances in technology, including remote sensing, drone photography, geographic information systems (GIS) and hydrologic modelling, enable the more accurate monitoring and management of this type of issue.

Flooding as well as water surges in water bodies may lead to structural damage, crop loss, and loss of life (Abdel-Mooty et al., 2021; Nofal & van de Lindt, 2021). Due to the rapid drop in elevation and increase in water speed, water surges in waterfall regions are particularly hazardous. Global statistics show that water surges and flood-related occurrences are having a growing influence around the world. Between 1970 and 2019, floods were responsible for 44% of all disasters caused by weather worldwide, with Asia experiencing the highest proportion, 31% of these events resulting in nearly a million deaths and over \$2 trillion in economic losses (World Meteorological Organisation, 2021). In Africa, while floods constituted 60% of weather-related disasters, they caused fewer fatalities compared to droughts. In North and Central America, floods represented 31% of recorded disasters (International Conference on Flood Management, 2022; Climate and Weather-Related Disasters Surge, 2024). Between 2021 and 2023, Malaysia had several devastating water surge disasters that caused the loss of many lives and the destruction of many facilities and infrastructure, emphasising the critical need for better knowledge and control of such phenomena (Table 1). In 2022, incidents included the rescue of 80 visitors at Laman Tiga Budaya waterfall in Melaka on May 16, and the deaths of three individuals, including a pregnant woman, in Baling, Kedah, on July 4 (Figure 1).

Remote sensing plays a pivotal role in water resource mapping by delivering essential data. Satellite-based remotesensing systems could deliver continuous, real-time data with global coverage and exploit their orbital capabilities, also relying on ground inspections for algorithm validation (Wang & Xie, 2018). Additionally, remote sensing technologies have been proven to be highly effective tools in improving many key functions relative to water surge risks, such as mapping accurately affected areas and identifying potential surge incidents before their occurrence (Iqbal et al., 2022; Munawar et al., 2021).

Table 1  
*Water surge events in Malaysia from 2021 to 2023*

Event Name	Date	Location
Gunung Jerai Surge	August 18, 2021	Yan and Tupah, Kedah
Laman Tiga Budaya Waterfall Surge	May 16, 2022	Asahan, Melaka
Baling Surge	July 4, 2022	Baling, Kedah
Lata Hulu Kekabu Surge	November 4, 2022	Setiu, Terengganu
Sungai Pinang waterfall Surge	November 28, 2022	Batang Kali, Selangor
Bukit Tinggi and Janda Baik Surge	February 12, 2023	Pahang
Kampung Asli Pertak Waterfall Surge	June 21, 2023	Kuala Kubu Bharu, Selangor
Jeram Air Putih Surge	July 1, 2023	Kemaman, Terengganu

*Note.* Adapted from (Selangor Journal, 2024; Sinar Daily, 2023)



*Figure 1.* Water surge impact on 12 villages in Baling, Malaysia (Malay Mail Newspaper, 2024)

To enhance monitoring and prediction capabilities that are essential in water surge risk management, remote sensing technologies have increasingly been applied in water surge risk mapping of waterfalls. Applications include using satellite imagery to monitor water levels, LiDAR to evaluate terrain and elevation, and vegetation cover analysis to determine erosion susceptibility (Parra, 2022; Trepekli et al., 2022). Further, climate data from satellites and radar are significant to understand precipitation patterns that could potentially signal future surge events (Sahoo & Bhaskaran, 2019), and predictive models can be developed for the forecast of flow rates and identification of high-risk

areas using an integration of this data with both historical and meteorological data, thus creating risk maps used to direct emergency preparedness through GIS system integration (Alaghmand et al., 2010).

Using previous in-situ measurement techniques, which required direct measurements of discharge in waterfall areas, new techniques for estimating discharge have been developed using remote sensing technology and now include the use of synthetic width or stage discharge evaluation curves. The new methodologies use remote sensing from satellites to assess the river's efficient wet width and water surface elevation in order to calculate flow rates. In addition to being able to monitor river discharge at relatively frequent intervals using data which are generally accurate and reliable, these new methodologies can provide this information for large regions that have historically been difficult to reach because of the resolution of the satellite images (e.g. MODIS (Moderate Resolution Imaging Spectroradiometer), ENVISAT (Environmental Satellite), Landsat, etc.) (King et al., 2018; Tourian et al., 2013).

Remote sensing techniques are increasingly being applied in hydrological research due to their growing popularity. The remote sensing technique can provide a high resolution of the spatial-temporal distribution of different types of water resources, as well as assess the operational status of hydraulic infrastructure. These remote sensing methods can also help with monitoring and assessment of droughts, detection of flood water surges, and collection of important information regarding sustainable development and disaster prevention of water resource management.

### **Water Surge Review Through Bibliometric Analysis**

Bibliometric research is the quantitative data collection and analysis used to identify trends in how academia produces, disseminates, and receives published works using statistical/mathematical methods (Danvila-del-Valle et al., 2019; Diodato, 2013; Donthu et al., 2021). Bibliometric research can be viewed as a study of the production, transmission, and reception of scientific knowledge through the analysis of bibliographic data from each article, including citations, author(s), institution(s), geography, and journal. Examples of how bibliometric research can be applied are to build intellectual networks among researchers, assess the contributions of individual researchers, organisations, or countries, and analyse the research trends across different disciplines (Donthu et al., 2021). The main goal of bibliometric research is to provide a systematic/ objective analysis of the status of a particular field of study.

Researchers can measure the impact of scholarly work on this topic and the relative quality of that work based on how often it is referenced by other peer authors in assessing the effectiveness of bibliometric studies (Danvila-del-Valle et al., 2019; Donthu et al., 2021; van Nunen et al., 2018) and also to determine if these studies have been used by

other researchers in evaluating the quantity of the literature and quality of the literature. This study will use bibliometric studies to find the most influential studies on waterfall flooding in tropical areas like Malaysia and the opportunities for future collaboration to identify current trends in research and provide methods and techniques to monitor and reduce the risk of flooding due to waterfalls because of climate change.

The main benefit of this type of analysis provides researchers, as well as funding agencies, with the ability to make informed decisions on resource allocation based upon the relative strengths and weaknesses in a particular field of research. A second major benefit of the bibliometric analysis process is to assist researchers in understanding the current trends and growth of innovation in a specific field by analysing the trend of publications and citations throughout a given time frame. Bibliometric analysis also offers a way to measure the performance of individual authors and institutions. Through the measurement of citations of an author's works, where those works were published, as well as how geographically widespread those citations were, bibliometrics provide a researcher with a global view of how the scholarly community evolves, and the extent to which international collaboration occurs among academics around the world. The results of a bibliometric study will allow researchers to assess their own scholarly productivity and potentially identify potential future collaborative research opportunities with other scholars in their field of study (Danvila-del-Valle et al., 2019; Diodato, 2013).

VOSviewer (van Eck & Waltman, 2007), BibExcel (Persson et al., 2009), and Bibliometrix (Aria & Cuccurullo, 2017) have become the most widely used applications in the field of bibliometrics by scholars around the world (Garrigos-Simon et al., 2018; Goerlandt et al., 2020). The purpose of this study is to evaluate all existing bibliographic data that pertains to the use of remote sensing technologies for assessing hazards resulting from increased water flow/levels, and for assessing the risk of falling water from waterfalls, due to the importance and urgent need for these assessments. This study will provide an overview of the current state of research in this field and establish a foundation for additional research and knowledge development.

This Bibliometric study accomplished its main objective via a science-mapping analysis, which analysed Co-Citation, Co-Authorship, and Co-Occurrences of Keywords, and also Performance Analysis in the form of Publication Metrics, Citation Statistics, and Identification of Top Publishing Nations using the bibliographic information contained within the WoS database (Alryalat et al., 2019; de Carvalho Pereira et al., 2015). The importance of this study aligns with national goals, global Sustainable Development Goals (SDGs), Environmental, Social, and Governance (ESG) principles and contributes to sustainable resource management and policymaking. By enhancing knowledge of water surge risks in tropical waterfall regions, this research helps fill a critical gap in disaster preparedness measures within the national climate change policy and supports Malaysia's

national efforts to reduce disaster risks. In line with Malaysia's Twelfth Plan (MyGOV, n.d.), this research also supports ecotourism and improves resource management, both of which contribute to sustainable development planning.

The study supports the UN Sustainable Development Goal 6: Clean Water and Sanitation globally by promoting sustainable water resource management and risk mitigation strategies (<https://sdgs.un.org/goals/goal6>). It also supports the UN Sustainable Development Goal 13: Climate Action by using remote sensing technologies to address climate-related risks (<https://sdgs.un.org/goals/goal13>), and the UN Sustainable Development Goal 11: Sustainable Cities and Communities by enhancing the resilience of communities near waterfalls (<https://sdgs.un.org/goals/goal11>). Furthermore, the research supports the principles of environmental governance and good governance (ESG) through data-driven governance in managing water scarcity risks and promoting environmental stewardship through ecosystem conservation. These contributions highlight the study's broader impact on policy innovation and sustainable development.

## METHODOLOGY

The principal gaps in using remote-sensing technology for detecting and mapping flood occurrences within watershed regions were identified using a combined analytical method, which consisted of a systematic literature review (SLR) and a bibliometric analysis. The purpose of conducting the SLR first was to completely and impartially evaluate the current body of knowledge to identify and examine all relevant research studies that studied remote-sensing technologies in relation to water-based systems by applying pre-determined inclusion/exclusion criteria. In addition to identifying the thematic content of the articles reviewed, this method allowed us to include in our review those studies that were relevant to our research objectives, thereby allowing us to identify trends and gaps in research that will be useful for the design of future studies. Additionally, we believe that the combination of these two methods will allow us to contribute to the achievement of the Sustainable Development Goals (SDGs) through the identification of regional and global shortcomings in research concerning the use of remote sensing technology to measure the level of water in water catchment regions. Finally, the SLR and Bibliometric Analysis methodologies used in this study will provide a solid foundation for future research in this rapidly developing field, as they will allow us to provide a comprehensive and data-based perspective on the depth of the knowledge base in this subject area.

A bibliometric analysis of the type used in this research employs a consistent three-step procedure (Figure 2), which is as follows: (a) keywords and search queries were defined, (b) searches on databases were conducted and data exported, and (c) the bibliometric analysis was performed. Stage I is presented with more details in the following.

To identify the relevant literature from the database, the first step was to select the appropriate keywords for a search query that would capture the subject area of the study. Therefore, the search query (“water surge” OR “waterfall areas”) AND (“remote sensing”) AND (“water surge risk mapping”) was used.

*Stage II:* The above-mentioned keywords were used to carry out an exhaustive search in a chosen database using the stated keyword query. Many databases contain scientific or technical information; however, the WoS contains a large amount of literature from various areas of science and technology, which provides powerful citation-based measures and tools to study relationships among articles, authors and institutions. Although both WoS and Scopus have generally been found useful for bibliometric studies, they were both the best choices available at the time of writing for the purposes of studying high-quality, peer-reviewed literature that would allow for the determination of the most relevant trends in the area of study.

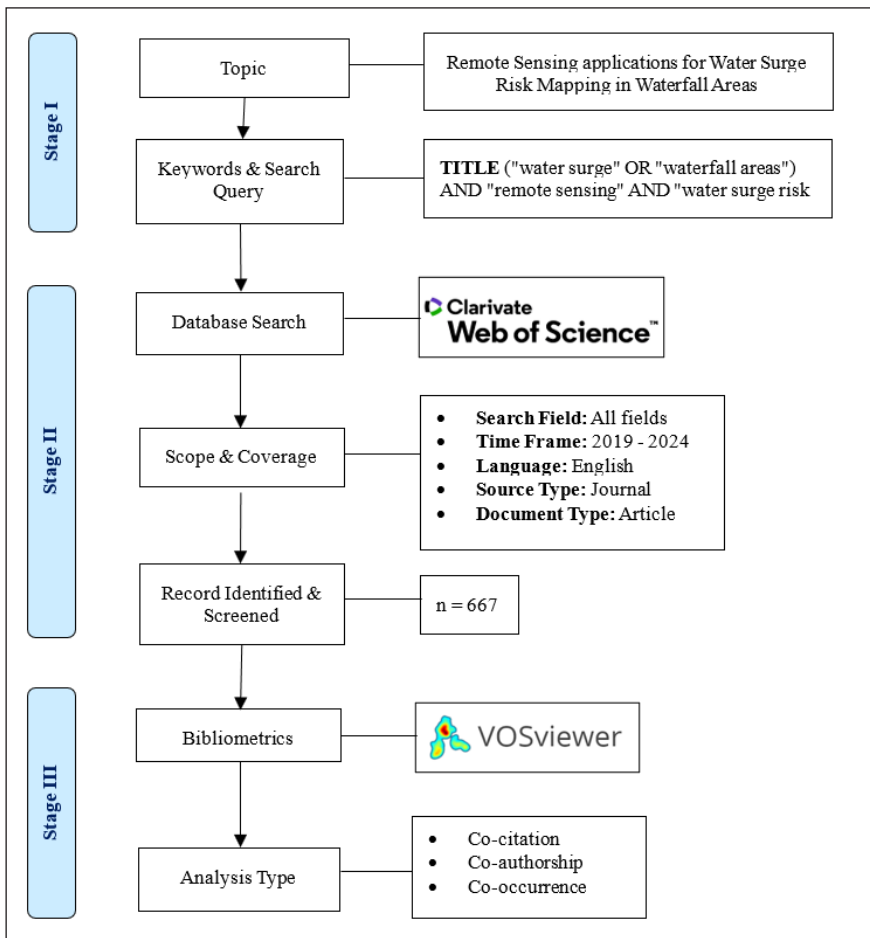


Figure 2. A diagram illustrating the search strategy

Filters were then applied to limit the results of searches made by performing a keyword query to the WoS to the results based on pre-defined criteria. These criteria included categories limited to environmental science and distance education, English as the language of publication, a publication period between 2019 and 2024 (covering the preceding five years), and document formats limited to articles and review articles. The records were then exported for bibliometric analysis.

*Stage III:* Statistical and graphical analysis was performed on bibliometric records exported from the WoS database. Science maps, which include patterns of co-citation and co-authorship, and performance analysis, which includes metrics such as publication statistics, number of citations, and top publishing countries, were used to present the results. The purpose of these analyses was to identify significant bibliometric patterns in the database. Exported data was used for performance analysis, while Microsoft Excel was used for processing and visualisation. VOSviewer (version 1.6.20), a program well-known in modern bibliometric studies for producing excellent visualisations, can also generate the network maps. The program's default settings were used for the generated maps, with minor adjustments to the threshold settings to improve visual clarity.

## **RESULTS AND DISCUSSION**

Although significant knowledge gaps and trends exist in terms of the risk of water surges from previous research that used a systematic literature review (SLR) and bibliometric analysis, there is a severe lack of previous remote sensing research specifically in tropical waterfall regions such as Malaysia to date, which was also supported by findings from the SLR. Although some of the studies using remote sensing to map water surge in tropical waterfall regions were limited, SLR indicated that many previous research studies had significant shortcomings. Most of the previous research has focused primarily on general hydrology and/or other environmental issues, with most studies utilising traditional ground-based measurement systems instead of advancing with new remote sensing technologies. The study clearly illustrated a pressing need to focus additional research on bridging this technological gap and enhancing community resiliency in vulnerable climates.

### **Performance Analysis**

This is a part of the research on biometrics that contains quantitative tendencies of the bibliography. Trends are identified as follows: yearly number of publications; yearly number of citations; the most important studies; the most important publishing centres; and the most important country contributions.

## Publications and Citations

As of November 1, 2024, 667 bibliographic records had been found because of an improved search query made possible by the WoS database. Due to the similar patterns in the Scopus database, there were roughly 2260 publications for the same search criteria. The total number of publications (TP) for remote sensing for water surge risk mapping in waterfall areas increased between 2019 and 2024, reaching a peak of 135 in 2022 before slightly decreasing to 129 in 2024 (Figure 3). The total citations (TC), which peaked at 3142 in 2021, exhibit a different pattern. This discrepancy suggests an expanding corpus of work with waning scholarly influence, perhaps because of a lack of creativity. Notably, studies focusing on water surge risks in waterfall areas are particularly scarce, highlighting an underexplored niche within this domain.

Table 2 lists the top ten most cited papers that discuss environmental research and remote sensing technology to highlight the most important topics and authors. It is also evident that, for at least the last five years, there have been very few scientific studies on the dangers of rushing water in waterfall locations, and none of them has been included in the top ten most referenced publications worldwide. The comparatively low number of citations indicates that the use of remote sensing technology to manage water surge risk, particularly in waterfall areas, is still underexplored. This shows that there is enormous, untapped potential for using these technologies to improve risk assessment, early warning systems, and management techniques in such domains. Expanding research efforts in this area may lead to more inventive solutions and a better knowledge of how remote sensing might reduce the hazards associated with water surges in complex and dynamic environments.

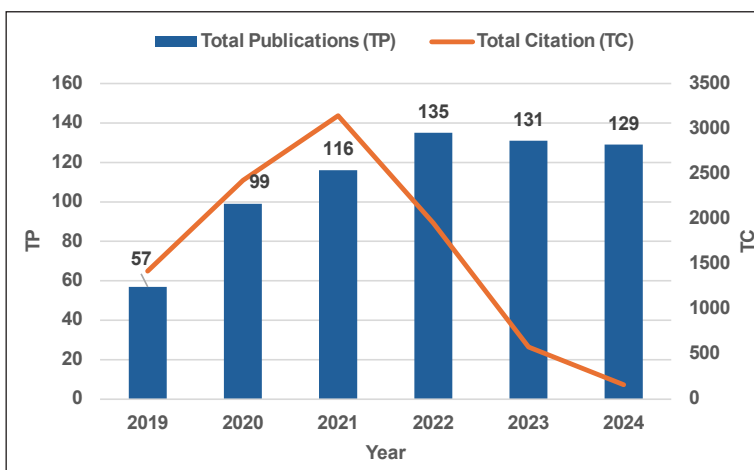


Figure 3. Trends in the number of publications and citations

Table 2

*Top 10 publications with the most citations on the use of remote sensing in environmental Sciences*

#	Article Title	Authors	No. of Citation
1	Antimicrobials and Antibiotic-Resistant Bacteria: A Risk to the Environment and to Public Health	(Serwecińska, 2020)	383
2	Effect of microplastics in water and aquatic systems	(Issac & Kandasubramanian, 2021)	364
3	Environmental impacts, pollution sources and pathways of spent lithium-ion batteries	(Mrozik et al., 2021)	338
4	Large-scale hydrogen production via water electrolysis: a techno-economic and environmental assessment	(Terlouw et al., 2022)	240
5	Combined Modelling of US Fluvial, Pluvial, and Coastal Flood Hazard Under Current and Future Climates	(Bates et al., 2021)	198
6	Mapping Industrial Symbiosis Development in Europe_ typologies of networks, characteristics, performance and contribution to the Circular Economy	(Domenech et al., 2019)	188
7	Catching a resurgence: Increase in SARS-CoV-2 viral RNA identified in wastewater 48 h before COVID-19 clinical tests and 96 h before hospitalisations	(D'Aoust et al., 2021)	139
8	A High-Resolution Global Dataset of Extreme Sea Levels, Tides, and Storm Surges, Including Future Projections	(Muis et al., 2020)	136
9	Phytoremediation of heavy metals in soil and water: An eco-friendly, sustainable and multidisciplinary approach	(Bhat et al., 2022)	114
10	Assessing Compound Flooding from Landfalling Tropical Cyclones on the North Carolina Coast	(Gori et al., 2020)	104

### Top Publishing Countries

Geographical statistics on publications serve as important performance indicators in bibliometric analysis. Table 3 presents a list of countries with the highest number of publications related to the application of remote sensing in environmental sciences. The People's Republic of China tops the list with 197 publications, followed by the United States of America (USA) as the second-largest contributor with 182 publications. While Malaysia ranked 33rd among countries, with 7 scientific consultations in the last 5 years, knowing that these publications also do not discuss the issue of water surge risk mapping in the waterfalls area.

Table 3  
*The top 10 countries and Malaysia with the most publications*

Rank	Country	Number of Publications
1	People's Republic of China	197
2	United States of America (USA)	182
3	England	63
4	Italy	47
5	Germany	42
6	Australia	36
7	Canada	35
8	Spain	33
9	India	32
10	Netherlands	30
33	Malaysia	7

### Top Publishing Organisations

Table 4 provides an overview of the top institutions and influential research groups actively contributing to research on remote sensing applications in water surge risk mapping. The Chinese Academy of Sciences and Hohai University are recognised as the leading organisations, with the most publications in this specialist field. Despite their high ranking, the overall number of publications from these universities is still quite low, which reflects the small amount of research that the academic community has produced in this field. In order to improve the research landscape and fill up the current knowledge gaps regarding the application of remote sensing technologies to water surge risk mapping in waterfall areas, this discovery highlights the necessity of expanded efforts and wider collaboration.

Table 4  
*The ten organisations with the most publications*

Rank	Organisation	Number of Publications
1	Chinese Academy of Sciences	40
2	Hohai University	28
3	University of Chinese Academy of Sciences	23
4	Ministry of Natural Resources	14
5	Sun Yat-Sen University	12
6	U.S. Geological Survey (USGS)	12
7	Wuhan University	11
8	Louisiana State University	10
9	Delft University of Technology	9
10	NOAA	9

## Science Mapping

The VOSviewer tool is used to create network maps that depict the bibliometric linkages. Network maps, density maps, and overlay maps are just a few of the visuals that this tool provides (van Eck & Waltman, 2007; van Eck & Waltman, 2010). In our investigation, we will concentrate on network maps. Nodes and links are used to create network maps. Each node represents an entity, such as an author, nation, document, institution, or keyword, and the connections show the co-occurrence relationships between these entities. While the thickness of the link reflects the strength of the relationship, the size of the node conveys the importance or prominence of an entity. The degree of association between nodes is reflected in their closeness; stronger relationships are represented by closer nodes. To categorise things into discrete clusters and provide a clear visual depiction of their relationships and grouping patterns, the nodes are also colour coded.

## Co-citations

Co-citation analysis is a science mapping method based on the premise that, according to the referred works, publications that are frequently mentioned together have comparable themes. When two publications appear in the reference list of a third publication, they are connected inside a co-citation network. This approach provides insightful information about the conceptual structure and thematic relationships within a subject of study (van Eck & Waltman, 2010). Co-citation-based network maps were used to show the thematic commonalities among texts in the research field. As seen in Figure 4, which displays the co-citation network map for writers, these maps examine the literature by looking at how frequently papers are cited together. The dataset was reduced to 53 writers out of 28,116 by using a minimum citation criterion of 25 for all authors to create this map.

## Co-occurrence

The keyword co-occurrence network map, which is shown in Figure 5, depicts the relationships between distinct author-defined terms based on their frequency of appearing together. To create this map, a minimum co-occurrence threshold of 5 was applied, resulting in the inclusion of 51 keywords from a total of 2,634 author-defined terms. The keyword “storm surge” has been referenced in the literature under various terms and emerged as the most frequently occurring keyword, with 85 mentions and a total link strength of 93. Other notable keywords include “sea level rise” (34 occurrences), “coastal flooding” (33 occurrences), and “remote sensing” (18 occurrences).

Moreover, it is important to stress that the current scientific literature does not include or has barely covered terms that are unique to waterfall zones when referring to water surge events.

This finding demonstrates an existing gap within the literature; therefore, it can be inferred that the academic community has not adequately emphasised the aspect of water surge dynamics in its recent publications.

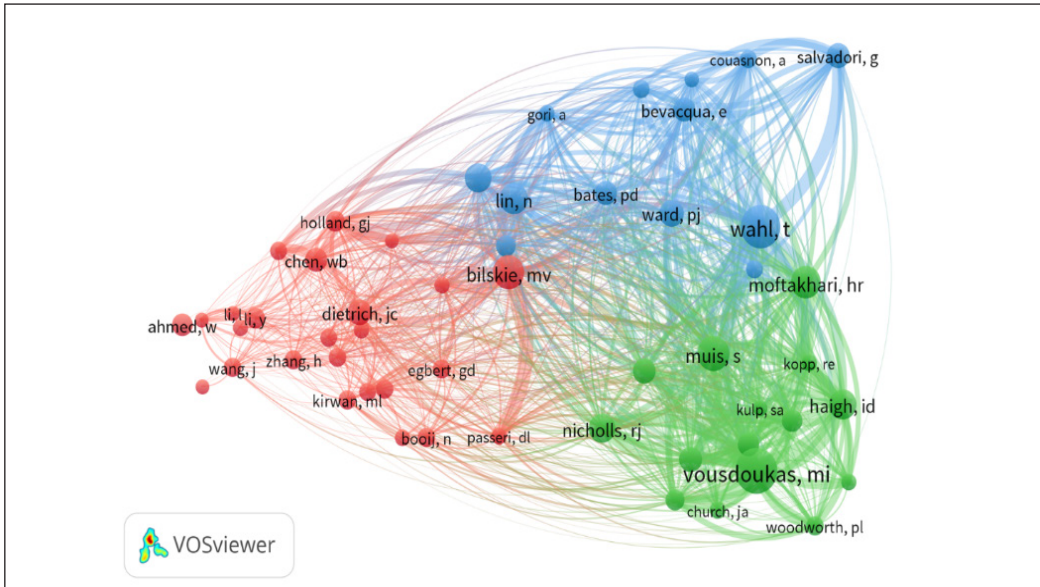


Figure 4. Network map of co-citations among authors

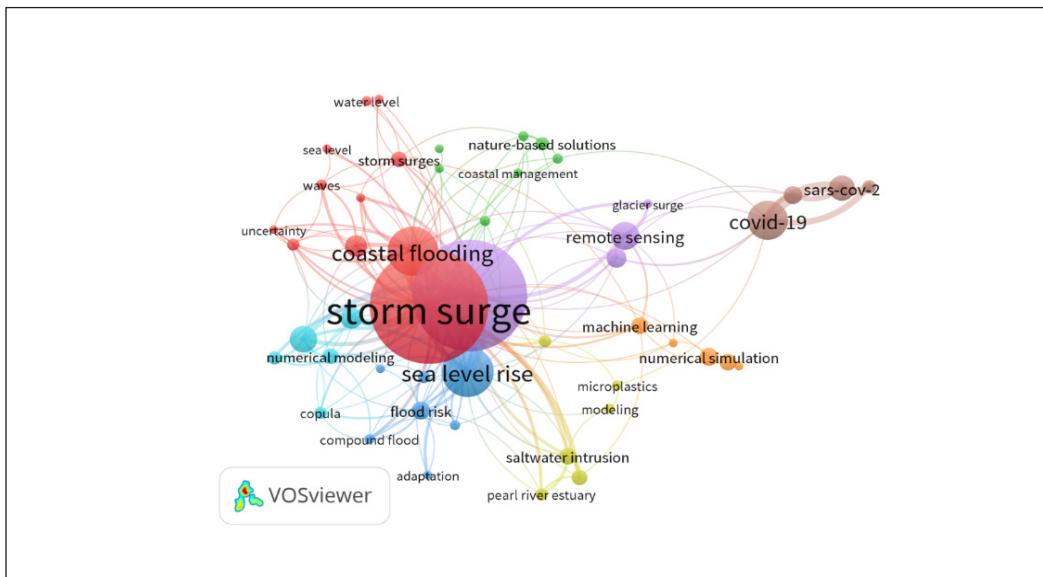


Figure 5. Network map of co-occurrence cited by author keywords

## Co-authorship

Co-authorship relationships are visualised in a geographic mapping by nation (as illustrated in Figure 6) that demonstrates the extent of international collaboration between researchers. Those nations that exhibit the greatest number of collaborations among one another, such as China, the United States, England and Australia, have both the highest publication output and are also most actively engaged in international collaborative research. The strength of those alliances is indicated by the width of the connections between nations. Thus, the minimal criterion for map generation was established at 5 publications per country, giving a total of 39 countries from 86. Countries are grouped into distinct clusters, such as the Asia-Pacific-North America region (e.g., China, USA, Australia, Japan), which is observed with the red cluster, Western Europe (e.g., England, Austria, France) with the green cluster, Europe-Asia (e.g., Italy, Poland, Saudi-Arabia, Malaysia) with the blue cluster, Europe-South America (e.g., Spain, Greece, Colombia, Brazil) with the yellow cluster, and Canada, Switzerland and South Africa with purple cluster, demonstrating regional collaboration patterns. Notably, China stands out as the leading contributor with the highest publication output and centrality in the co-authorship network. While the USA and England have the strongest relationship, with a link strength of 30.

The co-authorship map highlights the collaborative relationships among organisations (Figure 7) researching remote sensing applications within environmental science. A minimum threshold of 5 documents per organisation was established, narrowing the analysis to 37 institutions out of a total of 1,267. The Chinese Academy of Sciences and Hohai University are dominating, with the largest nodes denoting their major roles and considerable contributions. Strong collaborative links are seen between Chinese institutions, producing dense networks, especially within the Blue Cluster, which includes Northwest Normal University.

The U.S. Geological Survey, which serves as a focal point in the red group and represents foreign contributions with lesser but still significant collaboration, is another less noteworthy contributor. Regional-focused partnerships can be seen in many of the other groups also, i.e., groups with involvement from the Ministry of Water Resources and European organisations, including Utrecht University and Delft University of Technology. This is due to China being the dominant group on the map, indicating its extensive global presence; however, there are still some examples of foreign collaborations which appear to be less connected than they could be, thus suggesting a possible opportunity to develop more complete, global research networks.

This study provides a multi-dimensional view of the research landscape using both SLR and bibliometric findings. The bibliometric approach was able to quantify these gaps and to place the results in the context of larger trends in research; however, it is the qualitative findings from the SLR that identified methodological limitations and topical gaps.



The subject gaps within the field and the inter-disciplinary connections to other fields were identified using Keyword Co-Occurrence Analysis and Science Mapping, which illustrated the need for additional targeted research in this specific area. The results of the studies were effectively represented through Network Visualisations and provided a clear understanding of the bibliometric connections between authors in the field. Collectively, the studies provided an important addition to the existing body of literature, identified the status of the field and presented practical recommendations for future research projects.

Table 5

*Summary of the key findings from each analysis type, the usefulness of each analysis type to achieve the objectives of the study and comparative effectiveness of the analysis types*

Analysis Type	Key Insights	Utility for Study	Rank
Performance Analysis	Highlights publication and citation trends, major contributors, and geographic distribution	Useful for identifying key areas in remote sensing research for water surge in waterfalls	1
Network Visualisations	Presents relationships between studies and trends in an intuitive format	Excellent at presenting outcomes efficiently	2
Co-authorship Analysis	Maps collaborative networks among authors and institutions	Identifies top researchers and possible partners in this specialised subject	3
Keyword Co-occurrence	Identifies emerging research topics	Crucial for comprehending the gaps and current areas of interest in remote sensing applications for water surge	4
Co-citation Analysis	Reveals foundational studies	It identifies studies that are widely cited but may ignore recent trends relevant to the past five years	5

## CONCLUSIONS

This study has highlighted a very significant research gap regarding the use of remote sensing (RS) methods for evaluating and controlling the risk of water surges in waterfall areas, especially those found in tropical regions, like Malaysia. Even though RS methods have already been used in many different fields of environmental sciences, there are still no studies focused on using RS to monitor and manage the various risks found in waterfall environments, where the environment is constantly changing. This is due to the high level of uncertainty associated with the amount of rainfall experienced in tropical regions, increasing the risk of sudden, unexpected flooding.

The need for a dedicated study regarding RS and Waterfall Environments is evident when examining both the bibliographic study of relevant literature and the bibliometric analysis. The bibliographic study examined the major themes and trends from previous work and included trends that were found, including the number of publications, citation metrics,

and geography of papers that relate to RS and Waterfall Environments. The results from the SLR provided a qualitative component to the bibliographic study's findings to show that most researchers rely on data-based monitoring systems, and further, there was a lack of variety of methodologies used by researchers. The bibliographic study and SLR collectively illustrated that innovative research methods are needed and described a method of potentially advancing this critical area of research. The future studies can then develop and implement real-time monitoring systems and early warning systems that are specific to each location in Malaysia using the unique geology and climate of each waterfall environment by developing multi-disciplinary approaches utilising advanced remote sensing technology (such as satellite imaging, LiDAR, drone technology and GIS-based modelling). These types of programs can contribute towards protecting the ecosystem, disaster preparedness, and sustainable tourism for these natural wonders.

Additionally, studies focused on developing regionally relevant methods for evaluating flood dynamics and hydrologic patterns will lead to more effective and sustainable management of water resources. Finally, the integration of traditional and reference methods into future studies will allow for the identification of unexplored research topics and alignment with the United Nations' Sustainable Development Goals. The convergence of these perspectives will provide researchers with practical insights for enhancing environmental sustainability in highly vulnerable areas.

## **DECLARATION OF COMPETING INTEREST**

There are no conflicts of interest or known personal relationships that may impact the content of this manuscript.

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