Bibliometric analysis of paleotsunami research: current trends and overview

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Paleotsunami studies provide information that is crucial as primary data for tsunami mitigation planning and action. Studies that explicitly assess and evaluate paleotsunamis are not available. We carried out a quantitative analysis of published documents using a bibliometric study. We aimed to identify trends in paleotsunami studies based on the literature published until 2022. The study was conducted using the keywords 'PALEOTSUNAMI' or 'PALEOTSUNAMIS' in the Scopus database. Relevant publications that included information on document type, year, access type, author, journal and language were selected. The results were descriptively and quantitatively analysed based on annual progression, country, affiliation, author, journal, publication, area of study and keywords. A total of 199 documents were identified, representing 193 authors from 39 countries. Japan, the USA and Russia were the leading countries. The journal with the most publications was Marine Geology. Goto was the most productive and most cited author. The most frequently used keywords in paleotsunami studies were 'tsunami', 'paleotsunami', 'Holocene' and 'geological record'. There was a shift in the trend of paleotsunami studies beginning in 2018. A comprehensive analysis of previous paleotsunami studies is essential and can be an objective consideration in future research policies.

Keywords: Bibliometric analysis, hazard mitigation, paleotsunami, visualization and characterization.

PROGRESS on paleotsunami studies has been rapid, especially since the 2004 Indian Ocean tsunami. Also, after the 2011 Tohoku-Oki tsunami in Japan, new paleotsunami identification and characterization proxies have been rapidly developed. Recently, a geochemical proxy has been developed for paleotsunami identification[1–5]. The use of geophysical proxies in paleotsunami studies is also increasing[6,7]. Location for paleotsunami studies is expanding to many areas worldwide, although their dominance is still focused on specific countries. Paleotsunami studies must be comprehensive and use multiple proxies, as the identification of a paleotsunami is complex. These studies provide information on the recurrence interval of past tsunamis and the characteristics of tsunami sources in an area. They also provide crucial information as primary data for tsunami mitigation planning and action. However, studies that explicitly assess and evaluate paleotsunamis are not yet available. As a critical study for mitigation, the trends and general description of paleotsunami studies are needed to understand the newly emerging areas of research and the research gaps. To resolve this issue, a bibliometric study was conducted. A comprehensive analysis of previous paleotsunami studies is essential and can be an objective consideration in evolving research policies and providing opportunities for future studies.

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Materials and methods

The bibliometric method was utilized to summarize, assess and evaluate previous scientific publications using a specific keyword database. The Scopus database is reliable in providing accurate information and has been recognized in various fields of science[8]. Keywords are essential in expressing particular descriptions or explanations and can describe a publication's main topic or content. Figure 1 illustrates the stages of this study. The method used for this study was after Yang *et al.*[9]. The first step was to determine the relevant keywords: 'PALEOTSUNAMI' or 'PALEOTSUNAMIS' in the Scopus database. To account for the ongoing publishing process, publications up to 2022 were included, excluding the year 2023. Subsequently, all subject areas, except those less relevant, were selected and identified. The type of access, author, journal and language used were not restricted. The selected data were extracted into a comma-separated value (CSV) file format. The extracted data in CSV files were then processed and visualized using Microsoft Excel, Tableau Public (version 2022.3) and VOSviewer (updated 1.6.18)[10,11]. Microsoft Excel was used for statistical analysis

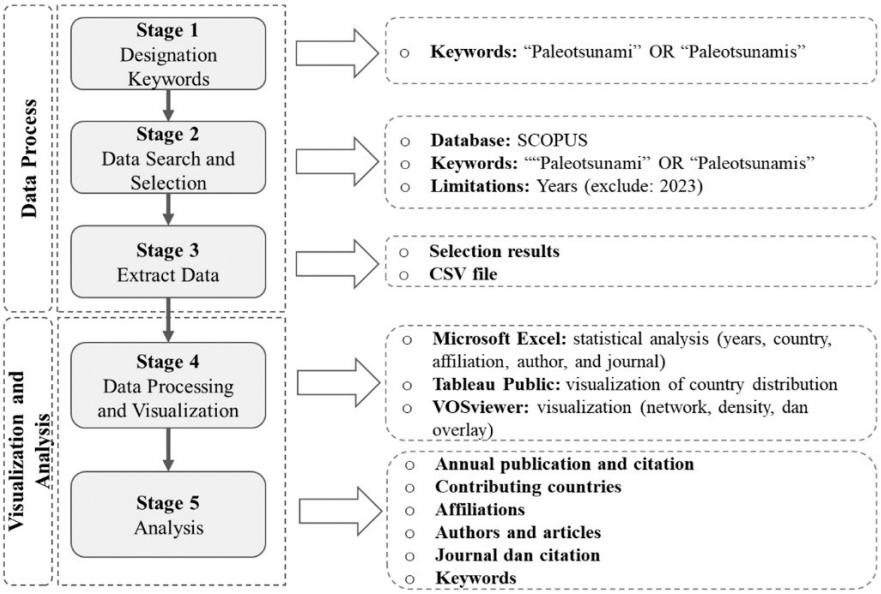


Figure 1. Stages of the paleotsunami bibliometric study.

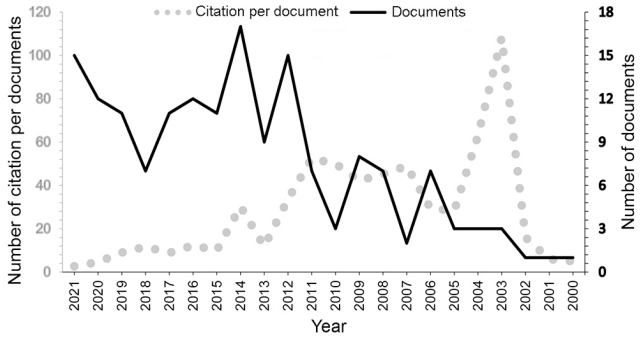


Figure 2. Publication and citation trends of published paleotsunami studies.

of year, country, affiliation, author and journal. Tableau Public was used to map the distribution of contributing countries, while VOSviewer was used for network, density and overlay visualization. The VOSviewer visualization was set with threshold options varying from a minimum of one to five documents. The results were subsequently descriptively and quantitatively analysed based on annual progression, country, affiliation, author, journal, publication, areas of study and keywords.

Results

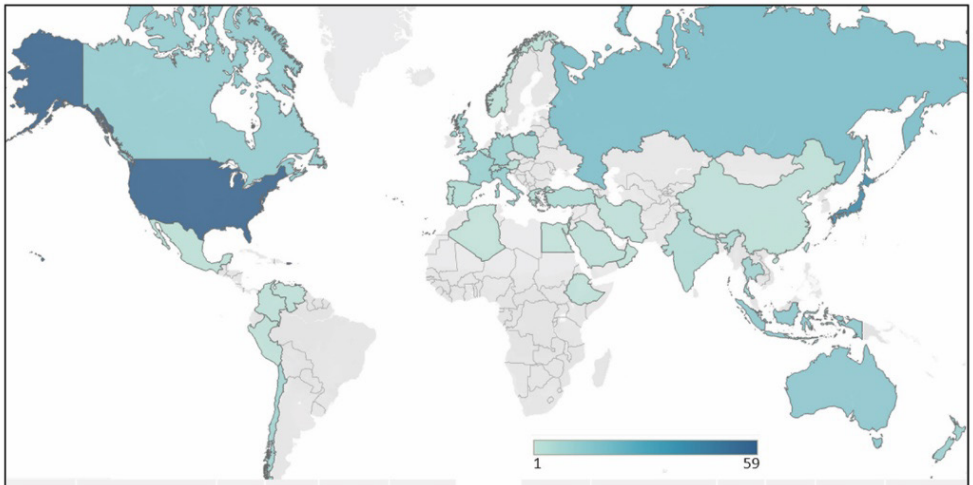
Publication year and citations

A total of 199 paleotsunami documents were identified. In 2005, following the 2004 Indian Ocean tsunami, there was a significant increase in the number of documents (Figure 2). From 2005 to 2011, the number of documents was relatively steady, no more than eight per year. Despite fluctuations, the average number of documents remained high, surpassing 12 from 2012 to 2018. There was a decrease in the number of publications in 2018 (seven documents). The year with the most publications was 2020 (25 documents). From 2018 to 2022, the number of documents increased from seven to 25. The citation trend showed the opposite pattern compared to the number of documents (Figure 2). The highest number of citations per document (112) occurred in 2003. From 2005 to 2011, the number of citations per document increased slightly from 30 to 54. This trend then decreased from 2011 to 2022.

Contributing countries and collaborations

Authors from 39 countries have published articles on paleotsunamis. Figure 3 shows the distribution of the top 15 countries with the highest productivity and citation rates per document. The United States leads in productivity, followed by Japan, Russia, Australia, Indonesia and Germany. The US also contributed the highest total citations. Poland and the United Kingdom had the highest total citations per document.

The collaboration network of authors between countries in paleotsunami studies was identified. The US was the most productive country, mostly collaborating with Japan, Canada, Australia, Indonesia and Singapore. France collaborated with Germany, Greece, Israel, Italy and Chile. Australia mostly collaborated with New Zealand, Indonesia, Japan, Poland and the UK. Researchers from Chile mostly collaborated with those from Belgium, Turkey, Australia, the UK, the US and Singapore. Of 39 contributor countries, 24 were interconnected in collaboration with the minimal



Rank.	Country	TD	TC	TC/TD	TLS	Rank.	Country	TD	TC	TC/TD	TLS
1	United States	59	2057	34.9	70	9	France	14	230	16.4	35
2	Japan	51	1270	24.9	42	10	Chile	11	255	23.2	27
3	Russian	22	323	14.7	9	11	Italy	11	224	20.4	11
4	Australia	21	546	26.0	39	12	New Zealand	10	122	12.2	10
5	Indonesia	16	439	27.4	19	13	Poland	9	568	63.1	17
6	Germany	16	295	18.4	36	14	Belgium	9	214	23.8	27
7	United Kingdom	15	650	43.3	48	15	Thailand	8	256	32.0	9
8	Canada	15	476	31.7	25						

Figure 3. Distribution of the top 15 countries with the highest productivity in paleotsunami studies. TD, Total documents; TC, Total citations; TC/TD, Total citations per document; TLS, Total link strength.

Table 1. Top 10 most productive affiliations in the field of paleotsunami

Rank	Affiliation	TD	TC	TC/TD	Country
1	Tohoku University	23	760	33.0	Japan
2	Hokkaido University	16	695	43.4	Japan
3	Russian Academy of Sciences	16	229	14.3	Russian
4	The University of Tokyo	15	139	9.3	Japan
5	UNSW Sydney	11	419	38.1	Australia
6	National Institute of Advanced Industrial Science and Technology	11	309	28.1	Japan
7	Geological Survey of Japan	11	296	26.9	Japan
8	Institute of Marine Geology and Geophysics of the Far East Branch, Russia	11	153	13.9	Russian
9	Portland State University	11	116	10.5	USA
10	Pacific Geographical Institute of the Far Eastern Branch of the Russian Academy of Sciences	10	63	6.3	Russian

TD, Total documents; TC, Total citations; TC/TD, Total citations per document.

output of three publications. China and Venezuela are yet to collaborate in paleotsunami studies.

Institution/affiliation

Table 1 lists the top ten most productive affiliations. The two top affiliations were Tohoku University and Hokkaido University from Japan, with 23 and 16 documents respectively. The Russian Academy of Sciences ranked third (16 documents). With respect to total citations, the two top affiliations also dominated. Hokkaido University had the highest total citations per document, followed by UNSW Sydney and Tohoku University. The top ten affiliations belonged to six countries. As shown in Figure 3, they are listed among the top 15 most productive countries.

Authors and collaboration networks

A total of 193 authors of paleotsunami documents were identified. Table 2 lists the top ten most productive authors and citation rates. Goto was the most productive author, with 20 documents. Sugawara and Peterson published 12 and 11 documents respectively. Authors ranked 4–6 had published the same number of documents (10). Goto also ranked first as the author with the highest total citations, followed by Sugawara, Nishimura and Szczuciński. In general, authors who published their documents also collaborated and created

Table 2. Top 10 authors with the most contributions

Rank	Author	Affiliation	TD	TC	TC/TD	Country
1	Goto, K.	The University of Tokyo	20	764	38.2	Japan
2	Sugawara, D.	Tohoku University	12	620	51.7	Japan
3	Peterson, C. D.	Portland State University	11	126	11.5	USA
4	Goff, J.	UNSW Sydney	10	316	31.6	Australia
5	Grebennikova, T. A.	Pacific Geographical Institute of the Far Eastern Branch of the Russian Academy of Sciences	10	66	6.6	Russian
6	Nishimura, Y.	Hokkaido University	10	610	61.0	Japan
7	Szczuciński, W.	Uniwersytet im. Adama Mickiewicza w Poznaniu	9	568	63.1	Poland
8	Pantosti, D.	Istituto Nazionale Di Geofisica E Vulcanologia	8	138	17.3	Italy
9	De Martini, P. M.	Istituto Nazionale Di Geofisica E Vulcanologia Institute of Marine Geology and Geophysics of the Far	8	138	17.3	Italy
10	Kaistrenko, V. M.	East Branch of the Russian Academy of Sciences	8	61	7.6	Russian

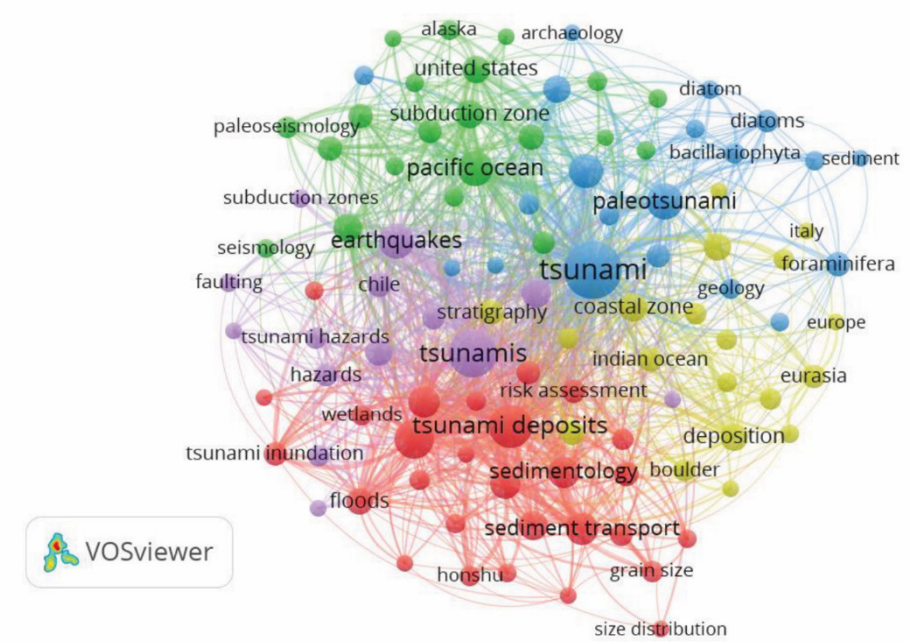


Figure 4. Visualization and clusterization based on co-occurrences.

a network. Visualization on the topic of paleotsunami shows that it consists of 12 clusters, seven of which are collaborations of more than three authors.

Journals and publications

Marine Geology was the journal that published the highest number of articles on paleotsunamis (15 documents). *Natural Hazard* ranked second with 12 documents, followed by *Sedimentary Geology* and *Earth Science Reviews* with six documents each. The highest total citations also belonged to the articles published in *Marine Geology*, followed by *Pure and Applied Geophysics*, *Journal of Geophysical Research – Solid Earth*, *Sedimentary Geology*, *Natural Hazards* and *Earth Science Reviews*. *Seismological Research Letters* had the highest total citations per document, followed by the *Journal of Geophysical Research – Solid Earth* and *Marine Geology*. *Natural Hazard* ranked second in total documents but eighth in total citations per document, indicating that citation rates do not correlate with the most productive publications. Of the 199 documents, the publication with the highest number of citations was 'New insights of tsunami hazard from the 2011 Tohoku-oki event' by Goto *et al.*[12], cited in 230 publications until 2022. The second most cited paper was 'Validation and verification of tsunami numerical models' by Synolakis *et al.*[13] cited by 216 publications. Fewer than 200 publications cited the other documents in the list. The third most cited paper was 'Sedimentologic and geomorphologic tsunami imprints worldwide – a review' by Scheffers *et al.*[14] cited by 197 publications, followed by a paper by Tuttle *et al.*[15] entitled 'Distinguishing tsunami from storm deposits in eastern North America: the 1929 Grand Banks tsunami versus the 1991 Halloween storm' cited by 185 publications.

The tenth document in the list of most cited papers was 'Horizontal and vertical variation of 2004 Indian tsunami deposits: an example of two transects along the western coast of Thailand' by Hori *et al.*[16] cited by 97 publications.

Keywords

The co-occurrence of keywords in paleotsunami studies from 2000 to 2022 revealed five significant clusters (Figure 4). The first cluster (blue colour) was related to past records of tsunamis and was composed of primary keywords, viz. tsunami, paleotsunami, Holocene and geological record. The second cluster (red colour) was related to the sedimentology of tsunami deposits and paleotsunami, and included major keywords such as tsunami, deposits, sedimentology and sediment transport. The third cluster (yellow colour) related to the geomorphic condition of the study area included major keywords like geomorphic, coastal morphology, coastal zone and Indian Ocean. The next cluster (green colour) was associated with the tsunami source dominantly caused by earthquakes, featuring keywords such as earthquake, earthquake magnitude, subduction zone and the Pacific Ocean. The last cluster (violet colour) comprised keywords such as sea level, tsunami inundation and hazards. Based on the co-occurrence with a minimum limit of one document from 2000 to 2022, the highest to moderately high topics included tsunamis, tsunami deposits, paleotsunami, earthquakes, Pacific Ocean, Holocene, tsunami event, coastal zone, geological record and sedimentation. Moderately low-to-low topics included bathymetry, geo-archaeology, grain size, inverse model, megathrust, microfossil, paleotsunami dating and XRF analysis.

The latest research topics for the period 2018–22, based on co-occurrence, were also classified. The research topics with the highest frequency (10–30) were tsunamis, tsunami deposits, paleotsunamis and earthquakes. This was followed by a frequency of 5–10, composed of the Holocene, tsunami event, Pacific Ocean, hazard assessment, geological record, subduction zone, sedimentology and coastal zone. Frequencies of 3–5 included geomorphology, subduction zones, stratigraphy, radiocarbon dating, depositional environment, earthquake rupture, sediment transport and paleoseismology. Frequencies of 1–2 included keywords such as age determination, coastal hazards, diatoms, foraminifera, geochemistry, grain size, magnetic susceptibility, portable XRF, database, recurrence interval, tsunami modelling, hazard management and event deposits. There was a shift in the trend of paleotsunami studies beginning from 2018 up to 2022. The studies in 2018 were mostly related to keywords like subduction zone, coastal zone, earthquake magnitude, sampling and grain size. The trends from 2018 to 2020 shifted to studies related to keywords such as tsunami, tsunami deposit, paleotsunami, earthquakes, stratigraphy and hazards. The trends between 2020 and 2022 shifted to studies related to keywords such as depositional risk assessment, geochemistry, tsunami inundation, paleoseismicity, paleoseismology, floods and depositional environment.

Discussion and concluding remarks

This study presents the results of a bibliometric analysis of paleotsunamis. Only a few documents were published on the topic before 2005, with an average of less than two documents per year. After the 2004 tsunami, geoscientists began to realize that information on tsunami hazards based on paleotsunami studies is vital and should form the basis for tsunami mitigation. Beginning in 2005, the average number of publications per year increased significantly. This upward trend indicates a consistent and growing interest in the field, with promising prospects for the future. The citation trend was the opposite of the increasing number of published documents. Many documents with a relatively shorter publication period affect the citation rate; therefore, relatively recent publications have a low citation rate. Countries and levels of collaboration could also affect the number of citations[17]. There is a positive correlation between collaboration and citations, the top-cited documents resulting from a solid international collaboration. The number of published paleotsunami documents peaked in 2014, when most publications referenced the results of the studies of the 2011 Tohoku-Oki tsunami deposit as a modern analogue for paleotsunami studies. The most cited paper by Goto *et al.*[12] highlighted that data on the 2011 event suggest that previous estimates of paleotsunamis in the Sendai area, Japan, have probably been underestimated. Their finding led to the realization that the risk from tsunami hazards in Japan is much greater than previously recognized. This information has significantly changed the perspective on the study of paleotsunamis worldwide. As the second most cited publication, Synolakis *et al.*[13] provided an understanding of the need to validate and verify tsunami numerical models before they are used to predict the inundation distance of paleotsunamis. In the third most cited publication, Scheffers *et al.*[14] reviewed state-of-the-art knowledge of sedimentologic and geomorphic imprints of tsunamis to highlight the importance of more detailed studies of paleotsunami depositional and geomorphological traces. In general, all publications listed in the top 10 most cited documents mainly discussed the characterization of modern analogues of paleotsunami as well as some general aspects of their identification. As paleotsunami identification is complex, the use of new proxies (e.g. refs 1–5 for geochemical proxies and refs 18 and 19 for paleoDNA of foraminifera) remains limited and is currently applied only in restricted locations.

Visualization and clustering of keywords support this hypothesis. Based on the co-occurrence analysis, paleotsunami studies can be divided into five significant clusters. The new proxies for paleotsunami identification are not included in these clusters, suggesting that new proxies for paleotsunami identification should be applied more widely,

not only to test the effectiveness of these new proxies but also to reanalyse unidentified paleotsunami candidates. Based on this study, it can also be concluded that research on the formation of a new paleotsunami identification proxy has not been widely and intensively conducted.

From the list of most productive countries combined with data from top affiliations and authors, it was identified that some countries are dominant only as the locus for paleotsunami studies. Authors from these countries who have contributed to paleotsunami studies are still inadequate. For example, Indonesia was listed in the top five most productive countries; however, no authors or affiliations from this country were included in the top ranking. This is unacceptable, as Indonesia, like Japan, the US and Russia, is one of the most tsunami-prone countries. However, the awareness and willingness of geoscientists to study paleotsunami still need to be improved. Researchers interested in paleotsunamis are limited. The Indonesian Government willingness to use and apply the results of paleotsunami studies for development planning and mitigation efforts remains minimal. Geographical and geological factors, along with past experiences, play a significant role in determining the involvement of countries in the field of paleotsunamis.

Notably, some countries known for their history of tsunamis, such as Madagascar, Sri Lanka, the Philippines, Solomon Islands, Papua New Guinea, as well as certain countries in Latin America and Africa, have not actively engaged in this field. Considering the contributions of more advanced countries, their affiliations and experts can be a valuable factor in fostering future collaborations. The results of this study indicate that Japan and the US have dominated paleotsunami studies and provided the most highly cited documents. These two countries also have excellent authors. Encouraging researchers in other tsunami-prone countries to be more involved in paleotsunami studies is imperative.

As a bibliography analysis of paleotsunamis, this study provides significant information on the trends in the field. A comprehensive analysis of previous paleotsunami studies is essential and can aid in developing paleotsunami research policies and encourage future research that will be insightful for tsunami hazard mitigation.

Conflict of interest: The authors declare that there is no interest.

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