Geoenvironmental Disasters

REVIEW

Open Access

Exploring the Mediterranean tsunami research landscape: scientometric insights and future prospects

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Abstract

Background The Mediterranean Sea is a region characterized by high seismic activity, with at least 200 tsunami events recorded from the fourth century to the present twenty-first century. Numerous studies have been conducted to understand past tsunami events, earthquake–tsunami generation, tsunami recurrence periods, tsunami vulnerability zones, and tsunami hazard mitigation strategies. Therefore, gaining insights into future trends and opportunities in Mediterranean Sea tsunami research is crucial for significantly contributing to all relevant aspects. This study aims to assess such trends and opportunities through a scientometric analysis of publications indexed by Web of Science from 2000 to 2023.

Results Based on a selection of 329 publications, including research articles, review articles, book chapters, and conference papers, published between 2000 and 2023, Italy has the highest number of publications and citations in this field. The number of publications has increased significantly, especially after the 2004 Indian Ocean, 2011 Tohoku, and 2018 Palu tsunamis. According to the keyword analysis, the terms "tsunami", "earthquake", "hazard", "wave", "Mediterranean", "coast", and "tectonic" were the most frequently used in these publications. Research themes consist of four classifications: motor themes, such as seismic hazard; specific but well-developed themes, like tsunamiite; emerging or disappearing themes, for example, climate change; and general or basic themes, such as equations and megaturbidite. The number of publications related to the motor theme classification continued to grow throughout 2000–2023. Topics from 2011–2023 are more complex compared to 2000–2010, characterized by the emergence of new keywords such as evacuation planning, risk reduction, risk mitigation, building vulnerability, coastal vulnerability, climate change, probabilistic tsunami hazard assessment (PTVA-3 and PTVA-4). However, topics that were popular in the 2000–2010 period (e.g., paleotsunami deposits, earthquake, and tsunami propagation analysis) also increased in 2011–2023.

Conclusions Research topics with high centrality and density such as seismic hazard will continue to develop and prospect. The cluster network of this topic includes seismoturbidites, sedimentary features, tsunami modeling, active faults, catalog, and historical earthquakes.

Keywords Tsunami, Mediterranean Sea, VOSviewer, Scientometric analysis

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Introduction

Tsunamis are the most devastating movements of oceanic waves, formed by shockwave-generating processes such as earthquakes, submarine and subaerial landslides, volcanic activities, atmospheric disturbance, and asteroid impacts (Behrens et al. 2021; Saito and Furumura 2009; Sugawara et al. 2020). The wave excitation mechanism induces the tsunami propagation process as long waves with periods ranging from a few minutes to several hours, wavelengths from tens to hundreds of kilometers, and in some cases, the tsunami's height reaches tens of meters near the coast before it runs up inland, causing a major impact on the coastal environment (Laksono 2023; Laksono et al. 2021; Siagian et al. 2014; Suppasri et al. 2018). When specific external forces disturb oceanic or lacustrine areas, the water mass is temporarily forced to move (Haugen et al. 2005). This displacement of the water mass propagates outward with a wavelength depending on the dimensions of the wave source (Heidarzadeh et al. 2022; Röbke and Vött 2017).

Throughout history, we have witnessed several catastrophic tsunami events. Prominent among these is the tragic 2004 Aceh, Indonesia tsunami, the devastating 2011 Tohoku, Japan tsunami, and the 2018 Palu and Sunda Strait tsunamis in Indonesia, all meticulously examined in the works of Rasyif et al. (2019), Schambach et al. (2021), Shinozaki et al. (2016), and Widiyanto et al. (2020). In addition to these tragedies, tsunamis have also occurred in other parts of the world, such as the Mediterranean Sea (England et al. 2015; Mastronuzzi 2010; Schambach et al. 2020; Zaniboni et al. 2019).Due to the active convergence of lithospheric plates, the Mediterranean Sea region is characterized by high seismicity and significant volcanism (Billi et al. 2023; Carafa et al. 2015; Fokaefs and Papadopoulos 2007). Additionally, submarine landslides are frequent owing to the steep topography that is typical of most basins (Mueller et al. 2020; Urgeles and Camerlenghi 2013). However, some people believe that tsunamis are very rare in the Mediterranean Sea because historical tsunami events are not well-documented. This assumption also contributed to neglecting the scientific study of tsunamis in the Mediterranean for a long time (Papadopoulos and Fokaefs 2005).

Until the beginning of the twentieth century, tsunamis were only occasionally mentioned in earthquake catalogues (Grünthal and Wahlström 2012; Papadopoulos and Fokaefs 2005). After the tsunami tragedies of December 20, 1908, in the southern Aegean Sea, Greece, and July 9, 1956, more systematic efforts to catalogue them began in the 1960s when numerical wave modelling and tsunami hazard assessment made significant progress (Antonopoulos 1972; Maramai et al. 2014). The turning point for tsunami research in the Mediterranean Sea and Europe occurred in the early 1990s when a series of research projects were properly coordinated, leading to rapid progress across the spectrum of tsunami science, technology, and risk mitigation (Papadopoulos 2015; Papadopoulos and Fokaefs 2005; Triantafyllou et al. 2023).

Catalogues of tsunamis in the Mediterranean Sea have been systematically compiled by authors such as Galanopoulos (1960), Ambraseys (1962), Antonopoulos (1972), Papadopoulos and Chalkis (1984), Amiran et al. (1994), Tinti and Maramai (1996), Tinti et al. (2004), Soloviev et al. (2000), Papadopoulos (2000), Papadopoulos and Fokaefs (2005), Fokaefs and Papadopoulos (2007), Papadopoulos et al. (2007, 2010, 2011), Maramai et al. (2014, 2019, 2021), and Triantafyllou et al. (2023). In the revised catalogue published by Triantafyllou et al. (2023), it was revealed in detail that the total number of tsunamis in the Mediterranean and connected seas before the fifth century BC to 2021 is 256 events, where 87 events occurred during 1900–2021, 163 events between the fifth century BC to 1899 AD, and 6 tragedies in prehistoric periods before the fifth century BC. The recurrence period of destructive tsunamis ($K \geq 7$) is 22 years throughout the Mediterranean Basin and 31, 118, 135, 424, and 1660 years in the eastern Mediterranean, western Mediterranean, Corinth Gulf, Sea of Marmara, and Black Sea basins, respectively (Triantafyllou et al. 2023). Geographically, severe tsunami events with the highest risk are found in seismogenic zones with complex geological structures such as the Messina Strait in southern Italy, the Hellenic arc, Adriatic Sea-Greece, and the active volcanic complex of Thera in the southern Aegean Sea, Greece (Anita et al. 2012; Flouri et al. 2018; McCoy and Heiken 2000; Selva et al. 2021). Meanwhile, lower-risk tsunamis are found in other tsunamigenic zones such as the western Mediterranean (Tunisia-Sicily including Tyrrhenian Sea), Alboran Sea, Liguria and Cote d'Azur, Tuscany, Calabria, Aeolian Islands, Gargano promontory, Cyclades, and Levantine Sea (Papadopoulos and Fokaefs 2005; Sørensen et al. 2012; Stiros 2010; Triantafyllou et al. 2023). The lowest tsunami risk lies in the Marmara Sea and Black Sea, while the risk in the Gulf of Corinth is comparable to the western Mediterranean (Kortekaas et al. 2011; Novikova et al. 2011; Šepic et al. 2015).

The tsunami of December 28th, 1908, that occurred in the Messina Strait, Italy, geographically belongs to the eastern Mediterranean Basin (Billi et al. 2008; Pino et al. 2009). On December 28th, 1908, a calamitous tsunami struck the Mediterranean Sea, leaving a trail of destruction along the eastern coast of Sicily and the southern Calabria region, Italy. The origins of this catastrophe can be traced to a magnitude 7.1 earthquake, vividly described in the studies by Paparo et al. (2017), Piatanesi

et al. (1999). This earthquake generatedwaves surging 250 m inland in the city of Messina, where both the port and the fortress of St. Salvatore bore the brunt of nature's fury (De Martini et al. 2010; Favalli et al. 2009). Even places like Syracuse and Augusta, located several kilometers south of the epicenter, found themselves submerged beneath 1.75 m of seawater, as extensively detailed in the research by Billi et al. (2010), Ridente et al. (2014), and Smedile et al. (2020).

Following the December 28, 1908 tsunami study, a wide spectrum of tsunami research topics in the Mediterranean Sea, including the development of paleotsunami databases, analysis of onshore and offshore tsunami sediments, simulation of past tsunami waves, investigation of tsunami zones, and assessment of tsunami wave impacts in coastal areas have been conducted(Maramai et al. 2014, 2019, 2021; Mueller et al. 2020; Papadopoulos 2009; Papadopoulos and Fokaefs 2005; Scardino et al. 2021; Stiros 2010; Triantafyllou et al. 2023; Zaniboni et al. 2019). However, comprehensive review articles encompassing all publications related to Mediterranean tsunamis, indexed in reputable databases, is still missing. There are even only two articles that explicitly discuss tsunami bibliometric studies such as Chiu and Ho (2007) and Jain et al. (2021). On the other hand, another study conducted by Nacházel et al. (2021) places more emphasis on improving data management in tsunami research which includes data compilation, cataloging, data distribution, incompleteness of several data types, connectivity of tsunami scientific study references published by Web of Science, government agencies, commercial organizations, and research institutions using ontology engineering. However, this study does not address in detail and specifically the development of research topics over time in the Mediterranean Sea and connected seas, research gaps, and current and future trends in tsunami research themes in the Mediterranean.

A scientometric analysis of tsunamis in the Mediterranean region is needed to assist researchers in establishing the state of the art and addressing unsolved research gaps. Although there have been many tsunami studies in the Mediterranean region (Mueller et al. 2020; Polonia et al. 2017; San Pedro et al. 2017; Stiros 2010; Visini et al. 2009), the absence of scientometric studies has led to the assumption that research on this topic is no longer prospective (Kaur and Sood 2020a, b; Sagar et al. 2010). In fact, many past tsunami events in the Mediterranean region have not been recorded in databases due to the lack of geological evidence in the field (De Martini et al. 2012; Smedile et al. 2011). The analysis of keywords, topics and themes that emerge in this scientometric analysis can assist in capturing the development of tsunami research outputs (Chiu and Ho 2007; Jain et al. 2021) in the Mediterranean and their impact on science and society, identifying current trends in Mediterranean tsunami research, and reflecting on the science structure evolution within the framework of connections among different scientific concepts (Goerlandt et al. 2021; Kaur and Sood 2020a, b) in order to understand the landscape of Mediterranean tsunami research. Insights into the progression of Mediterranean tsunami research topics over time can serve as a basis for searching future research prospects or finding solutions to current unsolved issues. This scientometric analysis is also useful in literature studies, especially to sort out references relevant to the Mediterranean tsunami research topic.

Data and methods

The method applied in this study consists of two stages: data extraction and scientometric analysis. The data extraction stage includes database selection and search strategy while the scientometric analysis stage comprises performance analysis and science mapping (Fig. 1).

Data collection

The data used in this study were obtained from the Web of Science (WOS) database on January 10, 2023 by inputting the keywords "tsunami in the Mediterranean Sea" OR "tsunami in the Mediterranean Region" OR "tsunami in south Europe" OR "tsunami in north Africa" with document types including research articles, review articles, book chapters, and proceedings. The document publication years range from 2000–2023 and are indexed by Science Citation Index Expanded (SCI-Expanded), Conference Proceedings Citation Index-Science (CPCI-S), Social Science Citation Index (SSCI), Book Citation Index-Science (BKCI-S), Emerging Sources Citation Index (ESCI), Arts & Humanities Citation Index (A&HCI), Conference Proceedings Citation Index-Social Science & Humanities (CPCI-SSH), and Book Citation Index-Social Sciences & Humanities (BKCI-SSH). The total number of research and review publications collected based on these criteria was 329 with information identified including citations, bibliographies, abstracts and keywords in plain text file format. Furthermore, the scientometric dataset files were transferred to SciMat software to extract strategy diagrams and thematic evolution maps.

The determination of publication years 2000–2023 is based on the existence of major tsunami events such as the 2004 Indian Ocean tsunami, the 2006 Pangandaran tsunami, the 2010 Mentawai tsunami, the 2011 Tohoku tsunami, the 2018 Lombok and Palu tsunamiswith overall casualties reaching several hundred thousand people and having impacts on a regional scale (Jihad et al. 2020; Laksono et al. 2022; Pilarczyk et al. 2014; Pribadi et al. 2021;

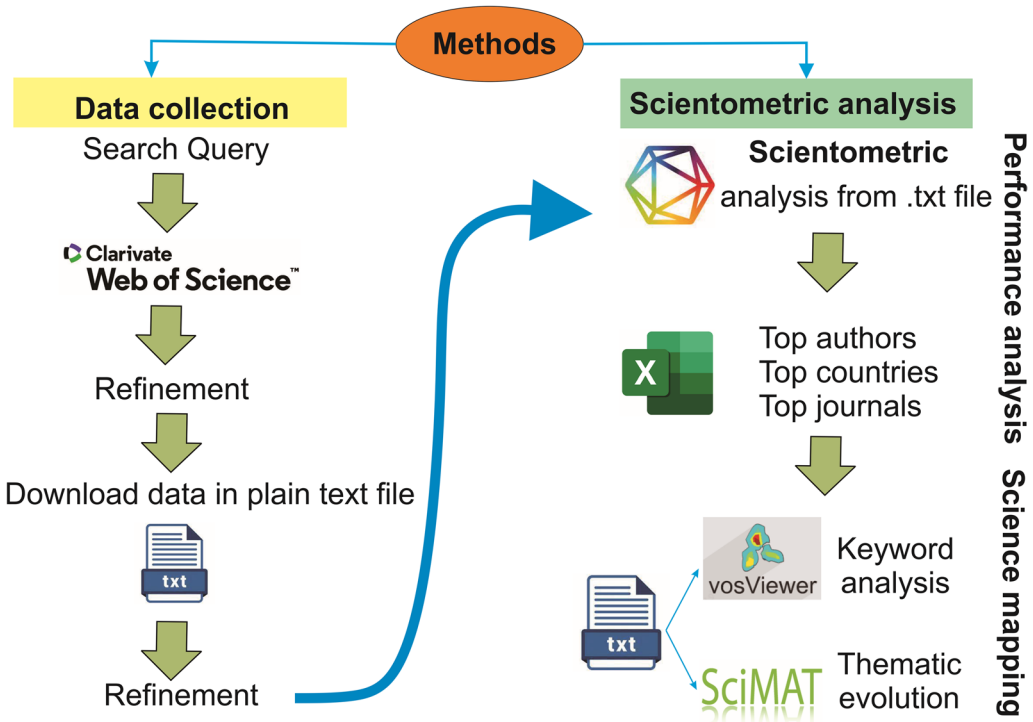

Fig. 1 Flowchart of the scientometric analysis study of tsunamis in the Mediterranean region. Two critical stages in the scientometric study are data collection and scientometric analysis using the two software VOSviewer and SciMAT

Schambach et al. 2021; Suppasri et al. 2018). In addition, at the beginning of the twenty-first century, tsunami modeling software was significantly developed in line with the rapid advancement of computer, communication and information technology (Behrens and Dias 2015; Rakowsky et al. 2013). High-resolution remote sensing technology, earthquake detection and tsunami early warning systems have developed very rapidly, especially after the 2004 Indian Ocean tsunami. (Bernard and Titov 2015; Koshimura et al. 2020; Utheim et al. 2014).

Scientometric analysis

Scientometrics is a scientific method that employs quantitative data, such as scientific publications, citations, research collaborations, and specific indices, to measure, analyze, and comprehend the development, impact, and structure of science, ultimately revealing trends in scientific research (Huang et al. 2022; Owolabi and Sajjad 2023; Sood and Rawat 2021). Scientometric analysis consists of two main stages: performance analysis and science mapping analysis (Mishra et al. 2023). Performance analysis is based on scientometric indicators that measure the number of publications of each individual such as authors and journals as well as the impact achieved through publication and citation data (Cobo et al. 2012; Mishra et al. 2023). Science mapping provides a topological and temporal representation of a particular research field's cognitive and social structure (Cobo et al. 2011). There are various tools available for scientometric analysis such as Biblioshiny (R Package), VOSviewer, SciMAT, CiteSpace, and BibExcel. Each of these software has different mapping principles, algorithms, output displays, advantages, and disadvantages (Acharyya et al. 2023; Aria and Cuccurullo 2017; Chen et al. 2012; Venkatraman et al. 2018). Therefore, the application of a single tool in scientometric analysis is less reliable, in this study we utilize two software namely VOSviewer and SciMAT (Cobo et al. 2011).

VOSviewer is a free open access scientometric tool employed to create scientometric networks of different individuals such as authors and institutional affiliations using various network analysis methods such as author collaboration, co-citation, co-occurrence, and bibliographic coupling (Mishra et al. 2021; Shen et al. 2023; van Eck and Waltman 2010). Data from the WOS database was imported into VOSviewer to perform several analyses, including co-authorship, co-occurrence, citation, and co-citation. The co-authorship analysis consists of the names, organizational affiliations, and countries of origin of the authors. Co-occurrence analysis is related to all keywords used in the publications and measures the strength of the relationship between keywords

(Kuzior and Sira 2022; van Eck and Waltman 2010). This measurement is based on the frequency of connections between the two entities. Citation analysis includes the most cited articles, journals, authors, author affiliations, and countries or regions.

The co-citation analysis type includes cited references, cited sources, and cited authors, which are articles, journals, and authors most frequently cited by other documents or research, indicating a connection between these sources. The publication period is divided into 2000–2010 and 2011–2023, aiming to determine the differences in keyword occurrence trends. The identification of research gaps is carried out based on the frequency of occurrence and the relationships among keywords (Fathianpour et al. 2023; Feng and Cui 2021). Keywords that rarely appear, have weak interrelationships or are not connected to other keywords likely indicate a research gap (Hossain et al. 2023; Waseem and Rana 2023). However, the relevance among keywords needs to be considered before determining the existence of research gaps based on the keyword network map in VOSviewer. Therefore, a scientometric analysis using SciMAT is required to classify relevant topics. SciMAT is also an open-access software developed to perform scientometric analysis under a longitudinal framework and supports various analyses (Cobo et al. 2012).

In this study we employed the term co-occurrence to identify closely related concepts and explore the thematic evolution over the past 23 years. The SciMAT software output is a strategic diagram (Fig. 2A) that illustrates the themes and keywords of the study based on two indicators: cluster centrality (horizontal axis) and density (vertical axis) (López-Robles et al. 2021; Rincon-Patino et al. 2018). Cluster centrality indicates the strength of interdisciplinary relationships and the centrality of themes in research development. Density reflects the degree of strength (Cobo et al. 2012; Selvavinayagam 2018). The diagram is divided into four quadrants based on their relevance. Research themes are symbolized as circles and their size is proportional to the number of publications related to the research theme (Acharyya et al. 2023; Mishra et al. 2023; Moral-Muñoz et al. 2020).

The motor theme/quadrant 1, located in the top right, indicates a theme that is well-developed and important for building the research field (Fig. 2A). The themes in quadrant 2 (top left) describe themes that are very specific and peripheral in character. Themes in this quadrant are considered to have low relevance because they have well-developed internal ties but their external links are not so important. The third quadrant at the bottom left includes themes that are less developed and relevant, representing emerging or disappearing themes. The fourth quadrant in the bottom right indicates themes that are relevant but less developed because they are understood as transversal, primary, and general topics (Li et al. 2021; Mishra et al. 2023). Additionally, SciMAT software can also generate diagrams showing the relationships among clusters (Fig. 2B).

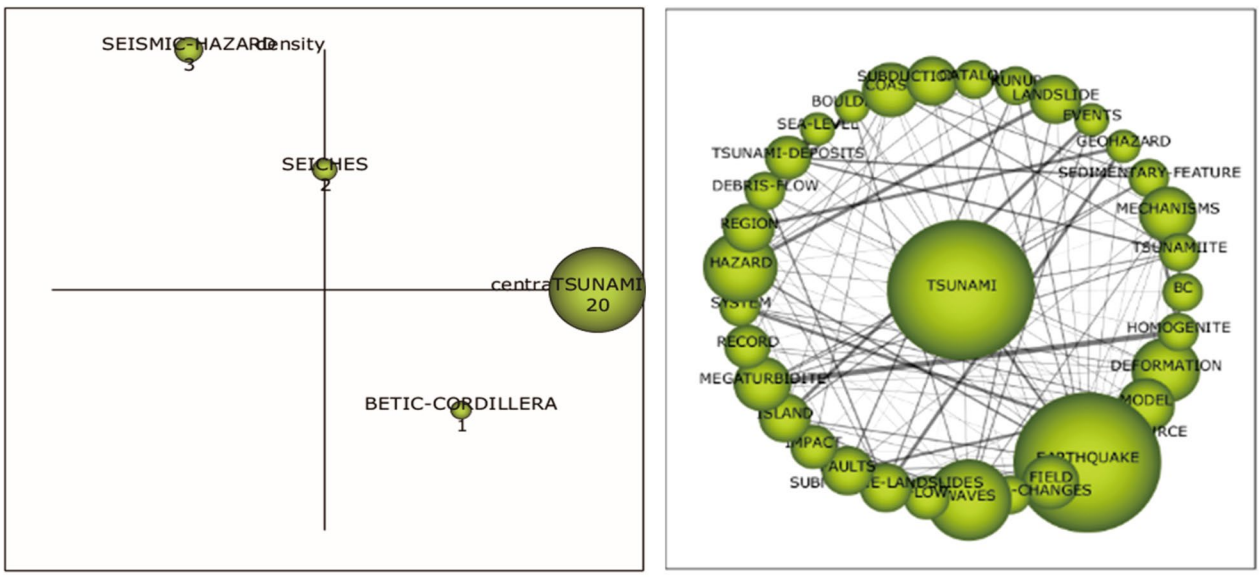

Fig. 2 **A** Strategic diagram and **B** cluster network diagram based on co-occurrence analysis of various tsunami-related research themes in the Mediterranean region using SciMAT software. The numbers in the figure denote the number of articles

Results

Number of publication trend

The total number of articles published between 2000 and 2023 generally shows an increasing trend. However,there are specific years when it fluctuates (see Fig. 3). For instance, between 2000 and 2006, the number of publications related to tsunamis in the Mediterranean Sea remained consistently below 10, and there was even a declining pattern. In 2001 and 2002, only one and two documents were published, respectively, down from eight papers in 2000. In 2003, the number of publications increased again to three papers, but fell to only one document in 2004 and 2005. The publications increased again in 2006 and 2007, reaching 9 and 13 documents, respectively. However, in 2008, the number of publications dropped slightly to 11, followed by an upturn to 18 papers in 2009. In 2010, the number of publications declined to 11 articles, matching the count in 2008. Between 2011 and 2014, the number of articles published fluctuated. In 2011 and 2012, the number of publications amounted to 14 and 20 articles, respectively, either maintaining or increasing compared to the previous year. However, the number of publications in 2013 dipped to 14 articles, the same as the count in 2011. In the following years, 2014 and 2015, the number of publications consistently climbed to 21 and 24 papers, respectively.

The highest number of publications in the last two decades was in 2021, with 28 articles. Meanwhile, the number of articles in 2023 was only 19, lower than in 2021 and 2022. Considering the number of citations, there is a tendency for papers published between 2006 and 2009 to be heavily cited by authors (Fig. 3), ranging from 340 to 696 times, as well as papers published in 2012 and 2014, which have been cited 615 and 500 times, respectively. On the other hand, the number of citations for articles published from 2015 to 2023 tends to decrease, ranging from 17 to 345 times. The top ten documents with the highest number of citations are listed in Table 1. A complete list of 329 articles collected in this study with detailed information, including year of publication, author name, article title, and number of citations, is provided in Additional file 1: Appendix 1.

According to Table 1, the document entitled "Eastern Mediterranean tectonics and tsunami hazard inferred from the AD 365 earthquake" published in 2008, has been cited the most by authors with a total of 197 times and an average of 16.42 citations per year. The content of this article comprehensively discusses the tectonic setting of the eastern Mediterranean concerning the AD 365 earthquake–tsunami event which is recorded as one of the largest earthquake and tsunami events in the Mediterranean throughout history. The article also presents essential information that the possibility of similar earthquakes and tsunamis occurs once every 5000 years for a single fault dislocation in western Crete and once in 800 years if the same process happens along the Hellenic

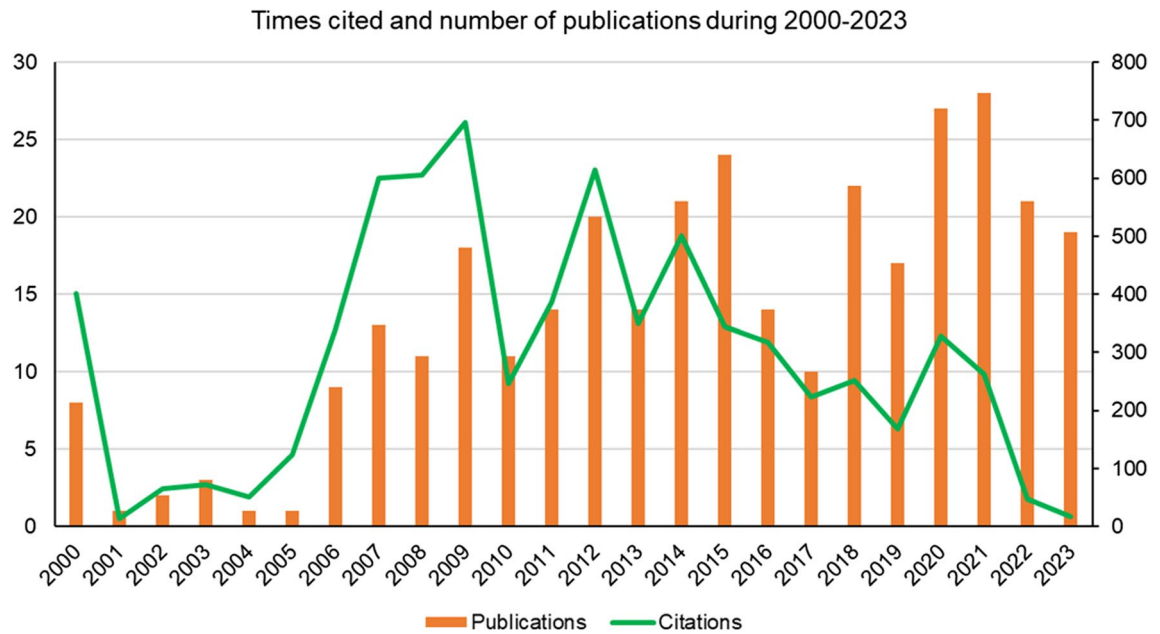

Fig. 3 Number of articles and citations on tsunamis in the Mediterranean Sea from 2000 to 2023: Generally, the number of publications shows significant growth, especially after 2005. However, the number of citations for articles published in the last two decades tends to fluctuate. Articles published in 2009 were cited by the most authors compared to the preceding and subsequent years

Table 1 Top ten articles indexed in the WOS database with the highest number of citations between 2000 and 2023

No	The title of the document	Number of citation	Citation average per year
1	Eastern Mediterranean tectonics and tsunami hazard inferred from the AD 365 earthquake	197	16.42
2	Large boulder deposits by tsunami waves along the Ionian coast of south-eastern Sicily (Italy)	127	10.58
3	Geoarchaeological tsunami deposits at Palaikastro (Crete) and the Late Minoan IA eruption of Santorini	123	10.25
4	The historical earthquakes of Syria: an analysis of large and moderate earthquakes from 1365 BC to 1900 AD	122	10.17
5	Numerical modelling of a landslide-generated Tsunami: The 1979 Nice event	107	8.92
6	Historical and pre-historical tsunamis in the Mediterranean and its connected seas: Geological signatures, generation mechanisms and coastal impacts	106	8.83
7	Active thrusting offshore mount lebanon: Source of the tsunamigenic AD 551 beirut-tripoli earthquake	103	8.58
8	Probabilistic tsunami hazard in the Mediterranean Sea	97	8.08
9	Earthquake-generated tsunamis in the Mediterranean Sea: Scenarios of potential threats to Southern Italy	95	7.91
10	The 1956 earthquake and tsunami in Amorgos, Greece	93	7.75

subduction zone. This article, published in the reputable international journal Nature Geoscience, serves as a reference to explain the precise location of the tsunamigenic source, the fault movement mechanism that caused the AD 365 earthquake, and the recurrence time of tsunami events in the Hellenic subduction zone. Therefore, the number of citations to this article is higher than the other articles, such as "Large boulder deposits by tsunami waves along the Ionian coast of south-eastern Sicily (Italy)" and "Geoarchaeological tsunami deposits at Palaikastro (Crete) and the Late Minoan IA eruption of Santorini" which are ranked second and third with only 127 and 123 citations respectively. The last two articles have fewer scope and implications than the first-ranked articles. For instance, the second-ranked article discusses the occurrence of calcareous boulders that might have been transported by tsunami waves in the Ionian Sea that struck the east and southeast coasts of Sicily in 1169, 1693, and 1908. However, the impact of these three tsunamis was smaller than the AD 365 tsunami that affected Greece, Italy, North Africa and Malta (De Martini et al. 2010; Laksono 2023; Scardino et al. 2021).

Author

Table 2 shows that the author with the highest number of publications from 2000 to 2023 is Andreas Vött, with 17 publications, 338 citations, and an average of 19.9 citations per article. This author has a strong research collaboration network with Hanna Hadler.. Both of them are affiliated with the same institution, Johannes Gutenberg-Universität Mainz, Germany. Taking into account their connectedness in terms of number of citations and co-authorship in scientific publications, Andreas Vött's total link strength is 139, which is fewer than Stefano Lorito's 224 (Table 2 and Fig. 4). Although the number of publications of Stefano Lorito and Fabrizio Romano is smaller than Andreas Vött, the total citations of their articles are more than Andreas Vött. This is directly proportional to the total link strength of Stefano Lorito and Fabrizio Romano, which is significantly higher than Andreas Vött.

Table 2 Top 10 authors by the number of publications and citations indexed in the WOS database between 2000–2023

Author	TP	TC	AC	CCO	TLS
Vött	17	338	19.9	Hadler, H	139
Lorito	15	519	34.6	Romano, F	224
Romano	14	410	29.3	Basili, R	225
Tinti	14	284	20.3	Sepic, J	85
Tonini	12	310	25.9	Romano, F	210
Amato	11	176	16	Lorito, S	202
Selva	11	372	33.9	Tonini, R	195
Basili	11	419	38.1	Romano, F	179
Piatanesi	11	408	37.1	Lorito, S	131
González	11	290	26.4	Canals, M	115

TP: total of publications, TC: total of citations, AC: average citation per article, CCO: closest collaborating object, TLS: total link strength

In the period from 2000 to 2010, the four authors with the highest number of publications were Helene Hébert from Sorbonne Université, France, Gerassimos Papadopoulos from Hellenic Mediterranean University, Greece, Andreas Vött from Johannes Gutenberg-Universität Mainz, Germany, and Efim Pelinovsky from the Russian Academy of Sciences. Helene Hébert and Gerassimos Papadopoulos had an equal number of publications, which was 54 documents. During this period, Stefano Lorito and Fabrizio Romano were not among the top three authors with the highest number of publications, and their names did not even make it to the top

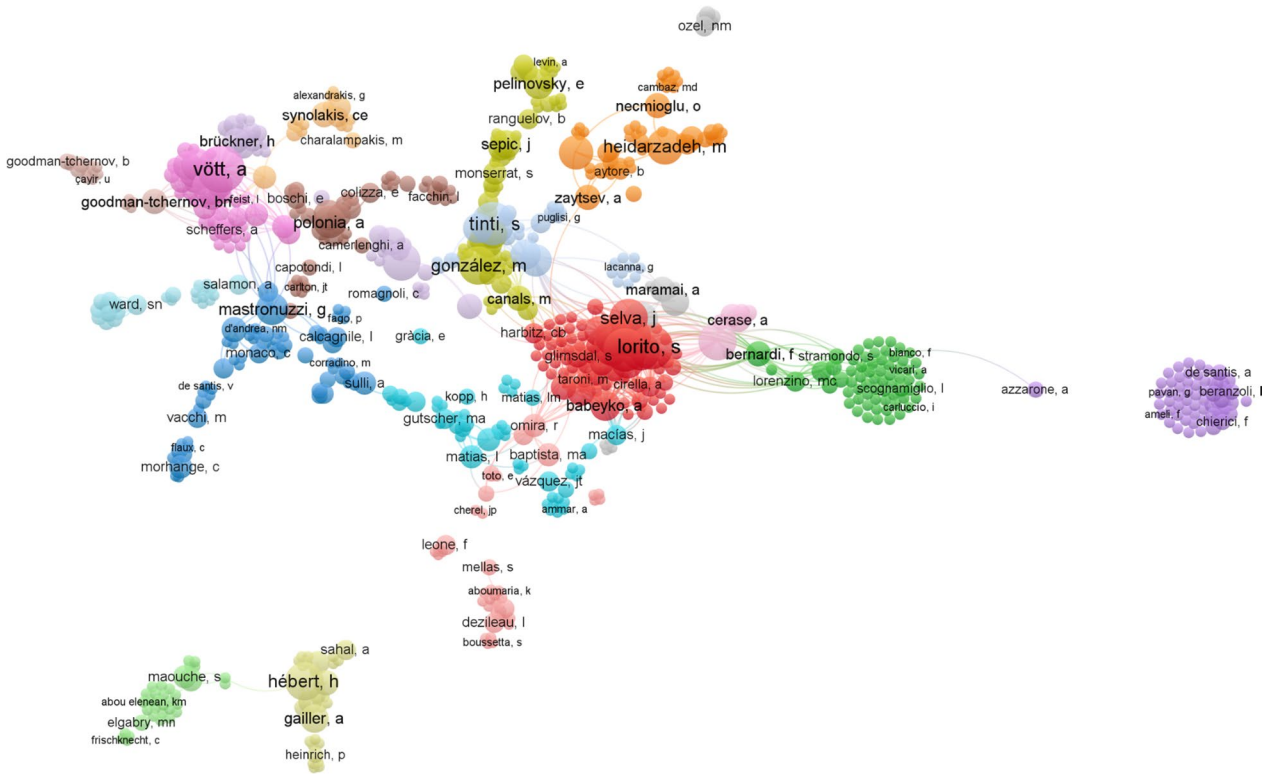

Fig. 4 Author occurrence and collaboration among authors in the Mediterranean tsunami research

10. When comparing the lists of the top 10 authors in the periods 2000–2010 (Table 3), 2011–2023 (Table 4), and 2000–2023 (Table 2), it is revealed that almost none of the authors who made it to the top 10 in the 2000–2010 period were included in the top 10 authors with the highest number of publications in the 2011–2023 or 2000–2023 periods, except for Andreas Vött, from Johannes Gutenberg-Universität Mainz, Germany, who ranked 3rd in the 2000–2023 timespan. However, the top 10 authors in the 2011–2023 period were almost entirely part of the top 10 authors in the 2000–2023 period, except for Hanna Hadler from Johannes Gutenberg-Universität Mainz, Germany, whose position was replaced by Alessio Piatanesi from the INGV, Italy. This notable change in rankings is evident due to the significant difference in the number of publications between the 2011–2023 period, with 245 documents, and the 2000–2010 period, with only 84 papers.

Based on co-citation, the authors who are most frequently cited in conjunction with other scholarly

Table 3 List of top 10 authors with the most number of publications between 2000–2010. TP: total of publications

Author	TP	Affiliation	Country
Hébert	5	Sorbonne Université	France
Papadopoulos	5	Hellenic Mediterranean University	Greece
Vött	4	Johannes Gutenberg-Universität Mainz	Germany
Pelinovsky	4	Russian Academy of Sciences	Russia
Fokaefs	4	Harokopio University Athens	Greece
Brückner	3	Philipps Universität Marburg	Germany
Herd	3	Brandenburgische Technische Universität Cottbus	Germany
Lang	3	Technische Universität Darmstadt	Germany
Brockmüller	3	Philipps-Universität Marburg	Germany
Olabarrieta	3	Universidad de Cantabria	Spain

Table 4 List of 10 authors with the highest number of publications in the period 2011–2023. TP: total of publications

Author	TP	Affiliation	Country
Romano	15	Istituto Nazionale di Geofisica e Vulcanologia (INGV)	Italy
Lorito	13	Istituto Nazionale di Geofisica e Vulcanologia (INGV)	Italy
Vött	12	Johannes Gutenberg-Universität Mainz	Germany
Tonini	11	Istituto Nazionale di Geofisica e Vulcanologia (INGV)	Italy
Tinti	10	University of Bologna	Italy
Amato	10	Istituto Nazionale di Geofisica e Vulcanologia (INGV)	Italy
Selva	10	Istituto Nazionale di Geofisica e Vulcanologia (INGV)	Italy
Hadler	10	Institute of Geography, Johannes Gutenberg-Universit€at Mainz	Germany
Volpe	9	Istituto Nazionale di Geofisica e Vulcanologia	Italy
Basili	9	Istituto Nazionale di Geofisica e Vulcanologia	Italy

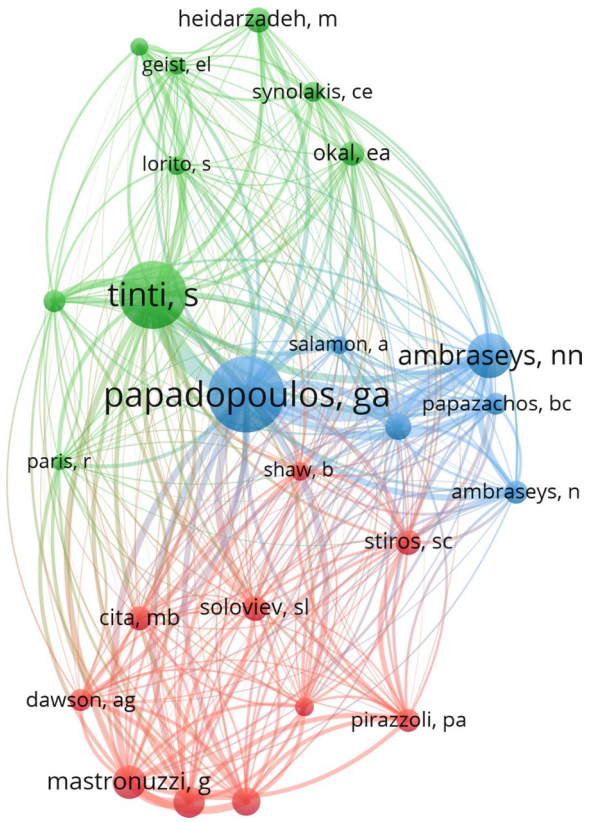

Fig. 5 Total link strength based on co-citation author. Papadopoulos, G.A. occupies the top position in this list which is indicated by the larger circle size compared to others

literature are Papadopoulos, G.A. from Greece, Tinti, S. from Italy, and Nicholas Ambraseys from the UK, with citation counts of 323, 284, and 181, respectively (Fig. 5). Meanwhile, the total link strength for these three authors in sequential order is 26,981, 25,471, and 18,681. Additionally, among the top ten authors are Giuseppe Mastronuzzi from Italy, Andreas Vött from Germany, Emanuela Guidoboni from Italy, Alessandra Maramai from Italy, Finn Løvholt from Norway, Anja Scheffers from Australia, and Emile Okal from France.

Institution

Based on Fig. 6, the most significant contribution to tsunami research in the Mediterranean Sea comes from the Istituto Nazionale di Geofisica e Vulcanologia (INGV) in Italy, with a total of 36 publications and has been cited by 1083 other articles (Table 5). The second-ranking institution is the University of Bologna, Italy, with 27 publications and 549 citations. Meanwhile, the Technical University of Crete ranks below the University of Bologna with 10 publications and 369 citations. Other institutions such as the Consiglio Nazionale Delle Ricerche (CNR), University of Cantabria, University of Lisbon, Russian Academy of Sciences, GFZ German Research Centre for Geosciences, and Ben Gurion University of the Negev are in the subsequent rankings with a number of publications between 5 and 15 articles and total citations range from 188 to 353. Based on the total link strength, INGV has the strongest research collaboration network compared to the others. The INGV research collaboration network comprises CNR, University of Bologna, University of Calabria, University of Granada, University of Malta, University of Palermo, University of Trieste, University of Zagreb, University of Catania, University of Patras, University of Bari, and University of Salento. These research collaborations involve multiple countries, including Italy, Spain, Malta, Greece and Croatia. Table 5 indicates that publications affiliated with institutions in Italy have the highest number of citations compared to other countries. Those institutions are INGV and the University of Bologna.

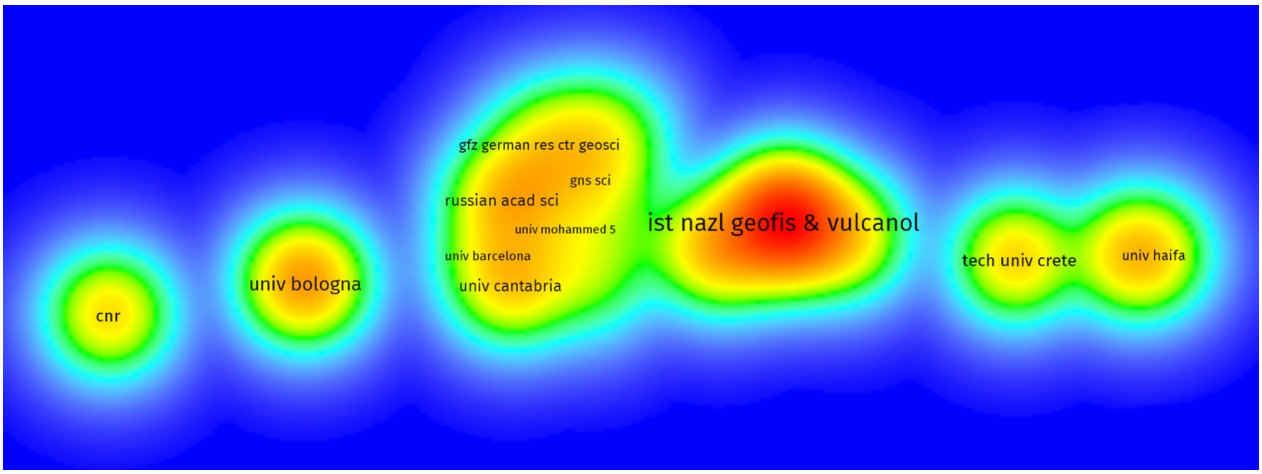

Fig. 6 Organizations involved in the Mediterranean Sea tsunami research and inter-institutional research cooperation density

Countries or regions

The top ten countries that have published the most articles on Mediterranean Sea tsunamis during the period from 2000 to 2023 are presented in Fig. 7. Italy and France are the countries with the highest number of publications, followed by Spain, Greece, Germany, the United States, Turkey, England, Russia, and Japan. Although Germany has fewer publications and citations compared to France, the total link strength for both countries is the same. This indicates that both countries have equally strong research collaboration networks. Most countries in the top ten rankings are located around the Mediterranean Sea and considered developed nations. Meanwhile, Italy, with the highest number of publications, citations, and the most substantial total link strength, has a close research network with all Mediterranean countries such as Algeria, Croatia, Spain, France, Greece, Turkey, Tunisia, Morocco, and Portugal (Fig. 8). Additionally, Italy also collaborates with several developed countries in Europe, Australia, Asia, and the Americas, including the USA, Israel, Germany, Japan, New Zealand, Australia, Belgium, Switzerland, the Netherlands, Norway, and Canada. In terms of average citations per article, Greeceranks highest with a score of 32, followed by the US and France with average scores of 29 and 28, respectively. On the other hand, Italy has an average citation score of only 23, below Germany, which reaches 25.

Table 5 Top ten organizations with the highest number of citations during 2000–2023. TP: total of publications, TC: total of citations, TLS: total link strength

Organization	TP	TC	TLS
INGV	36	1083	41
University of Bologna	27	549	36
National Observation Athens	10	443	4
Technical University of Crete	10	369	4
CNR	15	353	6
University of Cantabria	12	321	26
University of Lisbon	10	321	22
Russian Academy of Sciences	15	309	22
GFZ German Research Centre for Geosciences	5	188	25
Ben Gurion University of the Negev	5	188	7

Journals

The journal that contributed the most to tsunami publications in the Mediterranean Sea is Natural Hazards and Earth System Sciences and Pure and Applied Geophysics with a total of 32 and 24 articles, respectfully, followed by Natural Hazards with 21 articles, Marine Geology with 18 papers, and Geophysical Journal International with 16 articles (Fig. 9). Meanwhile, in the aspect of total citations, Natural Hazards and Earth System Sciences and Marine Geology occupy the first and second highest positions with 748 and 640 citations respectively. In the next position, the journals with the highest number of citations are Pure and Applied Geophysics, Geophysical Journal International, Natural Hazards, Journal of Geophysical Research-Solid Earth, and Geophysical Research Letters, consecutively. Based on total link strength, Natural Hazards and Earth System Sciences and Pure and Applied Geophysics rank first and second, followed by Marine Geology and Geophysical Journal International. Journals affiliated with major publishers such as Elsevier, Springer, and Wiley dominate the publication and citation ranking list compared to journals affiliated with educational and research institutions. Only Natural Hazards and Earth System Sciences and Geophysical Journal International, affiliated with the European Geosciences

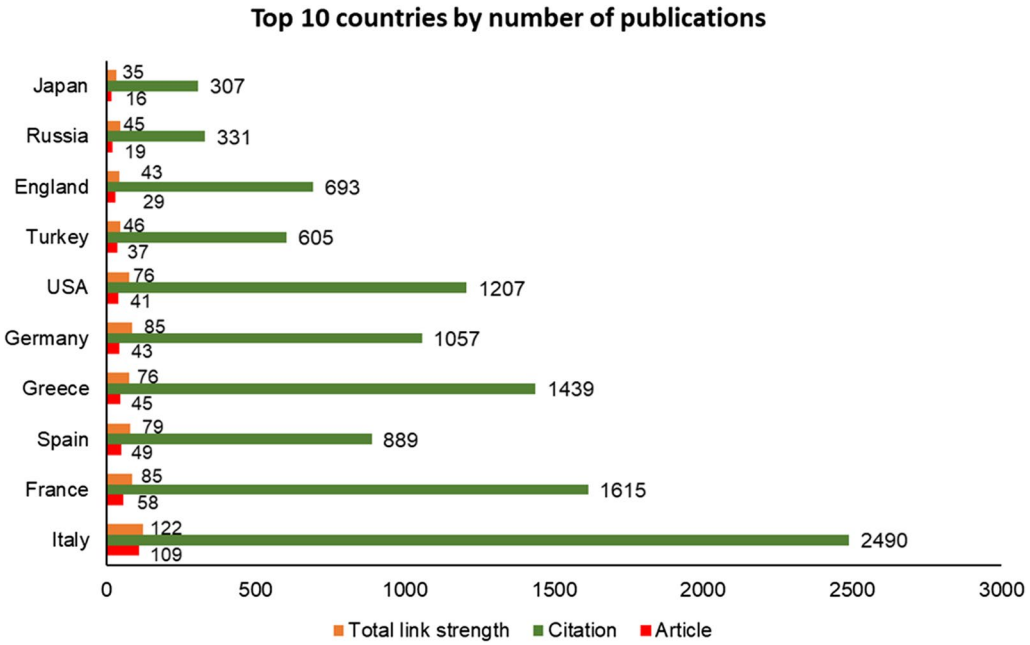

Fig. 7 The top ten countries with the highest number of publications and citations in tsunami research in the Mediterranean Sea

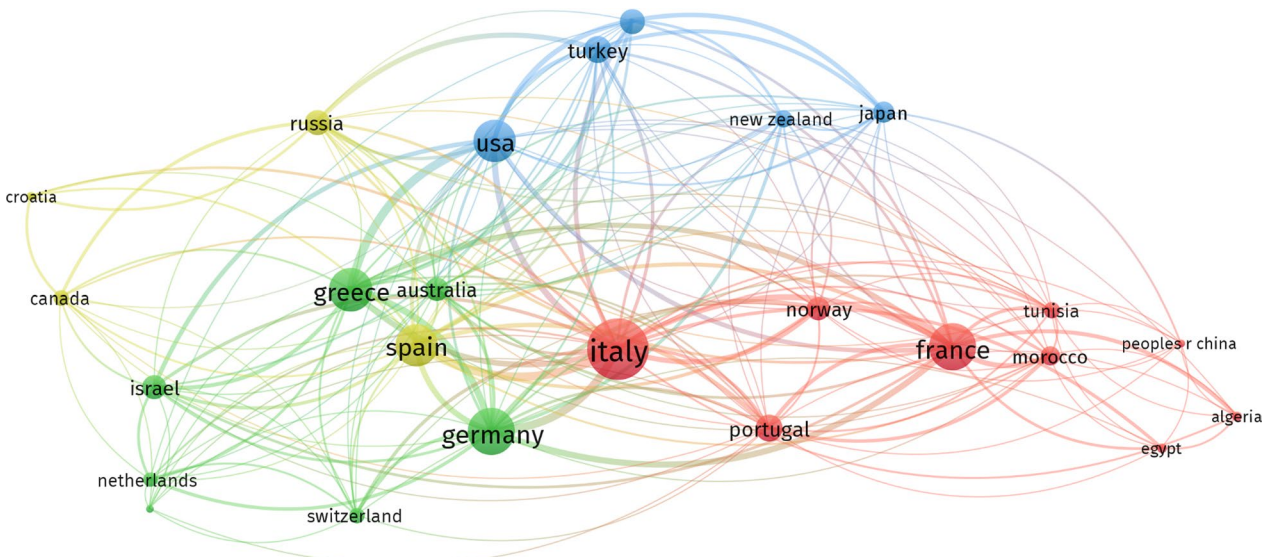

Fig. 8 Tsunami research collaborations in the Mediterranean Sea conducted by different countries. Italy has the strongest research collaboration network compared to other countries

Union and Oxford University respectively, are able to top the list for a number of publications (Table 6).

Based on total co-citations (Fig. 10), the Marine Geology journal is ranked first with 1115 co-citations and 92,827 total link strength. The difference in the number of co-citations and total link strength is very significant compared to Natural Hazard and Earth System Sciences and Tectonophysics which are ranked second and third on the list. Meanwhile, the fourth and fifth rankings are filled by the Geophysical Journal International and Pure and Applied Geophysics with a total co-citation of 57,197 and 51,829. The Pure and Applied Geophysics journal, which is ranked third in total citations, is ranked 5th in the list of co-citation rankings. In Fig. 10, it could be

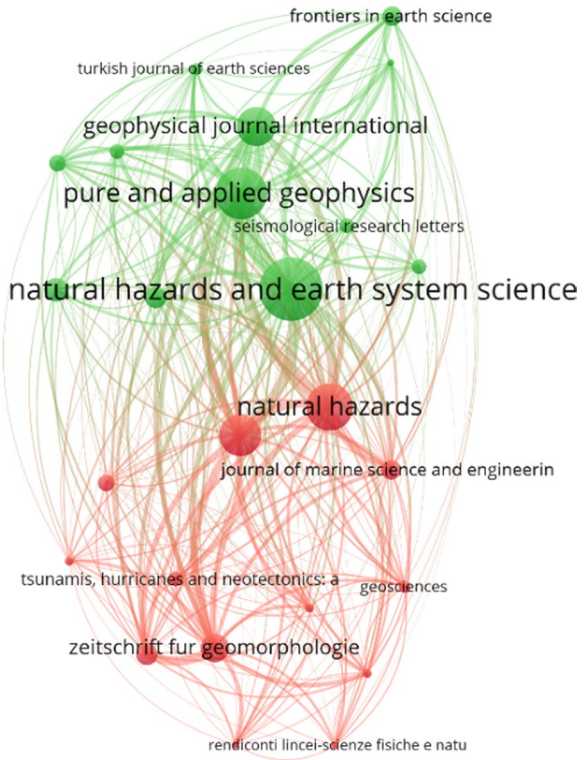

Fig. 9 Network visualization of journals that have the highest number of publications. The size of the circles reflects the number of publications, with the size of the circles increasing as the number of publications grows

Table 6 Number of documents, citations, and co-citations of journals associated with the topic of tsunamis in the Mediterranean Sea

Source	TP	TC	TCC
Natural Hazards and Earth System Sciences	32	748	697
Pure and Applied Geophysics	24	576	567
Natural Hazards	21	303	590
Marine Geology	18	640	1115
Geophysical Journal International	16	526	589
Zeitschrift fur Geomorphologie	10	150	198
Geophysical Research Letters	8	203	513
Quaternary International	7	141	240
Scientific Reports	7	152	105
Frontiers in Earth Science	6	90	79
Journal of Marine Science and Engineering	6	30	34
Tectonophysics	5	189	591
Sedimentary Geology	5	184	356
Journal of African Earth Sciences	6	46	27
Journal of Geophysical Research-Solid Earth	4	220	502

TP: total of publications, TC: total of citations, TCC: total of co-citations

identified that journals with more co-citations have a larger circle size.

Foundation programs

Publication data from 2000 to 2023 reveals that tsunami research funding programs in the Mediterranean Sea predominantly derive from the European Union (EU) with a total of 57 publications, the Spanish government 21, and the German Research Foundation 20 articles, Ministry of Education, University and Research 18 documents, and Agence Nationale De La Recherche 17 papers (Table 7). The majority of funding originated from developed countries in Europe and the European Union.

Keywords occurrences

The most frequently occurring keywords for the entire 2000–2023 period are tsunami (Fig. 11), tsunami, earthquake, hazard, wave, Mediterranean, coast, tectonic, deposit, deformation, and model. The exact keywords also commonly appear in the keywords written by authors to describe the content of their articles. Other keywords such as Greece, Ionian, Aegean, evolution, Algeria, subduction, sediment, Hellenic, seismic, Santorini, and fault, were also used by authors although with lower occurrence. These keywords are commonly combined with other words to form a phrase that represents the content of the article, such as tsunami hazard, tsunami catalogue, tsunami deposits, tsunami generation, tsunami modeling, tsunami potential, 1755 Lisbon tsunami, 1856 tsunami, AD 365 tsunami, arrival time of tsunami, and geoarcheological tsunami deposits. The exact keyword occurrence was also observed in the periods 2000–2010 and 2011–2023 (Fig. 12) where the words tsunami, earthquake, deposit, and hazard were most prevalent to describe tsunami research in the Mediterranean Sea. However, between 2000 and 2010, there was no vulnerability keyword, even though this keyword appeared in 10 articles published between 2011 and 2023. The complete list of keywords from 2000 to 2023 is in Additional file 1: Appendix 1.

The selection of keywords tends to be more varied in documents published between 2011–2023 such as extreme wave events, p-wave moment magnitude, probabilistic tsunami hazard assessment, proudman resonance, near-field tsunami, numerical modelling of tsunami propagation, numerical tsunami simulation, olympia tsunami hypothesis, microfaunal analysis, maximum inundation height, tsunami vulnerability class, tsunami zoning, tyrrhenian margin, tsunamigenesis, tsunami traveltime delay, tsunami warning and hazard mitigation, tsunami scenario study, tsunami hydrodynamics and modelling, tsunami fragility functions, tsunami hazard mapping, tsunami loss assessment, tsunami early

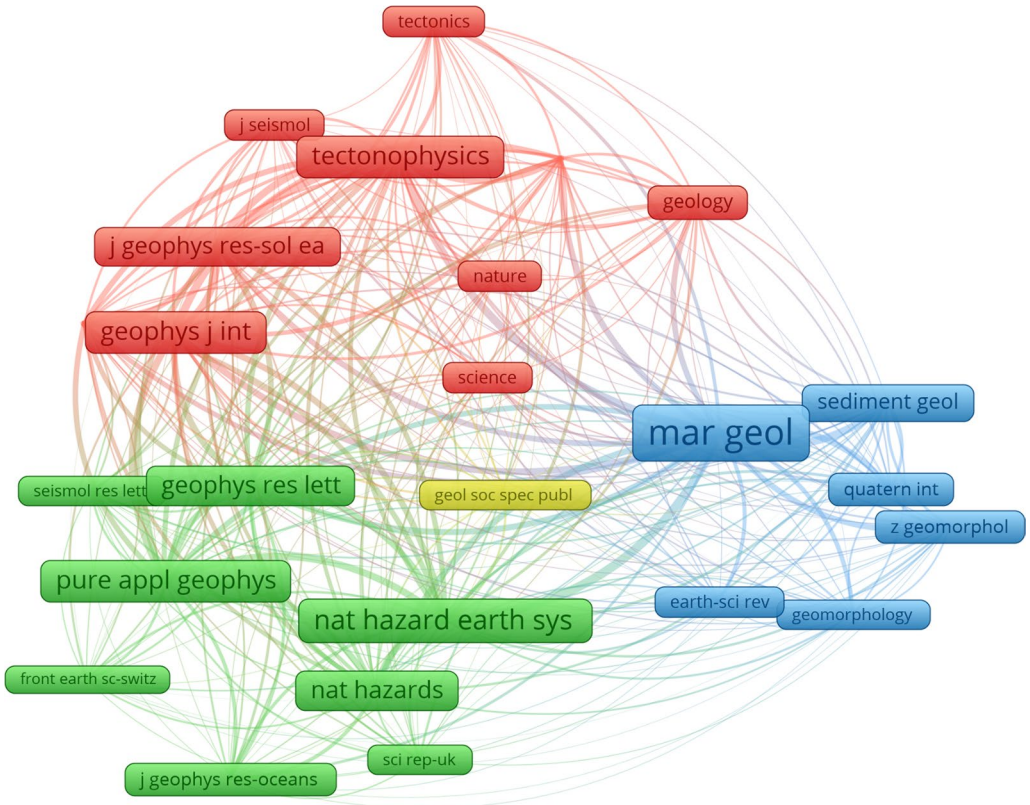

Fig. 10 The Marine Geology journal has more total co-citations than other journals, even the difference with the second-ranked Natural Hazard and Earth System Sciences journal is very substantial

Table 7 Top-ranked list of funding sources for tsunami research and publications in the Mediterranean Sea. TP: Total of publications

Source	TP
European Union	57
Spanish Government	21
German Research Foundation	20
Ministry of Education, University and Research of Italy	18
Agence Nationale De La Recherche	17
European Commission Joint Research Centre	17
National Science Foundation	17

detection, tsunami evacuation, tsunami early warning systems, triangular dislocation, seismic-probabilistic tsunami hazard assessment, coastal flooding, and samos 2020 earthquake and tsunami. Figure 13, which illustrates the connection among the keywords, reveals that there are several relationships between keywords that are weak or even not connected at all. For instance, the correlation between probabilistic tsunami building vulnerability assessment-4 (PTVA-4) and tsunamigenic and seismogenic potential in the Mediterranean and connected sea, paleotsunami deposits and tsunami potential in southern Sicily, numerical simulations with paleotsunami deposits in Lebanon, tsunami run-up and coastal flooding in Libya with the 365 AD tsunami event, probabilistic tsunami hazard assessment on the north coast of Libya with tsunamigenic potential in the eastern Mediterranean, and the relationship between tsunami wave amplification in the Mediterranean and lunar gravity.

Thematic evolution and research topic

To explore the most prominent themes in tsunami research in the Mediterranean and connected sea, the research period was divided into two periods, 2000–2010 and 2011–2023. In the thematic map (strategic diagram), the size of the circle is proportional to the number of articles related to each research theme. According to the strategic diagram for the period 2000–2010 in Fig. 14A, four research themes can be identified in 84 articles: tsunami, seiches, seismic hazard and Betic-Cordillera. Two of the four themes are considered motor themes (tsunami and seiches), one is highly developed and isolated (seismic hazard), and one is classified as basic (Betic-Cordillera).

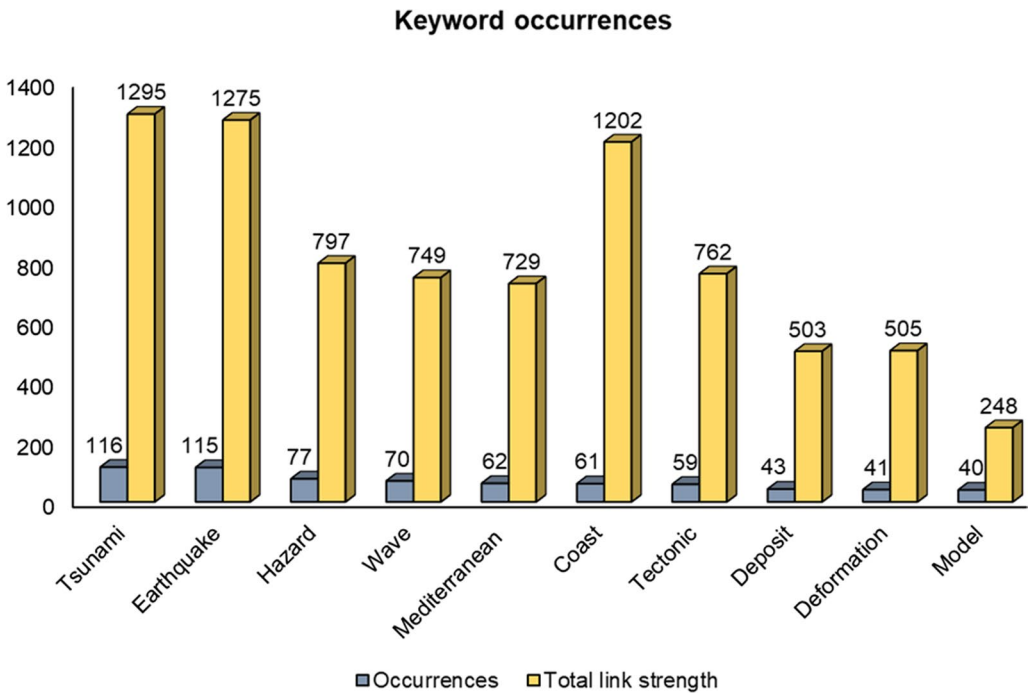

Fig. 11 Keyword occurrences and total link strength related to tsunamis in the Mediterranean Sea in 2000–2023. Tsunami, earthquake, and hazard are the keywords most frequently mentioned by authors

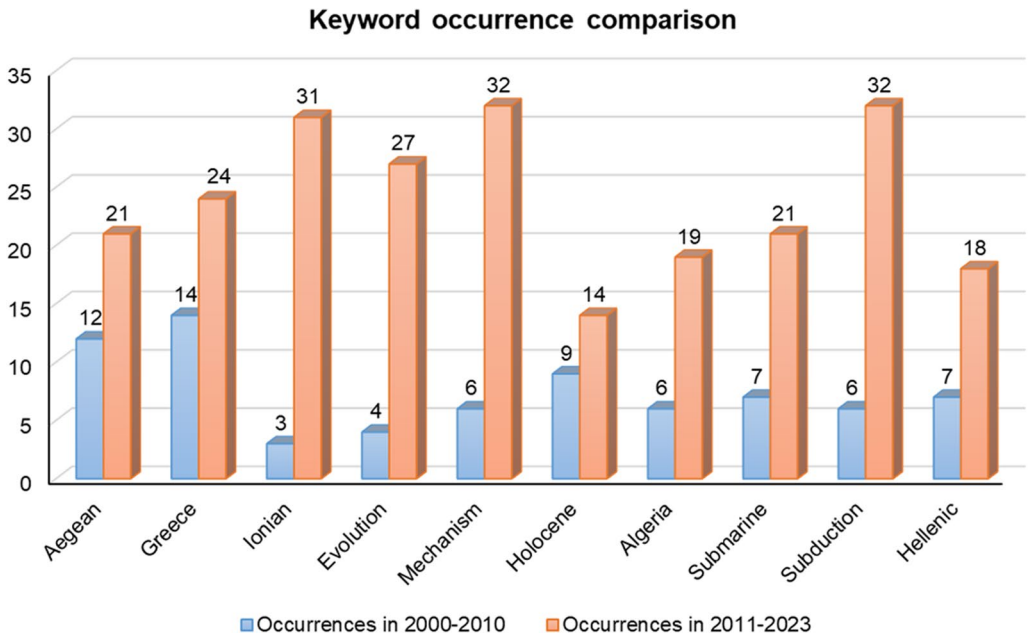

Fig. 12 Comparison of the number of keyword occurrences between 2000–2010 and 2011–2023

The motor tsunami theme gained the highest citations because it is related to the general topic of tsunamis in the Mediterranean and has close relevance to other themes such as earthquake, submarine landslides, coastal flooding and volcano eruption. The tsunami cluster network for the period 2000–2010 can be seen in Fig. 14B. Topics such as the eastern Mediterranean tsunami of 365 AD (Shaw et al. 2008), large boulder deposits by tsunami

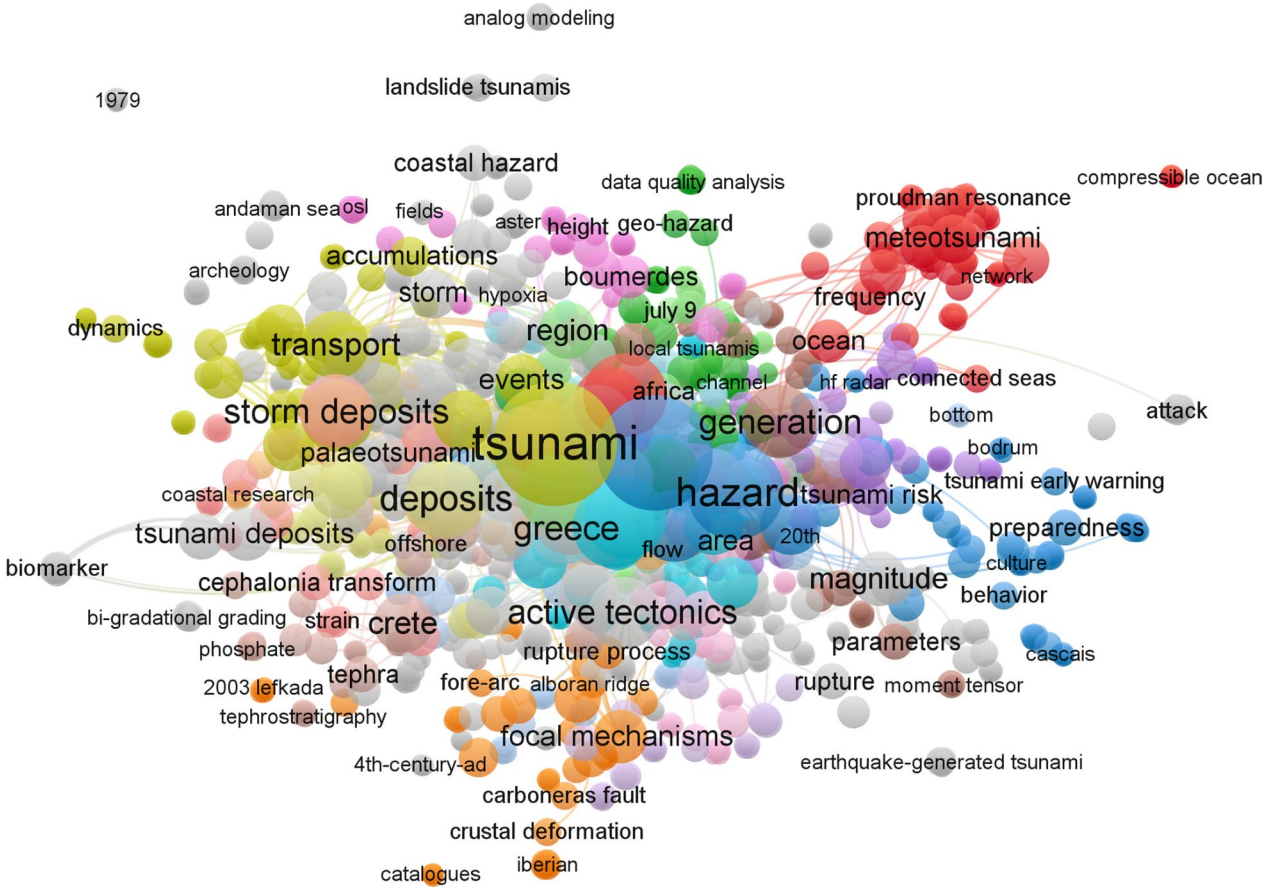

Fig. 13 The connection among keywords that appear in the Mediterranean Sea tsunami publications. The absence of correlation lines between keywords in the figure indicates a research gap that is likely to become a new trend for future research

waves (Scicchitano et al. 2007), geoarchaeological tsunami deposits (Bruins et al. 2008), numerical modelling of a landslide-generated tsunami (Assier-Rzadkiewicz et al. 2000), tsunami catalogs for the Eastern Mediterranean (Ambraseys and Synolakis 2010), the influence of the atmospheric wave velocity in the coastal amplification of meteotsunamis (Marcos et al. 2003) are discussed in this cluster.

The second motor theme is seiches (Fig. 15A) related to tsunami wave propagation mechanisms; for example: tsunami waves generated by the Santorini eruption reached Eastern Mediterranean shores (Goodman-Tchernov et al. 2009), sensitivity analysis on relations between earthquake source rupture parameters and far-field tsunami waves: case studies in the Eastern Mediterranean region, and modeling and visualization of tsunamis: Mediterranean examples (Yalciner et al. 2007). Seismic-hazard (Fig. 15B) is a highly developed but isolated theme or topic that is at a reasonable level in terms of density but are not very central and considered marginal (Mishra et al. 2023), e.g., the study of tsunami deposits in eastern Sicily, Italy (De Martini et al. 2010), tsunami deposits on the coastline of west Crete (Greece) (Scheffers and Scheffers 2007), and the Minoan Santorini eruption and tsunami deposits in Palaikastro (Crete): dating by geology, archaeology, 14C, and Egyptian chronology (Bruins et al. 2009). Meanwhile, Betic-Cordillera is classified as a basic and cross-determinant theme that has central issues but lacks density. This theme consists of only one publication and has been cited 28 times.

Motor themes in the period 2011–2023 comprised tsunamis and seismic hazards (Fig. 16A, B), e.g. publications on the topics of historical and pre-historic tsunamis in the Mediterranean and connected seas (Papadopoulos et al. 2014), probabilistic tsunami hazard in the Mediterranean Sea (Sørensen et al. 2012), probabilistic hazard for seismically induced tsunamis (Lorito et al. 2008), Mediterranean megaturbidite triggered by the AD 365 Crete earthquake and tsunami (Polonia et al. 2013), and integrating geologic fault data into tsunami hazard studies (Basili et al. 2013). Meteotsunami and tsunamiite themes are categorized as highly developed but isolated themes,

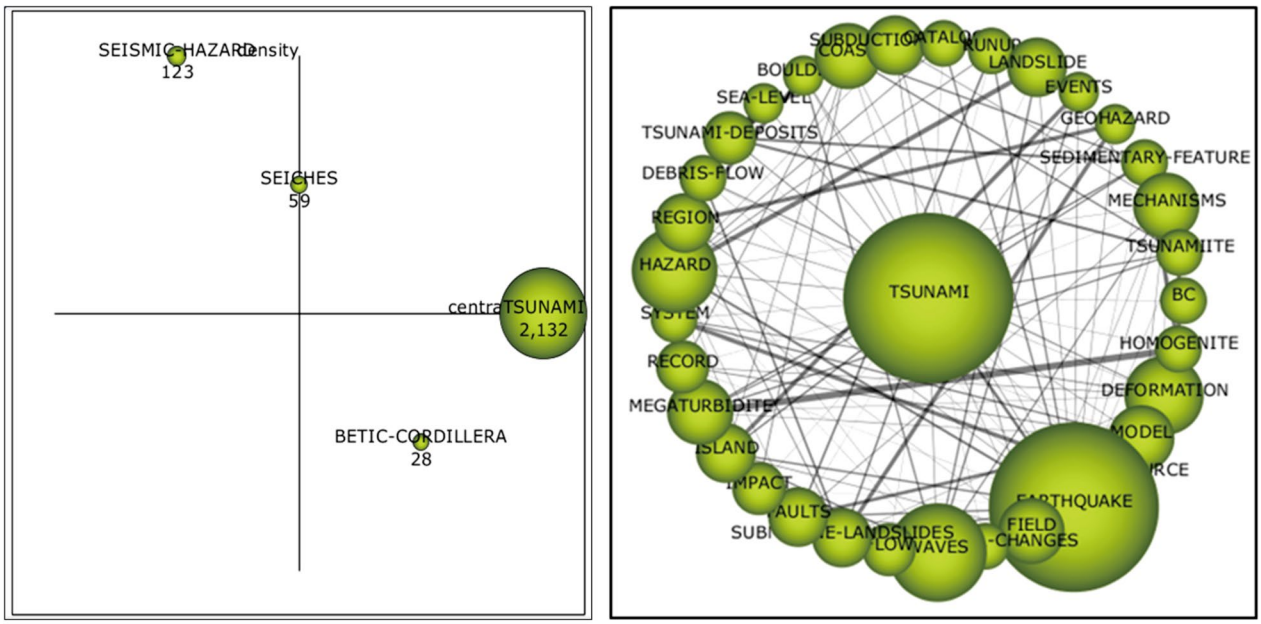

Fig. 14 **A** Thematic map for the period 2000–2010 and **B** tsunami thematic network. The numbers in the figure indicate the number of citations

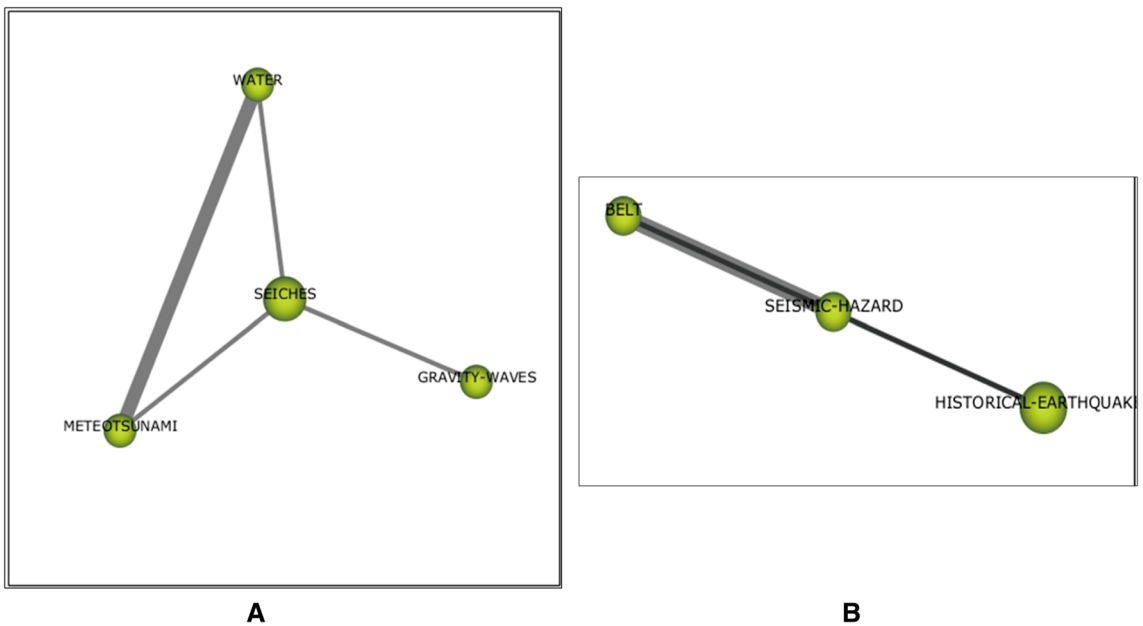

Fig. 15 Thematic network from 2000 to 2010. **A** Seiches thematic network and **B** seismic-hazard thematic network

while climate change themes are classified as emerging or declining themes. Basic and transverse themes encompass megaturbidate and equation applications in tsunami wave studies.

The evolution map consists of two columns; the left column represents the period 2000–2010, and the right column is the period 2011–2023. Based on Fig. 17, the most robust evolutionary lines are tsunamis and the link between seiches and meteotsunamis, which are marked with thick lines, the thickness of which represents the inclusion index. The number of articles related to tsunamis has also increased; this is indicated by the size of

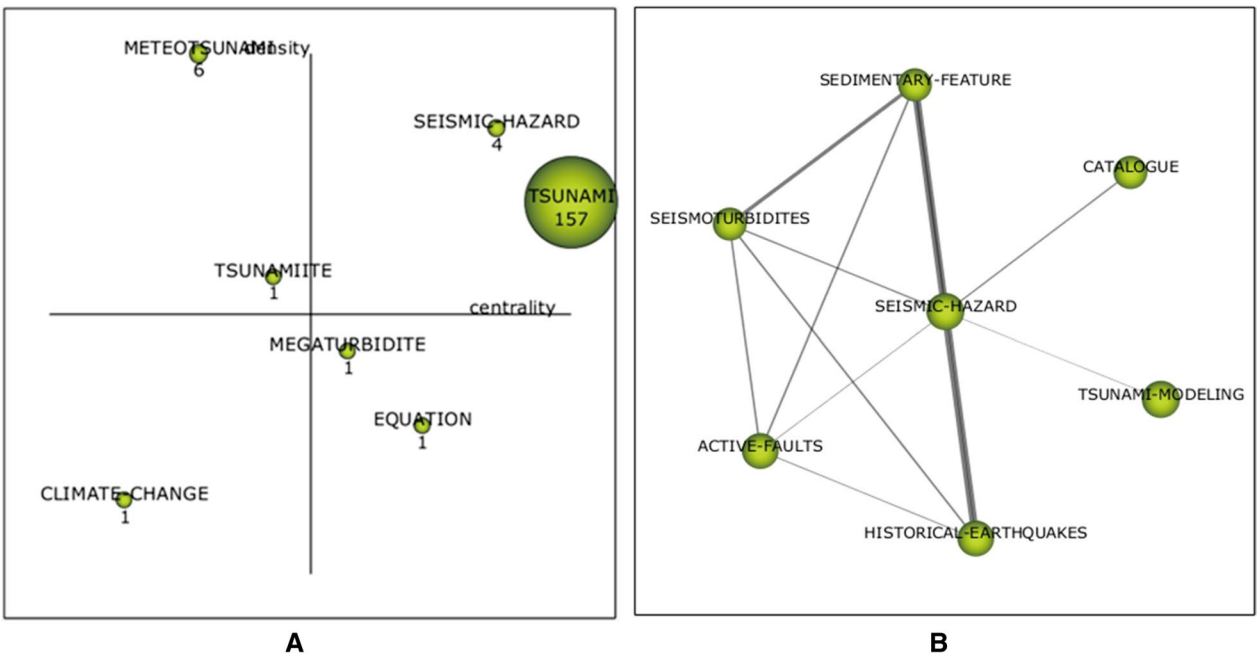

Fig. 16 **A** Thematic map 2011–2023. **B** Thematic network of seismic hazard. The numbers in the strategic diagram represent the number of documents

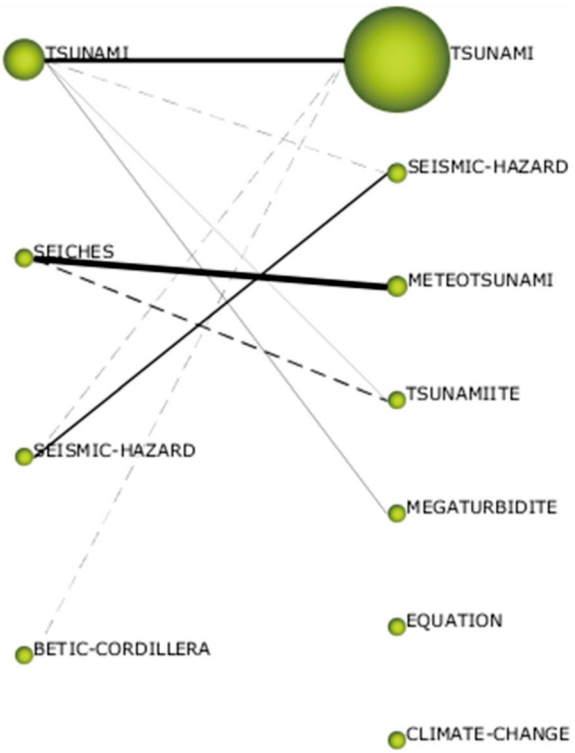

Fig. 17 Evolution map of the tsunami research focused on the Mediterranean and connected sea between 2000–2010 and 2011–2023. The graph has two new themes: climate change and equation

the nodes in 2011–2023, which is more significant than 2000–2010. Tsunami is closely related to seismic hazard, meteotsunami, tsunamiite, and megaturbidite to form a unified concept. Meanwhile, climate change that emerged in the 2011–2023 period is not closely associated with any themes in 2000–2010. It implies that this theme is relatively new. Based on the WoS database, there is only one relevant publication titled climate change risk evaluation of tsunami hazards in the Eastern Mediterranean Sea (Yavuz et al. 2020a).

Discussion

The number of publications related to tsunamis in the Mediterranean Sea increased significantly after 2004 and 2005 from only one article to over ten articles. The same phenomenon also occurred after 2011 when the number of publications reached more than 20 documents. Likely, the publication factor of tsunamis in the Mediterranean Sea was also driven by two major tsunami events in the world at the beginning of the twenty-first century, namely the tragedy of the Indian Ocean tsunami on December 26, 2004, that killed approximately 200,000 people and caused substantial economic losses, especially in Southeast and South Asian countries such as Indonesia, Thailand, Malaysia, India, Sri Lanka, and the Maldives (Ioualalen et al. 2007; Rodriguez et al. 2006; Wang and Liu 2006). The same event also took place in 2011 when a tsunami hit Tohoku, Japan resulting in thousands

of deaths and triggering the leakage of the Fukushima nuclear reactor. The economic losses from this event amounted to millions of dollars. The Fukushima nuclear reactor leak also triggered another tragedy as the waters around the power plant were contaminated with radioactive substances and thousands of residents were forced to evacuate to safer places (Goto et al. 2011; Matanle 2011; Mori et al. 2011).

The existence of these two major tsunami events motivated scientists to conduct research related to the potential for tsunamis in various other parts of the world that are considered to be earthquake and tsunami-prone zones, one of which is the Mediterranean region which indeed has several records of earthquakes and tsunamis in the past. This phenomenon is in line with Chiu and Ho (2007), Jain et al. (2021), and Suprapto et al. (2022), which state that tsunami studies in various parts of the world experienced a sharp increase after the 2004 tsunami tragedy. Although the number of publications each year has increased, the number of citations to articles published after 2012 tended to decrease. This trend might be attributed to the position of a publication theme on the strategic diagram. Suppose a theme has high centrality and density. In that case, it will be highly relevant to other themes, allowing it to develop properly, and the article is more likely to be cited by other articles (Börner et al. 2018; Cahlik 2000).

Although from early 2020 until the end of 2021 the world was affected by Covid-19, which limited outdoor activities, including research, the number of tsunami publications in the Mediterranean Sea did not decline; in fact, it rose significantly compared to 2019 before the Covid-19 pandemic.The possible factor that contributed to the number of publications continuing to increase despite the Covid-19 restrictions was that the data collection needed for research purposes had been carried out before the Covid-19 pandemic began (Miki et al. 2020; Rashid and Yadav 2020; Saraswat and Saraswat 2020). Furthermore, the availability of several tsunami wave analysis software (Delft3D, Delft Dashboard, Flow-3D, COMCOT, and Mike 21) and programming languages such as MATLAB, Python, Fortran, or C++(Franco et al. 2020; Laksono et al. 2020; Scardino et al. 2021; Xu et al. 2022) can serve as supportive tools for publications, especially during the Covid-19 pandemic..

Although tsunami research in the Mediterranean Sea has involved many European, American, Asian, and even Australian countries, developed countries such as Italy, France, Germany, Spain, Greece, the USA, and England tend to produce more publications than developing countries. Stable and large sources of research funding are a factor in the number of publications in developed countries compared to developing countries even though the study locations are further from these developed countries than developing countries around the Mediterranean Sea such as Algeria, Egypt, Tunisia, Morocco, Croatia, Albania, Turkey, and Libya. Moreover, developed countries have relatively more complete research facilities and a stronger and broader collaboration network among researchers from various institutions compared to developing countries (Babeyko et al. 2022; Lorito et al. 2021; Michelini et al. 2016). The number of citations for publications with authors from developed countries such as Italy, Germany, and Greece is much higher than those with authors from developing countries. The complexity and broader scope of the discussion affect the impact factor of the publication. The high impact factor of an article enhances the opportunity for the number of citations because the relevance to case studies and other topics is still reliable (Elkins et al. 2010; Emmer 2018; Finardi 2013). Additionally, articles that have novelty and significant contributions also boost the probability of citations (Neelam and Sood 2021; Sagar et al. 2010).

Basically, the keywords that often appear in publications 2000–2010, 2011–2023, and throughout the 2000–2023 period are similar; for example, the use of the keywords tsunami; Mediterranean; earthquake; hazard; evolution; coast; and deposit (Additional file 1: Appendix 1, Figs. 11, and 12) which always occupy the top position in the ranking list of keywords that are often mentioned by authors. However, there are more alternative keywords in the 2011–2023 publications compared to the 2000–2010 period, such as Lampedusa (Distefano et al. 2022); lagoon; risk mitigation (Necmioglu et al. 2023); risk reduction (Lorito et al. 2021); Russian coast (Nikonov et al. 2018); escarpment (Ventura et al. 2014); epistemic uncertainty (Basili et al. 2013); evacuation modelling (Scheer et al. 2012); experimental validation (Solovieva et al. 2021); fault parameter estimation (Ulutaş 2020); historical database (Larroque et al. 2012); Iberian Peninsula (Álvarez-Gómez et al. 2011); climate change (Yavuz et al. 2020a); semi-analytical modelling (Scala et al. 2020); Tunisia (Khadraoui et al. 2018); Sfax coastline (Kohila et al. 2021); social risk analysis (Yavuz et al. 2020a); Tyrrhenian Sea (Dignan et al. 2020); coastal planning (Lorito et al. 2021); coastal vulnerability (Saleh and Allaert 2014); coastal evolution (May et al. 2012); coastal erosion (Tyuleneva et al. 2018); probabilistic tsunami hazard assessment (Zaytsev et al. 2019); Yammouneh fault (Shtienberg et al. 2020); PTVA-3 model (Batzakis et al. 2020); and PTVA-4 model (Batzakis et al. 2020).

The emergence of new keywords is aligned with the expanding discussion of the topic in terms of research objectives, geographical scope of case studies and methodology, for example the use of the keyword climate change to describe coastal risk analysis research

that integrates the phenomenon of sea level rise due to climate change with the potential for tsunamis triggered by earthquakes in the Eastern Mediterranean Sea (Yavuz et al. 2020a). The occurrence of country keywords such as Tunisia dan Lampedusa (Distefano et al. 2022; Khadraoui et al. 2018) as well as regional names such as Tyrrhenian Sea and Sfax coastline (Dignan et al. 2020; Kohila et al. 2021) reveals that the geographical scope of the case studies has enlarged beyond Greece, Italy, Portugal, Egypt, France, Turkey, Cyprus and Spain, which appear several times as keywords in the list of publications for the period 2000–2010 and 2011–2023 (Altinok et al. 2009; Fokaefs and Papadopoulos 2007; Gerardi et al. 2012; Papadimitriou and Karakostas 2008; Scheffers 2006). The topic of probabilistic tsunami hazard assessment in 2011–2023 has also become more prevalent, with two keywords missing in the previous decade such as PTVA-3 and PTVA-4 (Batzakis et al. 2020).

Research trends in coastal risk analysis, evacuation modeling, tsunami early warning systems and tsunami mitigation are also growing (Khadraoui et al. 2018; Ozel et al. 2011; Necmioğlu et al. 2021; Yavuz et al. 2020a). This indicates that tsunami research not only addresses potential hazards but also how communities around vulnerable areas can minimize the worst impacts of tsunami disasters. In topics related to tsunami mitigation, the keyword social risk analysis also appears, implying that the discussion of tsunami wave propagation is not only related to the extent of inundation distance or the height of the tsunami run-up (Laksono 2023), but also expands to the impact of tsunami waves on the social and economic life of the community (Yavuz et al. 2020b).

Research topics for 2011–2023 also evolved towards risk assessment of infrastructure and building resilience to earthquake and tsunami disasters, characterized by the emergence of the keyword building vulnerability, which previously was not present in the 2000–2010 publications (Batzakis et al. 2020; Triantafyllou et al. 2019). Although the scope of research topics for 2011–2023 has expanded, topics related to rupture fault analysis, paleotsunami sediment analysis, and tsunami wave propagation modeling continue to emerge and develop (Laksono 2023; Nemati et al. 2019; Salama et al. 2018) because these topics are classified as motor themes based on the strategic diagram (Fig. 16A). In the future, topics classified as motor themes such as seismic hazard, which have high centrality and density, will continue to thrive because they are relevant to other topics (Cobo et al. 2012; Mishra et al. 2023) such as seismoturbidite, active-faults, historical earthquakes, tsunami modeling, sedimentary-feature, and catalog (Fig. 16B). This is highlighted by the increasing number of publications as seen in the evolution map Fig. 17.

Conclusions

The number of tsunami publications in the Mediterranean has generally been growing, especially after the 2004 Indian Ocean tsunami, the 2011 Tohoku tsunami and the 2018 Palu tsunami. Despite restrictions on outdoor activities during the Covid-19 pandemic, the number of publications has not declined and even increased to reach 28 articles in 2021. The number of publications in 2021 is the highest in the past two decades. The contribution of European developed countries in the Mediterranean tsunami publications is significantly higher than that of developing countries around the Mediterranean. Journals affiliated with major publishers such as Elsevier, Wiley, and Springer have contributed the highest number of publications and citations compared to other journal publishers.

The themes describing tsunami research in the Mediterranean between 2000 and 2023 can be divided into four types based on centrality and density. The first type is motor themes that are very well developed and important for building research fields such as tsunami simulations, early-warning systems, paleotsunami and seismic hazard. The second type is specific themes that are well developed with other keywords internally but have low relevance with different keywords externally, for instance, meteotsunami, seiches, gravity-waves and tsunamiite. The third type is less developed and relevant themes, representing either emerging or disappearing themes such as climate change. The fourth type is a theme that exhibits high relevance to other keywords beyond its network but lacks evolvement because it consists of general and primary topics such as megaturbidite and equation.

Generally, the most used keywords in the 2000–2010 and 2011–2023 publications are similar, for example tsunami, earthquake, deposit, coast, waves and hazard. However, the keywords in the 2011–2023 publications are more complex, the scope of discussion is more extensive, the geographical distribution of case studies is more widespread, and the research methods used are also more complex, e.g. risk mitigation, climate change, probabilistic tsunami hazard assessment, Yammouneh fault, Tunisia, Lampedusa, coastal erosion, coastal planning, semi-analytical modeling, fault parameter estimation, historical database, social risk analysis, Tyrrhenian Sea, coastal evolution, building vulnerability, PTVA-3 and PTVA-4. Research topics for 2011–2023 are more diverse compared to 2000–2010, as the focus is not only on potential hazard assessment but also on disaster mitigation, building and infrastructure resilience analysis, and the impact of coastal tsunami wave propagation on the social and economic life of communities. Nonetheless, topics concerning tsunami deposits, tsunami propagation simulation, and earthquake–tsunami potential in

the Mediterranean and connected sea remain thriving as indicated by the increasing number of publications compared to previous decades.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s40677-024-00269-6.

Additional file 1. A comprehensive list of scientific articles related to Mediterranean tsunamis indexed in Web of Science, which were utilized in the scientometric study of tsunamis in the Mediterranean.

Acknowledgements
The authors would like to thank ÚNKP for providing a research grant for tsunami research in the Mediterranean Sea under research grant number ÚNKP-23-3-II-PTE-1849. We also thank the University of Pécs for funding the publication of this article. The authors thank Polina Bochkareva for encouraging the first author to complete this article.

Author contributions
ATFX: conceptualization, data collection, data analysis, and article writing, MM: data analysis and wrote the article, MB, KJ: reviewing and editing of manuscript. All authors have read and approved the final manuscript.

Funding
Open access funding provided by University of Pécs. This research was fully funded by ÚNKP with research grant number ÚNKP-23-3-II-PTE-1849. Publication costs will be covered by the University of Pécs, Hungary.

Availability of data and materials
Data and materials are available upon request.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare no conflicting interests with this article.

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Received: 26 October 2023 Accepted: 26 January 2024
Published online: 10 February 2024

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