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RESEARCH PROFILE OF CLIMATE CHANGE AND TSUNAMI MITIGATION: EFFORTS TO REALIZE SDGS 11 AND 13

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ABSTRACT

Both tsunamis and climate change have a significant impact in many aspects. Therefore, it is necessary to conduct research through scientific publications on the most effective mitigation efforts to reduce these impacts. This study's objectives are to analyze the research profile of climate change and tsunami mitigation using bibliometric analysis. A total of 1750 climate change mitigation documents and 139 tsunami mitigation documents were analyzed. The study results show that the publication of climate change mitigation has increased rapidly in the last decade exponentially, while the publication of tsunami mitigation tends to stagnate. Furthermore, research trends in climate change mitigation, namely emission control, environmental policy, and carbon sequestration, are the most researched mitigation efforts. Meanwhile, the leading causes of climate change are greenhouse gases and carbon dioxide. On the other hand, the trend of tsunami mitigation research is more towards disaster management and mitigation, the causes of tsunamis by earthquakes, and coastal area mitigation objects. The research profile on climate change mitigation follows the 13th goal of the SDGs, namely climate action, while tsunami mitigation follows the 11th goal of the SDGs.

Keywords: *Climate Change, Tsunami, Mitigation*

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1. INTRODUCTION

The United Nations has initiated the Sustainable Development Goals (SDGs), a global commitment that includes 17 goals. The development commitment focuses on human development and pays attention to aspects of urban development, society, and the environment (Parnell, 2016). This is stated in the 11th goal (Sustainable Cities and Communities), which mainly focuses on building inclusive, safe, durable, and sustainable cities and settlements. In addition, the 13th goal (Climate Action) also focuses on tackling climate change by taking swift action to deal with climate change and its impacts. There are many ways to realize these two goals, one of which is through efforts to mitigate and reduce the risks of tsunamis and climate change. Therefore, a tsunami mitigation system with a particular focus on community awareness and preparedness to respond is very relevant to the 11th goal of SDGs (Kumar & Manneela, 2021). Meanwhile, climate change mitigation is the primary goal of the 13 SDGs, namely combating climate change (Doni et al., 2020).

A tsunami is a large wave with a speed of up to 900 km/h caused by disturbances on the seabed, such as earthquakes (Guler et al., 2018; Kumaat et al., 2018; Satake et al., 2020). Tsunamis may have significant repercussions on crucial infrastructure, direct and indirect societal losses, necessary supply lines, criminality, increased unemployment, and mental health concerns if preparation is not handled effectively (Himaz, 2022). In general, one of the reasons the tsunami was so devastating was that the tsunami warning system was still inadequate at the time, unable to issue advisories or warnings to communities, particularly in rural areas (Suprapto et al., 2022). One of the most famous tsunami phenomena is the tsunami in the Indian Ocean on December 26, 2004, which hit off the west coast of Sumatra (Aceh), causing the deaths of up to 150,000 people (Satyarno, 2013).

Climate change refers to long-term temperature and weather changes that can seriously affect the planet (Fu & Waltman, 2022). For example, extreme weather events such as heavy rains and heat waves are caused by climate change, and floods are becoming more common due to global warming (Taylor et al., 2014). In addition, environmental factors such as rising temperatures and greenhouse gas levels impact plant growth and wildlife, posing a growing threat to plant resources, biodiversity, and global food security (Chakraborty & Newton, 2011). Thus, the issue of climate change is critical and urgent today because it has a massive and global impact.

Based on the impacts caused by both tsunamis and climate change, it is necessary to conduct research through scientific publications on the most effective mitigation efforts to reduce these impacts. Scientific publications provide essential insight into how the scientific community responds to climate change and tsunamis because they reflect the priorities set by governments that support climate change and tsunami research as well as the study areas that scientists choose to focus on (Fu & Waltman, 2022). However, the rapidly increasing number of climate change and tsunami publications makes it difficult for this field researchers to keep an up-to-date overview of the literature (Rodrigues et al., 2014). Bibliometrics is a powerful method for quantitatively analyzing the development of scientific literature in a research field, and it has been widely used in many global studies (Kokol et al., 2021; Oliveira, 2019; Suprapto et al., 2022).

Therefore, this study will conduct a bibliometric analysis to determine the research profile on climate change mitigation and tsunamis. This research also discusses the wedges or relationships between climate change and tsunamis. The contribution of this research will provide information to researchers and policymakers on climate change and tsunamis

regarding appropriate mitigation efforts to realize SDGs 11 and 13. The specific objectives of this study are as follows:

1. Analyzing the number of publications by year on climate change mitigation and tsunamis.
2. Analyzing the most productive countries and affiliations of climate change and tsunami mitigation publications.
3. Analyzing researcher profiles and source titles of climate change and tsunami mitigation publications.
4. Identifying the keywords occurrence and its visualizations mapping of climate change and tsunami mitigation publications.
5. Analyzing the intersection or linkage between the impacts of climate change on tsunamis.
6. Analyzing the relationship between climate change and tsunami mitigation with efforts to realize SDGs 11 and 13.

2. METHOD

This study used bibliometrics to provide a precise method to evaluate the contribution of a paper to the advancement of knowledge (Chen & Ho, 2015; Moyle et al., 2021; Nurhasan et al., 2022), especially in climate change and tsunami mitigation. The steps of conducting bibliometric research include: finding keywords, initial search results, refinement of the search, compiling initial data statistics, and data analysis (see Figure 1).

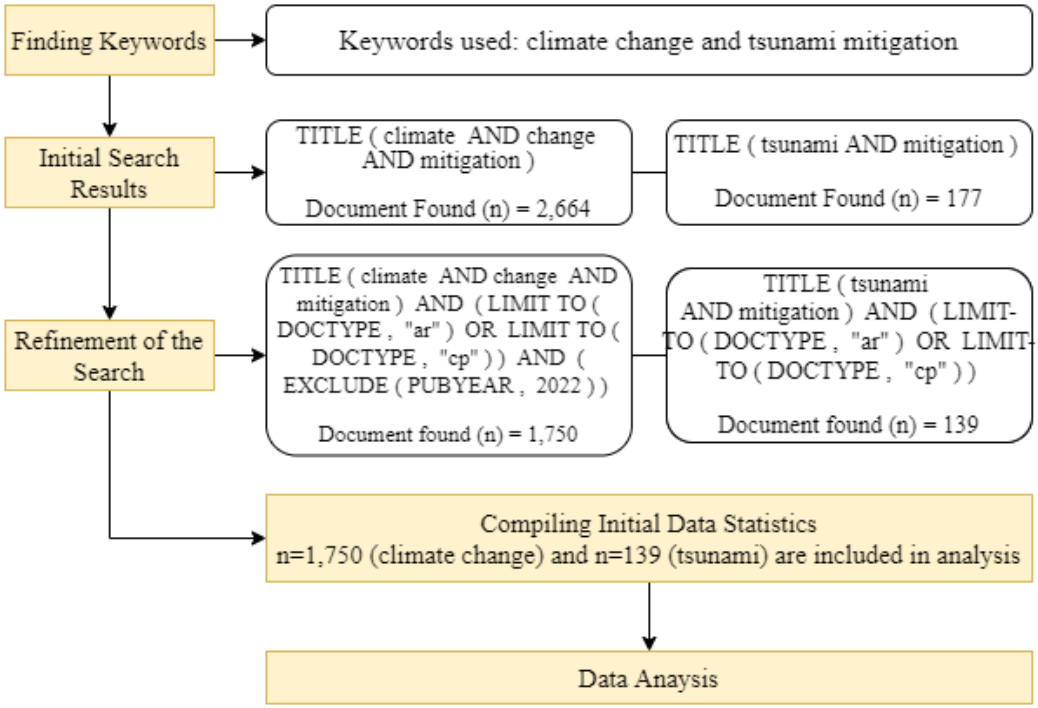

Figure 1. Research process and metadata collection

2.1 Finding Keywords

The keywords used are in accordance with the research objectives, namely "climate change mitigation" and "tsunami mitigation". The search year is also limited to 2021, as in 2022, the number of publications will still continue. The metadata used for data mining is the

Scopus database (www.scopus.com) because it has the world's largest academic database, with citations that provide abstracts from various scientific and research literature that have been examined, making it useful for visualizing, tracking, and evaluating publications.

2.2 Initial Search Results

Data mining will be carried out on June 16, 2022. Preliminary search results can find 2,664 documents for climate change mitigation and 177 for tsunami mitigation. However, this raw data still needs to be filtrated later.

2.3 Refinement of the Search

The findings are then specifically filtered for documents in journals and conference proceedings because these documents contain primary research results that are more credible and up-to-date than books, book chapters, and editorials because they are peer-reviewed by experts. After screening and filtering, 1,750 documents were found for climate change mitigation and 139 for tsunami mitigation.

2.4 Compiling Initial Data Statistics

The final document is then extracted in .csv format and inserted in VOS viewer and Microsoft Excel applications to visualize the data into graphs, tables, and maps. These applications were chosen because they are open source, produce simple visualizations, and can operate on large databases (van Eck & Waltman, 2010).

2.5 Data Analysis

The climate change and tsunami mitigation publications were analysed descriptively to determine the type of publication, distribution of articles/papers by year, publication source, author, institution, country, and keywords. Based on the results of mapping or visualization with VOS viewer, analysis can also be performed by looking at node size and link strength. Finally, the analysis was carried out based on a literature review to determine the intersection and linkage between climate change and tsunamis.

3. RESULTS AND DISCUSSION

3.1 Publications by Year

The publication trend of climate change and tsunami mitigation by year can be seen in Figure 2. The orange graph shows the trend of climate change mitigation publications has increased very rapidly in the last decade exponentially with equations $y = 0.3662x^2 – 1462.7x + 1E+06$. For example, if in 2011 there were 80 documents, then in 2021 there were 219 documents, so there was an increase of up to 273.75%. One of the triggers was that on November 28, 2011 in Durban, South Africa, there was a conference that discussed reaching a new agreement for reducing greenhouse gas emissions and other pollutants to combat climate change (Roberts, 2016). The problem of climate change is currently still in a critical phase, so many researchers are to find the most appropriate mitigation efforts.

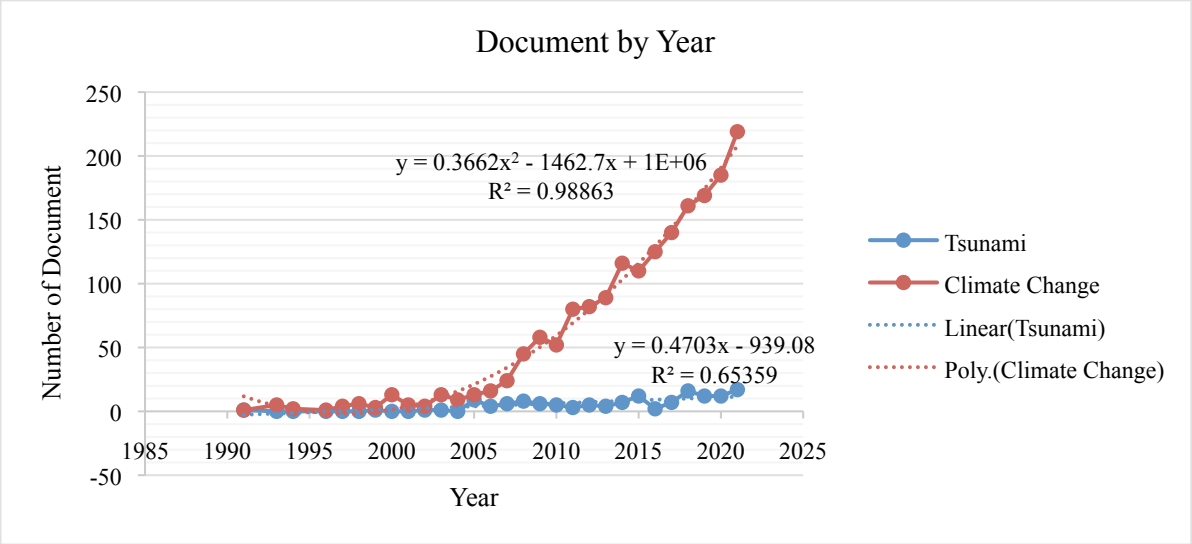

Figure 2. Distribution of climate change and tsunami mitigation publications by year

Contrary to climate change, tsunami mitigation publications tend to stagnate, and there is no significant increase. However, if it looks at the pattern, the number of publications will increase after a significant tsunami occurs. For example, in 2004 there were no publications on this at all, then in 2005, it increased rapidly to 9 documents. The cause was after the massive tsunami in Aceh, Indonesia, which caused the death of up to 150,000 people.

3.2 Countries and Affiliations

A list of the top 10 countries in the publication climate change and tsunami mitigation can be seen in Table 1. The United States is the richest country in climate change mitigation, with 424 publications. Followed by the United Kingdom with (n=217) publications, Germany (n=191), Australia (n=115), and China (n=105). Meanwhile, Japan led the highest number of publications in tsunami mitigation with 47. Followed by Indonesia (n=39), United States (n=25), United Kingdom (n=6), and China, India, New Zealand, and Sri Lanka 5 each. The majority of countries that dominate tsunami publications have coastlines prone to tsunami hazards, such as Japan, Indonesia, and Chile (Esteban et al., 2013; Mulia & Satake, 2020).

Table 1. Top 10 countries with the most climate change and tsunami mitigation publications

Climate Change		Tsunami	
Country	**Amount**	**Country**	**Amount**
United States	424	Japan	47
United Kingdom	217	Indonesia	39
Germany	191	United States	25
Australia	115	United Kingdom	6
China	105	China	5
Netherlands	103	India	5
India	95	New Zealand	5
Canada	93	Sri Lanka	5
France	78	Germany	4
Italy	76	Chile	3

A list of the top 10 affiliates with the most climate change and tsunami mitigation publications can be found in Table 2. In climate change mitigation, the International Institute for Applied Systems Analysis, Laxenburg, became the most productive affiliate with a total of 40 publications. It was followed by *Potsdam Institut fur Klimafolgenforschung* (n=38), Wageningen University & Research (n=33), PBL (*Planbureau voor de Leefomgeving*) Netherlands Environmental Assessment Agency and the University of California, Berkeley 23 each. Meanwhile, Saitama University led the highest number of publications of 12 documents in tsunami mitigation. Then Tohoku University (n=9), The University of Tokyo (n=6), *Institut Teknologi Bandung* and *Universitas Syiah Kuala* 5 documents each. This is in line with the most significant number of countries, where the most domiciled affiliates come from Japan and Indonesia.

Table 2. Top 10 affiliates with the most climate change and tsunami mitigation publications

Climate Change		**Tsunami**	
Affiliation	**Amount**	**Affiliation**	**Amount**
International Institute for Applied Systems Analysis, Laxenburg	40	Saitama University	12
Potsdam Institut fur Klimafolgenforschung	38	Tohoku University	9
Wageningen University & Research	33	The University of Tokyo	6
PBL Netherlands Environmental Assessment Agency	23	*Institut Teknologi Bandung*	5
University of California, Berkeley	23	*Universitas Syiah Kuala*	5
Universiteit Utrecht	22	*Universiti Sains Malaysia*	4
The Australian National University	22	University of Miyazaki	4
National Institute for Environmental Studies of Japan	22	National Oceanic and Atmospheric Administration	4
Helsingin Yliopisto	21	*Universitas Negeri Surabaya*	4
Lawrence Berkeley National Laboratory	20	The University of Auckland	3

3.3 Researcher Profile and Subject Area

The list of the top 10 researchers with the most climate change and tsunami mitigation publications can be seen in Table 3. On the topic of climate change mitigation, van Vuuren became the most prolific researcher with 12 documents. One of his articles with the most citations (121 times) titled "Exploring SSP land-use dynamics using the IMAGE model: Regional and gridded scenarios of land-use change and land-based climate change mitigation" which describes regional and gridded scenarios up to the year 2100 were generated using five iterations of the Shared Socio-economic Pathways (SSP) within the framework of the IMAGE 3.0 integrated assessment model. This collection of SSP land-use scenarios provides a thorough quantification of interrelated trends in the land system, both socioeconomically and biophysically (Doelman et al., 2018). The other researchers with the highest number of documents are Fujimori and Smith (11 each), Creutzig, Hasegawa, and Popp (10 each).

Table 3. Top 10 researchers with the most climate change and tsunami mitigation publications

Climate Change		Tsunami	
Researcher	**Amount**	**Researcher**	**Amount**
van Vuuren, D.P.	12	Tanaka, N.	11
Fujimori, S.	11	Imamura, F.	4
Smith, P.	11	Koshimura, S.	4
Creutzig, F.	10	Muhari, A.	4
Hasegawa, T.	10	Nandasena, N.A.K.	4
Popp, A.	10	Bernard, E.N.	4
Kurz, W.A.	9	Comfort, L.K.	4
Bauer, N.	7	Dengler, L.	3
Daioglou, V.	7	Hariyono, E.	3
Edenhofer, O.	7	Igarashi, Y.	3

Meanwhile, Tanaka became the most productive researcher on the topic of tsunami mitigation with 11 documents. One of his articles with the most citations (102 times) was titled "Vegetation bioshields for tsunami mitigation: A review of effectiveness, limitations, construction, and sustainable management" which conducted a review of vegetation bioshields for tsunami mitigation. This paper highlighted that proper planning and management of vegetation are required to maintain the tsunami buffering function of coastal forests (Tanaka, 2009). Other researchers with 4 documents are Imamura, Koshimura, Muhari, Nandasena, Bernard, and Comfort.

A list of the top 10 subject areas with the most climate change and tsunami mitigation publications can be found in Table 4.

Table 4. Top 10 source titles with the most climate change and tsunami mitigation publications

Climate Change		Tsunami	
Source Title	**Amount**	**Source Title**	**Amount**
Climatic Change	59	Natural Hazards	8
Mitigation And Adaptation Strategies For Global Change	49	IOP Conference Series Earth And Environmental Science	6
Energy Policy	46	AIP Conference Proceedings	5
Journal of Cleaner Production	38	International Journal of Disaster Risk Reduction	5
Climate Policy	37	Journal Of Physics Conference Series	5
Environmental Research Letters	36	Ocean Engineering	5
IOP Conference Series Earth And Environmental Science	36	Journal Of Earthquake And Tsunami	4
Sustainability Switzerland	35	Proceedings Of The International Offshore And Polar Engineering Conference	4
Global Environmental Change	23	Pure And Applied Geophysics	4
Environmental Science And Policy	18	Science of Tsunami Hazards	3

On the topic of climate change mitigation, "Climatic Change" is the source with the most publications, namely 59 documents. This source has Scopus CiteScore 7.4 as of 2021 and the 84th percentile for Atmospheric Science and 81st percentile for Global and Planetary Change. One of the articles with the most citations (4437 times) on the Climatic Change source is titled “The representative concentration pathways: An overview”. This paper summarizes the method of creation and critical features of the Representative Concentration Pathways (RCPs), a group of four new pathways created for the climate modeling community as the foundation for both long-term and short-term modeling experiments. Some of the other sources with the highest number of documents are Mitigation And Adaptation Strategies For Global Change (n=49), Energy Policy (n=46), Journal of Cleaner Production (n=38), and Climate Policy (n=37).

Meanwhile, on the tsunami mitigation topic, "Natural Hazards" became the most published source with eight documents. One of his articles with the most citations (774 times) was titled "People at risk of flooding: Why some residents take precautionary action while others do not", the results of this study showed that the explanatory power of the socio-psychological model, with important implications for public risk communication efforts. It is crucial to convey not only the risk of flooding and its potential consequences, but also the possibility, effectiveness, and cost of taking private precautions in order to encourage residents in flood-prone areas to contribute to damage prevention (Grothmann & Reusswig, 2006). Other sources with the highest number of documents afterwards are IOP Conference Series Earth And Environmental Science (n=6), AIP Conference Proceedings, International Journal of Disaster Risk Reduction, Journal of Physics Conference Series, and Ocean Engineering (5 each).

3.4 Keyword Trends

A list of the top 10 keywords in climate change and tsunami mitigation research can be seen in Table 5.

Table 5. Top 10 keywords with the most climate change and tsunami mitigation publications

Climate Change		**Tsunami**	
Keyword	**Occurence**	**Keyword**	**Occurence**
Climate Change	1406	Tsunamis	73
Climate Change Mitigation	541	Tsunami	60
Mitigation	500	Disasters	34
Greenhouse Gases	263	Earthquakes	21
Greenhouse Gas	261	Mitigation	16
Emission Control	259	Disaster Management	15
Carbon Dioxide	233	Tsunami Disaster	15
Environmental Policy	224	Disaster Mitigation	14
Carbon	174	Coastal Zones	12
Carbon Sequestration	166	Hazards	12

It can be seen that the most keywords occurring in climate change mitigation research are climate change (n=1406), climate change mitigation (n=541), mitigation (n=500), greenhouse gases (n=263), greenhouse gas (n=261), emission control (n=259), carbon dioxide (n=233), environmental policy (n=224), carbon (n=174), and carbon sequestration (n=166).

Based on the list, it can be seen that emission control, environmental policy, and carbon sequestration are the most researched mitigation efforts. Meanwhile, the main causes of climate change are greenhouse gases and carbon dioxide. Consistent with Huang et al. (2020); B. Wang et al. (2014); Z. Wang et al. (2018) found that some of the most popular keywords in climate change research are climate change, mitigation, carbon sequestration, and carbon dioxide.

On the topic of tsunami mitigation, the most widely used keywords are Tsunamis (n=73), Tsunami (n=60), Disasters (n=34), Earthquakes (n=21), Mitigation (n=16), Disaster Management (n=15), Tsunami Disaster (n=15), Disaster Mitigation (n=14), Coastal Zones (n=12), and Hazards (n=12). Based on the list, it can be seen that research trends 1) mitigation efforts are more towards disaster management and mitigation; 2) the cause of the tsunami from the earthquake; 3) the object of mitigation is the coastal area. These findings are in line with research by (Chiu & Ho, 2007; Suprapto et al., 2022), who also found that earthquake, disaster mitigation, and tsunami disaster are the top keyword trends in research on tsunamis.

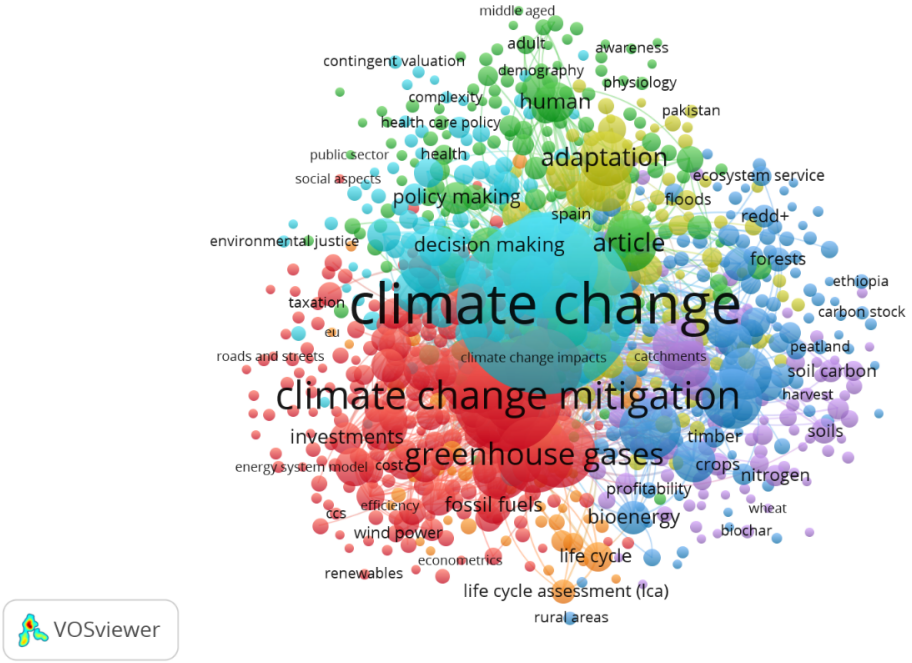

Figure 3. Visualization of Keyword Mapping in Climate Change Mitigation

Figure 3 shows seven clusters in the visualization of keyword mapping for climate change mitigation. In cluster 1 with red nodes (n=217) about aspects of climate change mitigation aspects, such as emission control, energy efficiency, carbon capture, climate models. Cluster 2 with green nodes (n=142) about the role of humans and government, such as human, environmental protection, policy making, decision making, and conservation of natural resources. Cluster 3 with blue nodes (n=126) about objects and locations, such as forest ecosystem, India, Nigeria, wetland, ecosystem, and peatland. Cluster 4 with yellow nodes (n=115) on climate change adaptation, such as adaptation, adaptive management, resilience, disaster management, and risk assessment. Cluster 5 with violet nodes (n=99) about the effect of climate change on the agricultural sector, such as agriculture, food security, land use, food supply, and agricultural emissions. While other clusters have fewer occurrences.

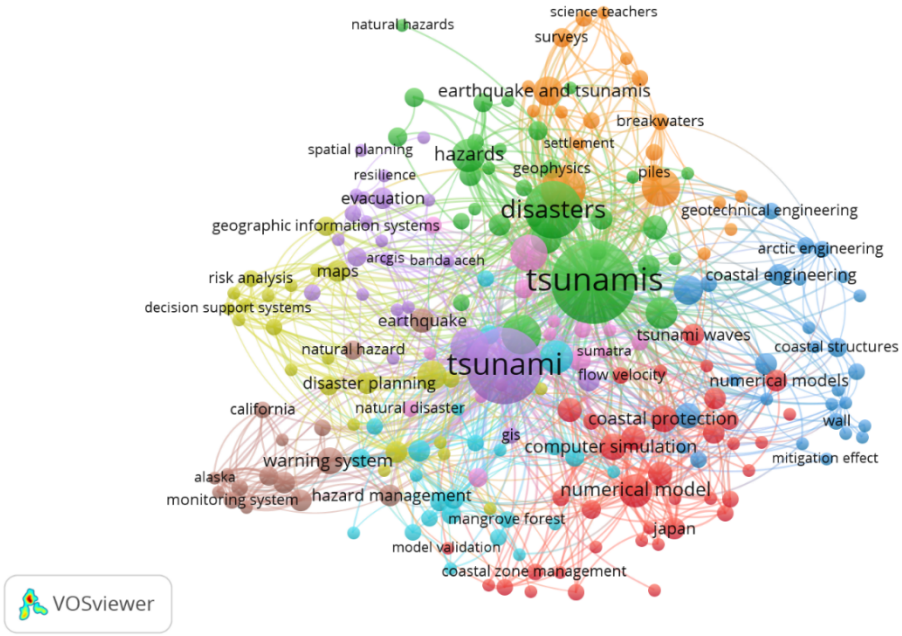

Figure 4. Visualization of Keyword Mapping in Tsunami Mitigation

Figure 4 shows there are nine clusters (n=221) in the visualization of keyword mapping for tsunami mitigation. In cluster 1 with red nodes (n=38) about coastal areas, such as coastal protection, coastal forest, coastal zone management, and coastal mitigation. Cluster 2 with green nodes (n=31) about evacuation, such as evacuation planning, evacuation route, evacuation modeling, and disaster prevention. Cluster 3 with blue nodes (n=28) on engineering aspects, such as arctic engineering, barrier (equipment), coastal engineering, impact force, and underwater foundations. Cluster 4 with yellow nodes (n=24) about aspects of informatics, such as geographic information, complex networks, information systems, and artificial intelligence. Cluster 5 with violet nodes (n=24) about tsunami-prone countries/areas, such as Banda Aceh, Java, Chile, and Indonesia. In comparison, other clusters have a smaller number of items.

3.5 Impacts of climate change on tsunamis

The most significant impact of climate change is the rise in global temperature or global warming. The average temperature of the Earth's climate system is rising over a lengthy period of time due to global warming. Rising sea levels, altered precipitation patterns, and the subtropical expansion of deserts are all ongoing or projected implications. Global sea level will increase by up to 60 cm by the end of the 21st century as a result of ocean warming and glacier melting, according to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2007). Several types of research also revealed the possibility of a future sea-level rise of up to 2 m by 2100 (e.g., Grinsted et al., 2010; Martin & Stefan, 2009).

Independent of earthquake-triggered tsunamis, global warming, a long-term event, is expected to result in an accelerated increase in sea-level rise (Meehl et al., 2005; Nicholls & Cazenave, 2010). This may lead to a higher risk of inundating low-lying coastal areas (Galbraith et al., 2002). Consequently, damages due to coastal floods are expected to increase significantly during the 21st century and beyond as the sea level rises, making socio-economic damages in coastal regions more prevalent.

Yavuz et al. (2020) have done simulations using NAMI-DANCE software and showed that social risk level decreases due to sea-level rise and sea level rise+earthquake triggered tsunamis for Fethiye City Center due to a decrease in PGR from 2080 to 2100. However, relative to 2020, social risks due to sea level rise+earthquake triggered tsunamis at Fethiye and Cairo increased almost 90 and 900 fold, respectively. In conclusion, sea-level rise effects influence both sites' economic and social risks. However, this influence does not show the same trend at both sites. The topography of the region, proximity to the earthquake zones, economic growth rates, and population levels are other factors that need to be considered in this analysis.

Shao et al. (2019) study of the influence of climate change on the tsunami-like solitary wave inundation over fringing reefs, the shock-capturing Boussinesq wave model FUNWAVE-TVD was utilized. The numerical experiments clearly showed that as the water depth over the reef flat increased, there was a significant increase in the horizontal inundation distance over the back-reef beach. As the sea level rises, the impact of a tsunami will be worse over the back-reef beach, particularly in areas that are closer to the original shoreline in the inundation zone. Additional protective measures or adaptations might be required to lessen the tsunami damage that will be greatly increased by future sea-level rise for the low-lying zones of the reef-lined coasts. Sea-level rise has a more significant impact than the detrimental effects of the reef's surface roughness degradation on inundation distance and tsunami damage. The findings presented here give coastal managers a rough idea of how tsunami hazards change over fringing reefs in response to sea-level rise and coral bleaching caused by climate change. In order to mitigate the increased future tsunami hazards that many tropical and sub-tropical shorelines will face, efforts in response to climate change, especially sea-level rise, will be necessary. This is because climate change will significantly impact the protective capability of fringing reefs against tsunami hazards in the future.

3.6 Climate change and tsunami mitigation: efforts to realize SDGs 11 and 13

The research profile on climate change mitigation is in accordance with the 13th goal of the SDGs, namely climate action, while tsunami mitigation is in accordance with the 11th goal of the SDGs because it can provide information to the government, librarians, and subsequent researchers to make the best efforts in mitigating climate change and tsunamis. The government, as a policymaker, can design environmental policies, especially those related to climate change, that are efficient in accordance with the recommendations and research trends that have been carried out. Meanwhile, the government can also pay attention to coastal areas prone to tsunami hazards by making mitigation efforts to reduce the impacts caused, as well as creating resilient, resilient, and sustainable coastal communities. The mapped research profile can also provide information for librarians to provide reputable journal documents to the fullest. Researchers can then explore novelty ideas for developing climate change and tsunami mitigation (according to Figure 3 and Figure 4).

CONCLUSIONS

This study mapped the research profile of climate change and tsunami mitigation as an effort to realize SDGs 11 and 13. The profiles mapped are: (1) The trend of climate change mitigation publications has increased rapidly in the last decade, while tsunami mitigation publications tend to stagnate. (2) The most productive countries and institutions in climate change mitigation are the United States and the International Institute for Applied Systems Analysis Laxenburg, while in the publication of tsunami mitigation are Japan and Saitama

University. (3) The researchers and source titles that have produced the most successful climate change mitigation publications are van Vuuren and Climatic Change, while in tsunami mitigation are Tanaka and Natural Hazards. (4) Research trends in climate change mitigation, namely emission control, environmental policy, and carbon sequestration, are the most researched mitigation efforts. Meanwhile, the leading causes of climate change are greenhouse gases and carbon dioxide. On the other hand, the trend of tsunami mitigation research is more towards disaster management and mitigation, the causes of tsunamis by earthquakes, and coastal area mitigation objects. (5) Climate change will increase global temperatures so that it can trigger sea level rise, as the number of water increases and the impacts caused to coastal areas become significant. (6) The research profile on climate change mitigation follows the 13th goal of the SDGs, namely climate action, while tsunami mitigation follows the 11th goal of the SDGs because it can provide information to the government, librarians, and subsequent researchers to make the best efforts in mitigating climate change and tsunami.

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