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Tsunami event in Flores: literature review

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Abstract: The Flores Sea has experienced devastating earthquakes with magnitudes >7 over the past 30 decades. It can trigger a tsunami and provide important theoretical, experimental, and field information. The seismicity study stated that the island of Flores had experienced tsunamis during the pre-instrumental period (1815, 1818, 1820, and 1836) and the pre-instrumental period in 1992. This study discusses the development of tsunami research in Flores using a literature review approach. The data source comes from the Scopus database, with data analysis using VOSviewer. The search results obtained a total of 22 documents, with the result that the 1992 Flores earthquake became the main research topic and the beginning of the era of modern tsunami science.

Keyword : Tsunami Event, Flores, Seismology, Earthquake, Literature Review

1. Introduction

A tsunami is a series of sea waves with a large wavelength. Tsunamis occur due to the movement of considerable volume of water. This event can be caused by an earthquake or a shift in the ground in the sea (Nisa et al., 2021). A tsunami can be marked by a sudden drop in sea level followed by an increase in the volume of seawater towards the coast and creates a tsunami in a vertical direction (Tandel et al., 2021).

Flores Island, which is located in East Nusa Tenggara, is one of the islands in Indonesia which is included in the Pacific Ring of Fire and shows high tectonic activity (Jufriansah et al., 2021). Prananyo et al. (2021) wrote that in this area there were tsunamis during the pre-instrumental period (1815, 1818, 1820, and 1836) and the period after the 1992 pre-instrumental with Mw 7.8. This phenomenon is related to the tectonic activity of the Flores back-arc thrust (Pranantyo et al., 2021; Julius & Daryono, 2021).

The seismicity study states that there are five zone classifications in the Flores region, namely the Flores back arc thrust zone in the north of the island with shallow to medium thrust, and medium thrust zone in Timor Through, intermediate depth thrusts in the Sawu Basin, between Sumbawa and Flores Islands with strike-slip and subduction earthquake zones (Handayani, 2020; Pranantyo & Cummins, 2020). New seismotectonic findings suggest that the Flores back-arc thrust, which previously consisted of isolated thrust fault segments of the islands of Flores and Wetar, has now extended along the southern margin of the Java Sea from Alor in the East to East Java in the West Java Sea. (Pranantyo & Cummins, 2019; Supendi et al., 2020).

Tsunami disasters can sometimes be global, originating from one place, and can be destructive at a distance of thousands of kilometers from the source. It resulted in geological changes in the disaster area. Based on the literature, the tsunami in the Flores region has been widely studied, this is shown by the number of studies that have examined the 1992 Flores earthquake and tsunami (Kim et al., 2015; Felix et al., 2022). In this research, many studies discussed tsunami modeling (Zaytsev et al., 2019). However, of the many studies, there has been no bibliometric analysis research that has mapped the development of the tsunami in Flores. Therefore this study will discuss how the development of tsunami research in Flores is based on the results of the publication database, mapping publication data based on journal rank, and visualizing it using VOSviewer. The results obtained can then provide an overview of the development of the distribution map for tsunami research in Flores, mainly based on the Scopus database.

2. Methods

The method used in this study is a qualitative method with a literature review approach. The research flow follows Figure 1. The data source comes from the Scopus database (https://www.scopus.com/). Data retrieval by searching data using search documents: TITLE-ABS-KEY (tsunami), then the database search results are stored in .ris format (RIS Format EndNote, Reference Manager).

The next step is to visualize the bibliometric map using VOSviewer. Based on the results of the analysis, a keyword visualization will appear. These results provide an overview of the relationship of each keyword. the next step is to minimize the search with the keyword “tsunami event”. After determining the keywords, a search for literature data was then carried out using the Scopus database with the keyword "tsunami event in Flores" with the keyword Search documents: TITLE-ABS-KEY (tsunami AND event AND in AND flores). Document analysis is carried out by identifying based on journal rank based on Scimago Institutions Rankings (https://www.scimagojr.com), which is divided into four Q (Quartile) criteria between Q1 to Q4 and Not yet assigned Q. The final stage is to conduct a review analysis from each document, by linking the results and keywords that appear based on the VOSviewer visualization.

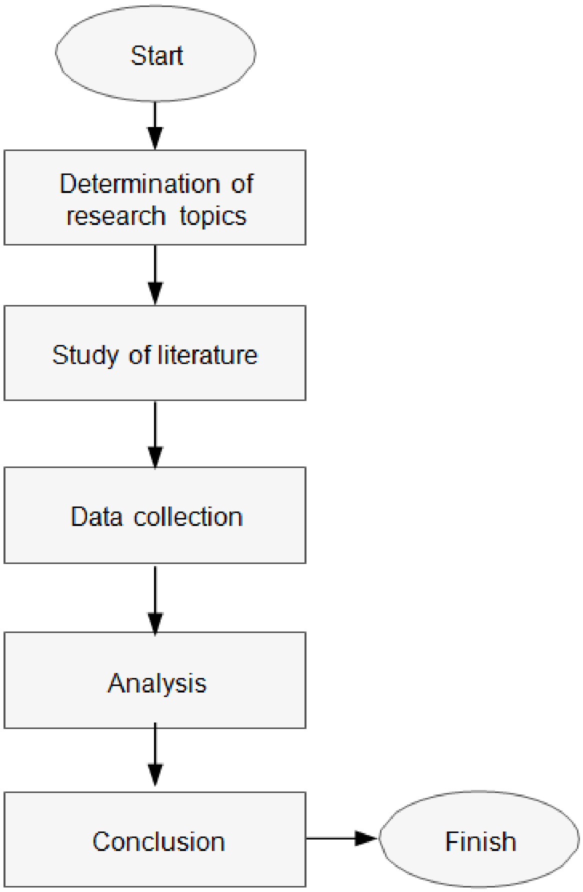


Figure 1. Research flow

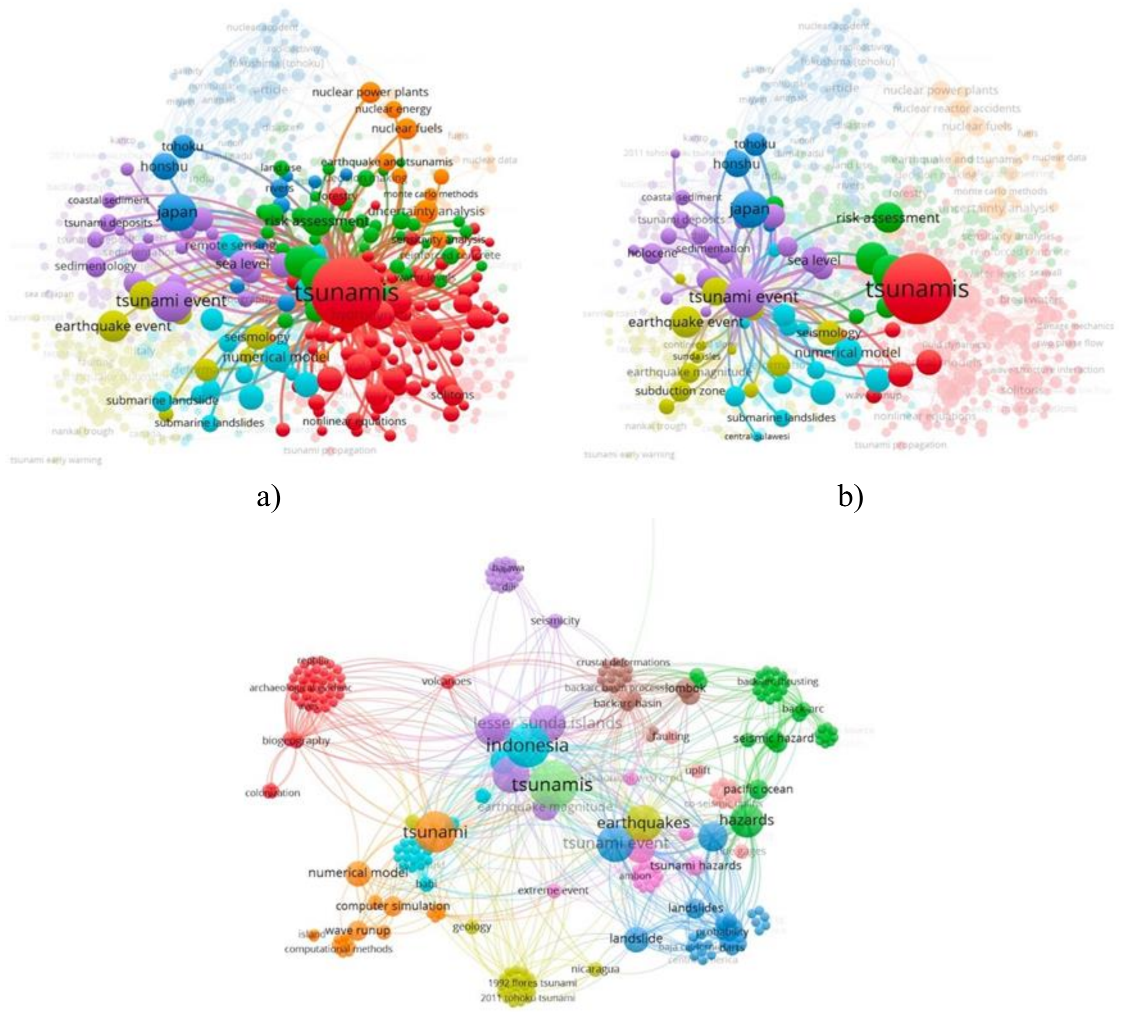
3. Results and Discussion

The following results are reached in light of the findings of the research and analysis:

3.1. Publication Search Results

According to the Scopus database, the term "tsunami" is associated with 28,106 documents, "tsunami event" with 8,175 documents, and "tsunami event in Flores" with 22 documents. For research that was more focused on the Flores region, the keyword selection was trimmed down. The visualization displayed in Figure 2 illustrates the continuity between each key. Figure 2 shows that a tsunami event is a component of a tsunami, and these terms are primarily concerned with the connection between a tsunami's occurrence.

The papers that have been acquired are then identified using data from Scimago Institutions Rankings and journal rank. As shown in Figure 3 and Table 1, the identification findings showed that articles using the Scopus database met eleven of the Q1 criteria, five of the Q2 criteria, one of the Q3 and Q4 criteria, and four of the not yet assigned Q journals.



a) b)

c)

Figure 2. Keyword visualization using VOSviewer with a) tsunami, b) tsunami event, and c) tsunami event in Flores

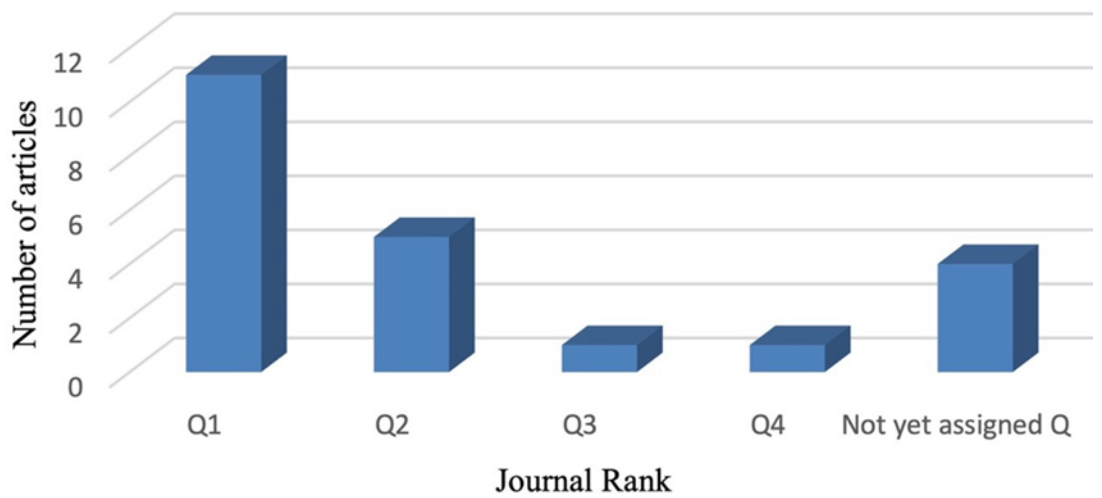


Figure 3. The papers of tsunami event in Flores based on journal rank

Table 1. Document identification based on journal name and journal rank

Journal Rank	Number of articles	Journal Name
Q1	11	Natural Hazards, Journal of the Geological Society, Coastal Engineering, Quaternary Science Reviews, Geology, Journal of Human Evolution, Geophysical Research Letters, Natural Hazards and Earth System Sciences, Geophysical Journal International, Journal of Geophysical Research: Solid Earth, Solution to Coastal Disasters Congress 2008
Q2	5	Pure and Applied Geophysics
Q3	1	Journal of Coastal Research
Q4	1	Ocean and Polar Research
Not yet assigned Q	4	Research, Proceedings of the 7th Mathematics, Science, and Computer Science Education International Seminar, MSCEIS 2019

3.2. Literature review

Following identification, the literature review of all documents (22 documents), as shown in Table 2.

Table 2. Literature review data

Author and Year of Publication	Research Result
Pranantyo & Cummins (2019)	An ENE-inclined fault was ruptured by the Flores earthquake in 1992, deviating from the backarc thrust's general EW direction in the eastern Sunda Arc.
Beckers & Lay (1995)	The northern back arc of Flores Island is deformed mostly by compression forces, which confine body waves to the hypocentral at a depth of 16 km. As a result, the majority of these waves disperse at shallow depths and occur in Flores' northeast.
Cho & Liu (1999)	The shallow water equations were tested numerically and in experiments. The maximum run-up heights were observed using these methods. It was discovered that the run-up heights at Babi Island depend on the height of the incident wave's crest.
Kim et al. (2015)	Three-dimensional numerical modeling

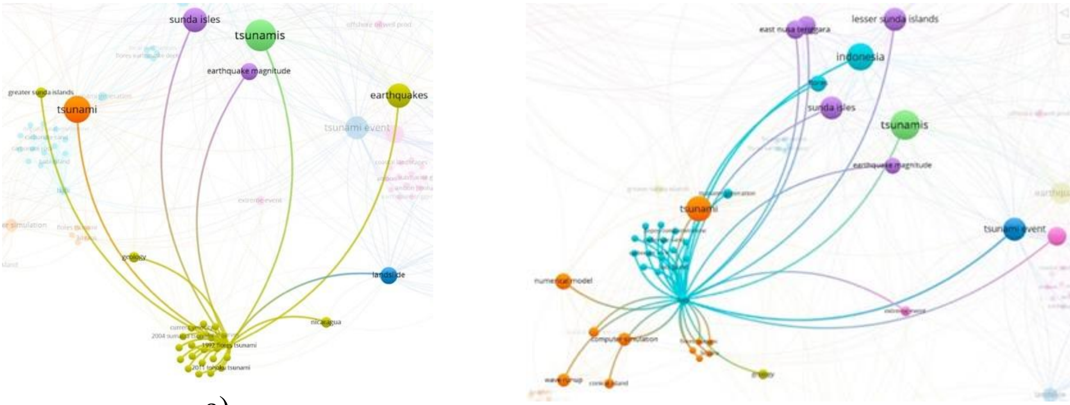
Author and Year of Publication	Research Result
	can be used to investigate the extreme occurrence of run-up on Pulau Babi, Indonesia. Other findings indicate that the modeling process has an impact on flooding by applying a wave reflection process.
Koulali et al. (2016)	The 300 km onshore westward extension of the back-arc thrust to East Java, which contains about 6 mm/yr of slip. These findings underline the genuine earthquake and tsunami threat to the Flores Sea shores of Bali, Lombok, Nusa Tenggara, and other islands.
Felix et al. (2022)	Since 1800 AD, the Flores fault system in the Lombok and Bali regions has been the source of at least six tsunami-causing Ms 6.5 earthquakes. Tsunamis with several waves that can be caused by faults in this area can strike Mataram in 9 minutes and Denpasar in 23–27 minutes. Maximum wave heights for earthquakes in Mataram and Denpasar range from 1.6 to 2.7 meters and 0.6 to 1.4 meters, respectively. Our earthquake models also predict a coseismic subsidence of 20–40 cm for both cities, increasing their vulnerability to tsunamis and other coastal hazards.
Yang et al. (2020)	Most of the crustal deformation caused by the 2018 Lombok earthquake occurred in the northern and northeastern parts of the island. Maximum vertical deformation was ~36 cm near the northwestern boundary of the island, caused by the 6.9 Mw event on August 5.
Satake et al. (1993)	The damage caused by the 1992 Flores earthquake and tsunami was more damaging than the great 1992 tsunami in Nicaragua in Japan.
Okal (2019)	Reviewing 47 tsunamis with geological origins (caused by earthquakes, landslides, or volcanoes) over the course of 25 years, it was discovered that run-up, a non-linear

Author and Year of Publication	Research Result
	interaction between tsunamis and dry land along the coast, occurs in both near and far fields.
Kânoğlu et al. (2019)	Zeno's paradox from Elea has been resurrected in the context of improvements in tsunami science and mitigation efforts as a result of significant discoveries in several sectors of tsunami study during the past 25 years.
Pranantyo & Cummins (2020)	The 100 m high Ambon 1674 tsunami is the largest run-up height ever documented in Indonesia, and with more than 2300 fatalities, it is one of the deadliest tsunami disasters in Indonesia. The 1674 Ambon tsunami strengthened the argument that landslides in Indonesia constitute a significant source of tsunami hazards, along with subsequent tsunamis like the 1992 Flores, 2018 Palu, and Sunda Strait tsunamis.
Kânoğlu et al. (2020)	The tsunami numerical model has made substantial progress, and although the tsunami warning system has improved significantly, the number of casualties affected by the tsunami has not been able to decrease despite this.
Pailoplee & Chenphanut (2019)	A considerable change in seismicity happens before an earthquake, according to quantitative mapping of seismicity variations along the Indonesian island chain. There are at least seven locations along the ISM that have a Z value anomaly and are still the result of a damaging earthquake, but they could also be earthquake sources.
Choi et al. (2007)	The three-dimensional calculation is quite good compared to laboratory and 2D numerical findings, as demonstrated by the application of the three-dimensional RANS model to simulate wave run-up on a conical island.
Handayani (2020)	According to a seismic study, the Flores

Author and Year of Publication	Research Result
	back arc thrust was the seismic event that had the greatest impact on soil attenuation at Maumere.
Ha et al. (2008)	Run-up height results from the numerical model used to analyze the 1992 Flores tsunami and the 1993 Hokkaido tsunami on a circular island showed a modest discrepancy in the results for diagonal wave circumstances between observations and experiments.
Dennell et al. (2014)	Based on biogeography, we deduce that Java, Sulawesi, and Sahul are among the origins of the Flores mammal, avian, and reptile fauna. Rodents and hominins may have accidently rafted from Sulawesi by following currents, and many terrestrial species, such as stegodons, giant tortoises, and Komodo dragons, are able to float or swim. Basic energy models indicate that smaller-bodied hominins likely outnumbered larger-bodied hominins on Flores. All taxa on the island would have undoubtedly been impacted by the region's regular tsunamis and volcanic eruptions, yet at least one alternating event the extinction of Stegodon sondaari was documented.
Cabral (2021)	When creating a Management Master Plan (RIP), it is crucial to estimate the tsunami risk, particularly for coastal areas that will be affected by a tsunami. The study concentrated on building and managing maps and constraint maps, including lithology, hydrology, coastal stability, and erosion patterns in the area, as well as volcanic areas, tectonic structures, and lithology.
Coutinho et al. (2009)	Geomorphology, volcanic characteristics, tectonic structures, lithology, hydrology, coastal stability, and erosion patterns in this region should all be given special consideration. The Coastal Zone

Author and Year of Publication	Research Result
	Management Master Plan for the aforementioned islands was created using the results of seismic, landslide, and tsunami risk assessments. The geology team and the planning team produce the management map, constraint map, and pertinent legal requirements that must be followed in this domain after the hazard assessment is finished.
Minoura et al. (1997)	There are two waves with distinct strengths, according to a numerical simulation of the tsunami generator and its spread. The information was then compared to field observations, including the discovery of coarse carbonate sand layers made up of mollusk shells along Pulau Babi's coast. This supports the hypothesis that the waves that swept the south coast at the time were significantly more destructive than those that swept the north shore.
Pranantyo et al. (2017)	The Ambon tsunami of 1674 and the Flores earthquake and tsunami of 1992 were both caused by submerged landslides or local tectonic faults on Ambon Island's north shore.
Ruxton & Wilkinson (2012)	The model's findings support the idea that early island colonization, including the presence of Homo erectus on Flores, may have resulted from highly anomalous natural occurrences (such as a tsunami), other findings indicate that colonization of an area may have been possible through the arrival of groups of people who did not deliberate on the island. The probability of successful colonization through the arrival of planned sailing ships should be about half as high as it is with the arrival of individuals who did deliberate.

Table 1 demonstrates that there is no specific discussion of the Flores tsunami phenomenon throughout the whole manuscript. The 1992 Flores tsunami (Figure 4a) and Babi Island (Figure 4b) may be found as the two main keywords for the tsunami phenomenon in Flores, according to a trace of the keyword-related data based on Figure 4. These links will lead you to information about Babi Island, geology, numerical models, computer simulations, wave run-ups, Flores tsunamis, tsunami generation, earthquake magnitudes, severe run-ups, tsunami events, landslides, and Nicaragua Japan.



a) b)

Figure 4. Keyword linking visualization for a) the 1992 Flores tsunami, and b) Babi Island

According to the study's findings, the 1992 Flores earthquake and tsunami were severe run-up phenomena that occurred on Babi Island (Kim et al., 2015), and they were more damaging than Nicaragua 1992 earthquake (Satake et al., 1993). The Tsunami Bulletin Board (TBB) network was founded as a result of this phenomenon, which was also the focus of global post-tsunami surveys (Kanolu et al., 2019). According to Pranantyo & Cummins (2019), only one tide gauge, which is situated in Palopo, Sulawesi, provided proof of the 1992 Flores earthquake and tsunami due to a lack of current technology. The 1992 Flores earthquake and tsunami broke faults that were inclined towards ENE (east-northeast), but the Flores Back Arc Thrust Fault also played a significant role (Beckers & Lay, 1995; Koulali et al., 2016) and is connected to the 2018 Lombok earthquake phenomenon (Felix et al., 2022; Yang et al., 2020). So, according to Koulali et al. (2016), this fault poses a threat to earthquakes and tsunamis in the regions of Bali, Lombok, Nusa Tenggara, and beaches along Flores.

Run-up analysis explains that the 1992 Flores tsunami phenomenon allows the run-up height to depend on the crest of the incoming wave (Cho & Liu, 1999) and can be analyzed using three-dimensional numerical modeling (Choi et al., 2007). Other results explain that landslides are the source of tsunamis (Okal, 2019; Pranantyo & Cummins, 2020), this is consistent with the phenomenon of the 1674 Ambon tsunami (Pranantyo & Cummins, 2020). Given its geological environment, Flores' coastal area is highly vulnerable, necessitating the creation of a master plan for its management. Based on numerical models of the 1992 Flores earthquake and tsunami, it was discovered that there were invasions of tsunami waves from two directions with varying magnitudes, which dumped sand on the north and south beaches (Minoura et al., 1997).

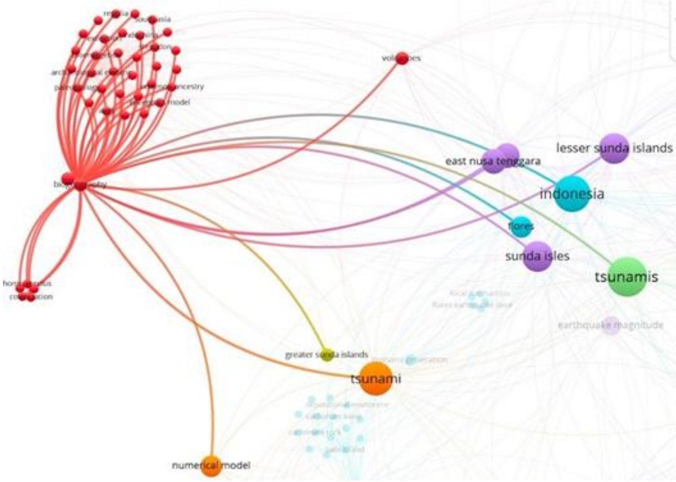


Figure 5. Keyword link visualization for biogeography

The database also revealed that there are two documents pertaining to the study of biogeography. Changes in taxonomy (body) in the Flores region are a result of earthquake and tsunami occurrences (Dennell et al., 2014). According to additional research, this phenomenon is connected to the mammalian flora that visits Flores. Animals like Komodo dragons and turtles (based on terrestrial taxonomy) might be able to swim, while other creatures might be rafting down to Flores. Additionally, this occurrence alters the model of an island's demographic trajectory, such as that of Homo erectus on Flores (Ruxton & Wilkinson, 2012).

4. Conclusion

Based on the study's findings, it was discovered that there were 22 articles linked to documents, of which 20 were dedicated to science and two were related to social issues, when the search for the Flores tsunami incident was narrowed. This result shows that studies on earthquakes and tsunamis have increased, particularly after it was realized that the 1992 events in Flores and Nicaragua signaled the advent of the current tsunami science age. In the meantime, research in adjacent domains demonstrates that this natural phenomenon causes population changes and taxonomic alterations. It is necessary to conduct additional research by looking over these keywords and choosing different databases.

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