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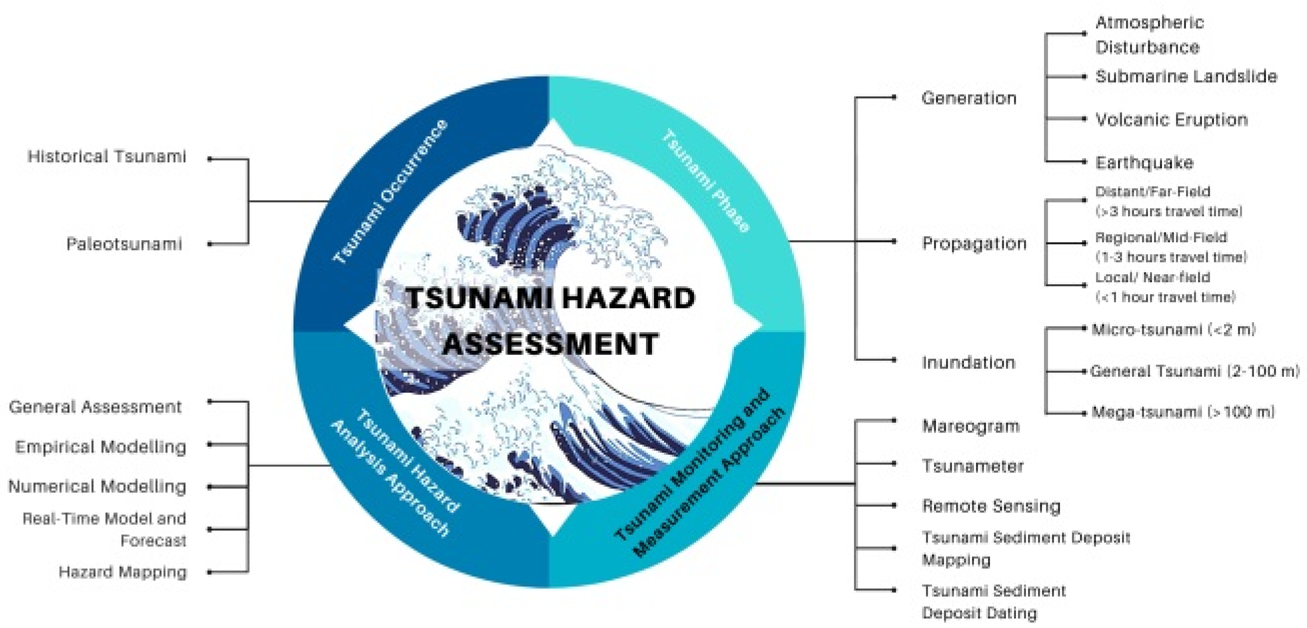
Indonesia Disaster Knowledge Update - November 2022

Research Publications about Tsunami Hazard Assessment in Indonesia

In the spirit of the Tsunami Awareness Day on the 5th of November 2022 which aims to create awareness among people about the environmental destruction caused by tsunami, CARI! has compiled the Indonesian Disaster Knowledge Update (IDKU) regarding the tsunami hazard assessment in Indonesia. In this edition of IDKU, we are bringing the overview of tsunami hazard assessment publications to see how well research related to the hazard has progressed over time.

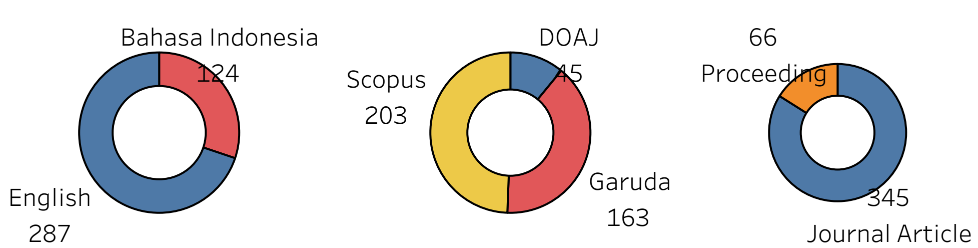


As we have already aware, tsunamis occur quite frequently in Indonesia since the pre-historic era until present time. A tsunami's life cycle is commonly referred to three phases: The generation (Tsunami source), the propagation, and the inundation [1]. Combining those phases, the hazard appears as a series of waves coming from the deep-sea source with massive energy that turned into a higher wave with destructive ability by the time it reaches shallow coastal areas. The force of a tsunami is generated by many factors, from typical to atypical origins, other experts may use the term seismic and non-seismic. Here we use atypical and non-typical, and combined them. The typical origin-tsunami concentrates around the earthquakes event, while the atypical tsunami can be originated from the submarine landslides, atmospheric disturbance and sudden earth surface movements adjacent to the ocean such as volcano eruptions, meteorite strikes, and falling rocks [3][4][8][12].

Most of the tsunamis in Indonesia are formed in the ocean. According to historical records, more than 80% of world tsunamis were generated by earthquakes, and 70% of them, including large tsunamis, were observed around the Pacific Ring of Fire [4]. As Indonesian Waters are interconnected, the effect of tsunami in any place can also be anticipated on the surrounding area, so as the damages that might be occurred. This makes Indonesia more susceptible to damage from tsunami and thus tsunami hazard literacy must be strengthened. For that, in this IDKU we will give an analysis of specific information regarding tsunami categorization starting from three big categories: time occurrence, life phase, and methodology.

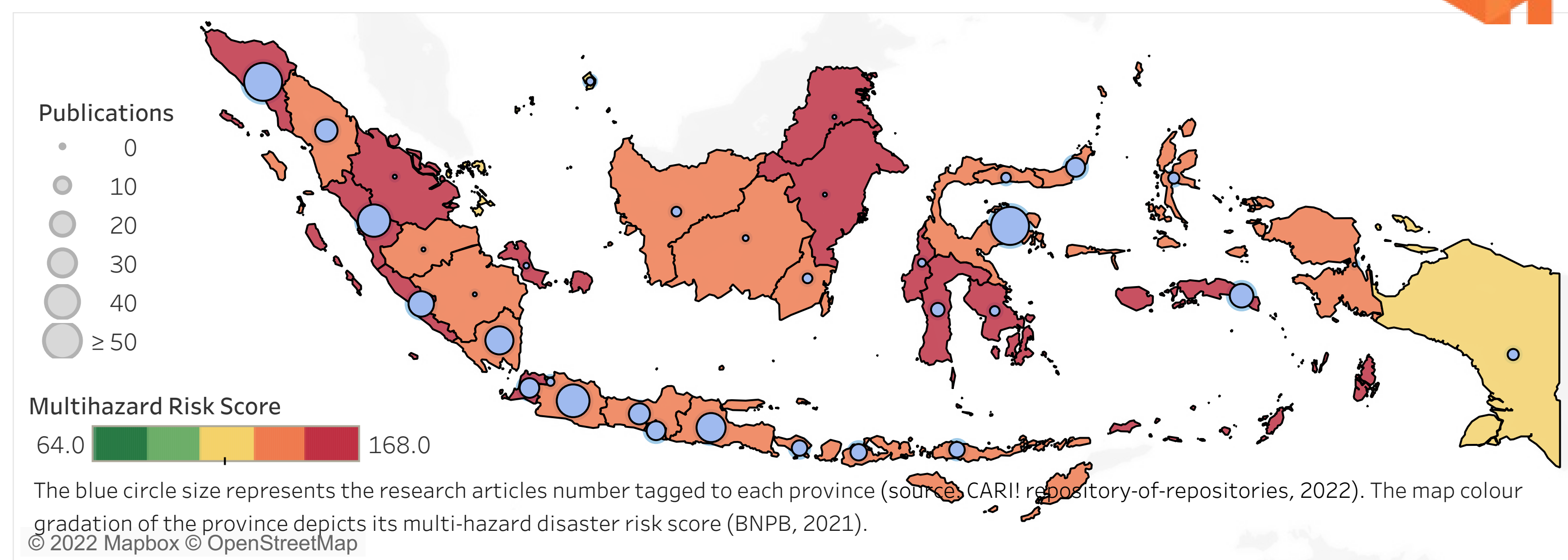
Research Articles Statistics

411 Publications | 261 Publishers | 387 Authors



For analysis purposes, we examined research articles that related to tsunami hazard assessment in Indonesia only. We excluded tsunami article that is not directly about hazard assessment such as the topic of tsunami preparedness, evacuation, response, and recovery. The scientific articles we used were obtained from CARI! Knowledge Engine sourced from Scopus, DOAJ, and Portal Garuda repositories that were published from 1995-2022. Upon the multi-stage filtration process, we selected 411 research articles to be processed in the subsequent analysis.

Research Articles Distribution Map

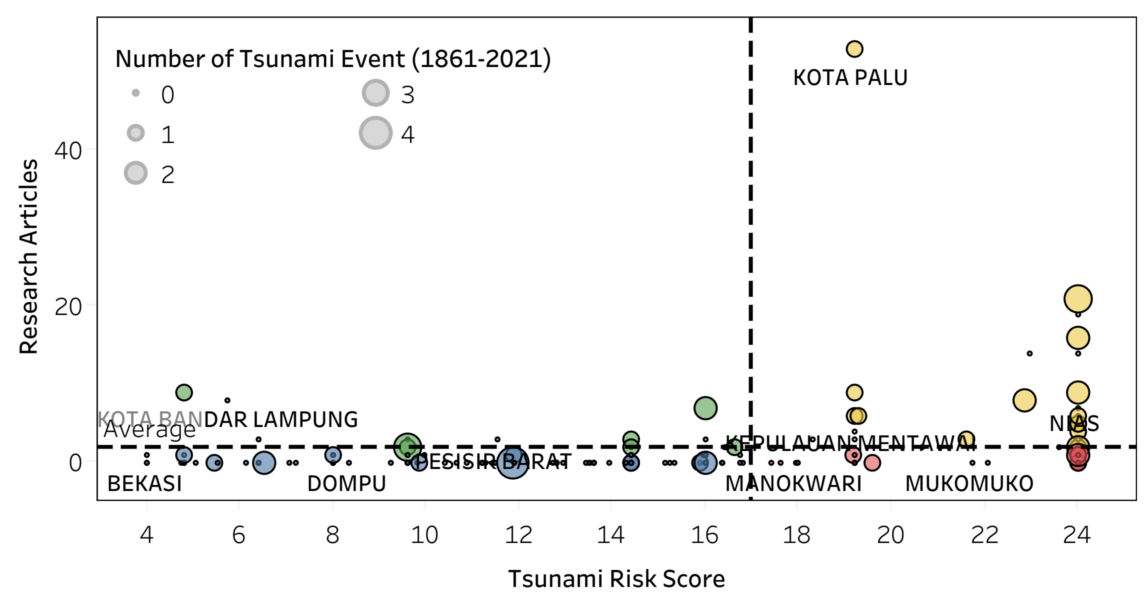


The blue circle size represents the research articles number tagged to each province (source: CARI! repository-of-repositories, 2022). The map colour gradation of the province depicts its multi-hazard disaster risk score (BNPB, 2021).

As can be seen from the map, research on tsunami hazard assessment is distributed evenly across the country. The provinces with the highest number of studies were Aceh (64 articles), Central Sulawesi (56 articles), West Java (37 publications), and West Sumatra (36 publications). Provinces in Sumatra, Java, Bali and Nusa Tenggara tend to have more publications, while other provinces, especially in the central and eastern regions, have a fewer number of publications. Based on our record, we found that some provinces have a very limited number of publications such as West Papua and Gorontalo.

The word cloud shows the cities/regencies that have been researched, its size is proportional to the number of publications. Palu City topped the rankings with 44 publications. Meanwhile, other cities/regencies that have been struck by tsunami disaster event also has a quite notable number of publications.

Research Articles VS Tsunami Risk Score by Coastal Regency/City



The quadrant plot shows the city/regency category (represented by different colours) based on the number of research articles and tsunami risk score (source: BNPB, 2021). The circle's size depicts the number of tsunami events in the city/regency (source: BNPB, 2022).

There is 33 regency/city that has more publications than the average (2 publications per city/regency), namely 12 city/regency in the green category and 21 city/regency in the yellow category which is located in Sulawesi, Sumatra, Java, and Nusa Tenggara. There are dozens of other cities/regencies that only have 1-2 articles and dozens of other cities which prone to tsunami but have not been studied yet. This result suggests that tsunami hazard assessment research at the city/regency scale needs to be boosted, particularly in city/regency adjacent to tectonic faults or volcanoes which capable of generating tsunami.

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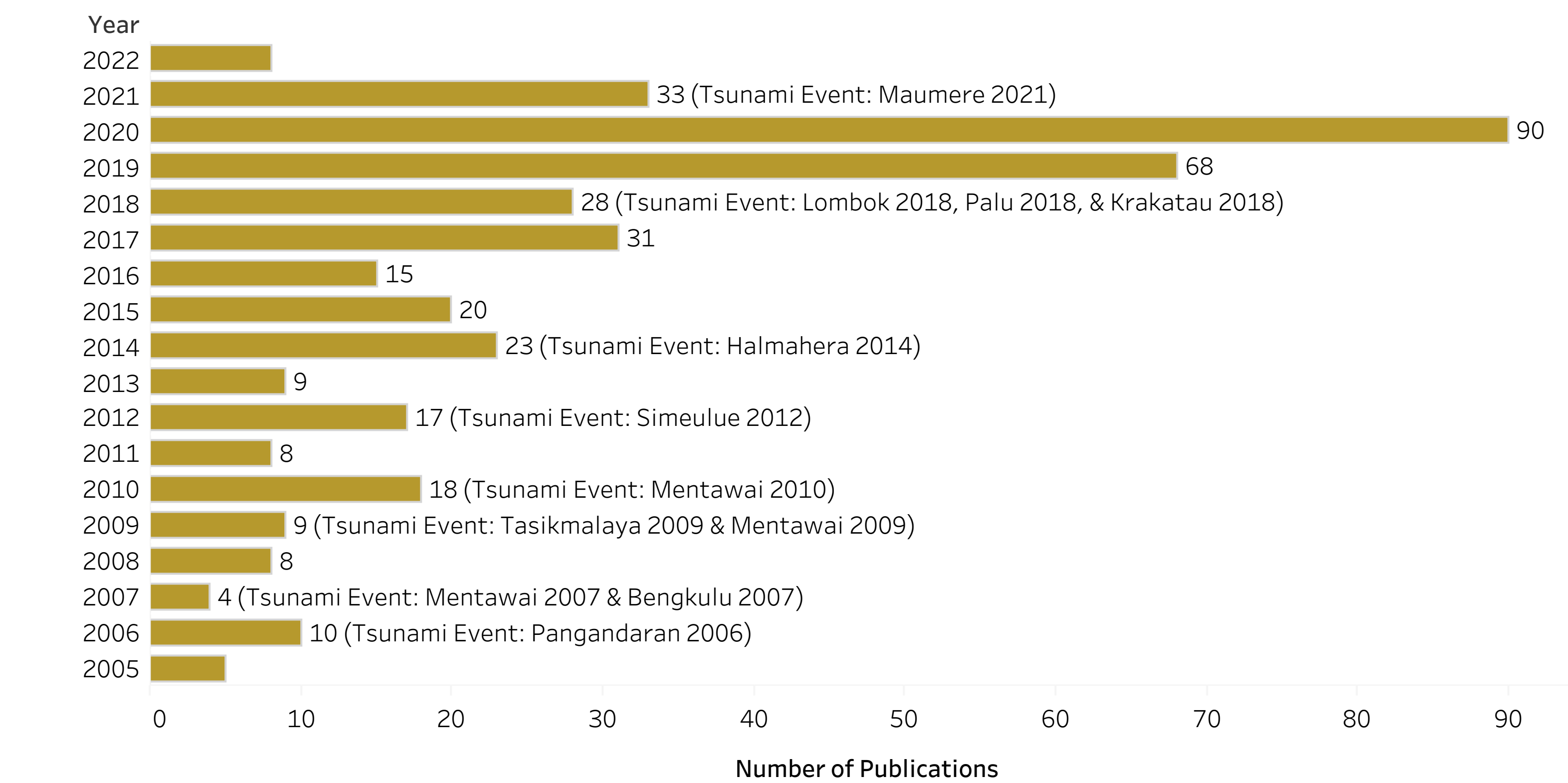
Growth of Research Publication



Research published on the issue has existed since the early 1990s but has only been continuously published each year since 2005. Tsunami hazard assessment research then slowly began to be widely researched and reached the trend of the highest number of increases in 2019 and peaked in 2020 with 90 publications. The event of a major tsunami disaster seems to trigger many researchers to publish their research during the year's event or after. As it seen after Pangandaran 2006 and Mentawai 2010 tsunami event, and more noticeably after year of 2018 Lombok, Palu, and Krakatau Tsunami events.

Top Research Articles

Coseismic Slip and Afterslip of the Great Mw 9.15 Sumatra-Andaman Earthquake of 2004
Chlieh, M., Avouac, J. P., Hjorleifsdottir, V., Song, T. R. A., Ji, C., Sieh, K., Sladen, A., Hebert, H., Prawirodirdjo, L., Bock, Y., and Galetzka, J. | Bulletin of the Seismological Society of America
Published on January 1, 2007 | Cited by 344 articles

Plate-Boundary Deformation Associated with the Great Sumatra-Andaman Earthquake
Subarya, C., Chlieh, M., Prawirodirdjo, L., Avouac, J. P., Bock, Y., Sieh, K., Meltzner, A. J., Natawidjaja, D. H., and McCaffrey, R. | Nature
Published on March 2, 2006 | Cited by 298 articles

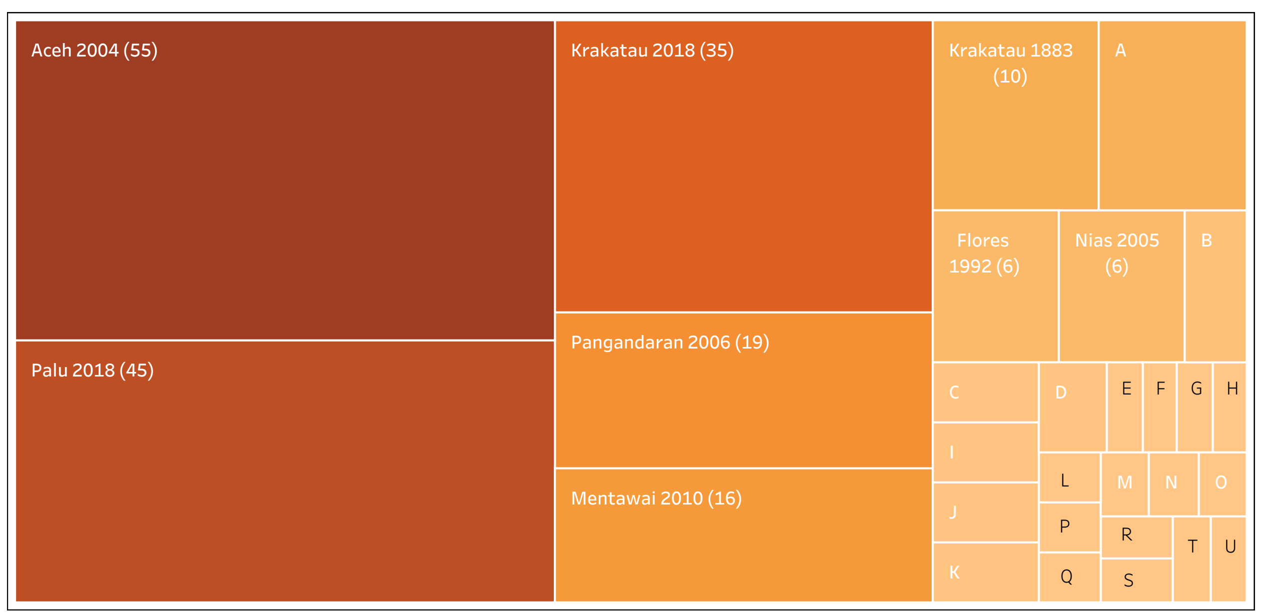
Source Parameters of the Great Sumatran Megathrust Earthquakes of 1797 and 1833 Inferred from Coral Microatolls
Natawidjaja, D. H., Sieh, K., Chlieh, M., Galetzka, J., Suwargadi, B. W., Cheng, H., Edwards, R. L., Avouac, J. P. and Ward, S. N. | Journal of Geophysical Research: Solid Earth
Published on June 4, 2006 | Cited by 159 articles

The 2010 Mw 7.8 Mentawai Earthquake: Very Shallow Source of A Rare Tsunami Earthquake Determined from Tsunami Field Survey and Near-Field GPS Data
Hill, E. M., Borrero, J. C., Huang, Z., Qiu, Q., Banerjee et al | Journal of Geophysical Research: Solid Earth
Published on June 1, 2012 | Cited by 118 articles

Far-Field Tsunami Hazard from Megathrust Earthquakes in the Indian Ocean
Okal, E. A. and Synolakis, C. E. | Geophysical Journal International
Published on March 1, 2008 | Cited by 116 articles

The list above is the top 5 research publications on tsunami hazard assessment in Indonesia, ranked by citation number from 2006-2022 measured by Scopus. All 5 publications is focusing on tsunami generation analysis with regard to past tsunami events and probable future occurrence in Sunda Megathrust and Mentawai intra-plate fault.

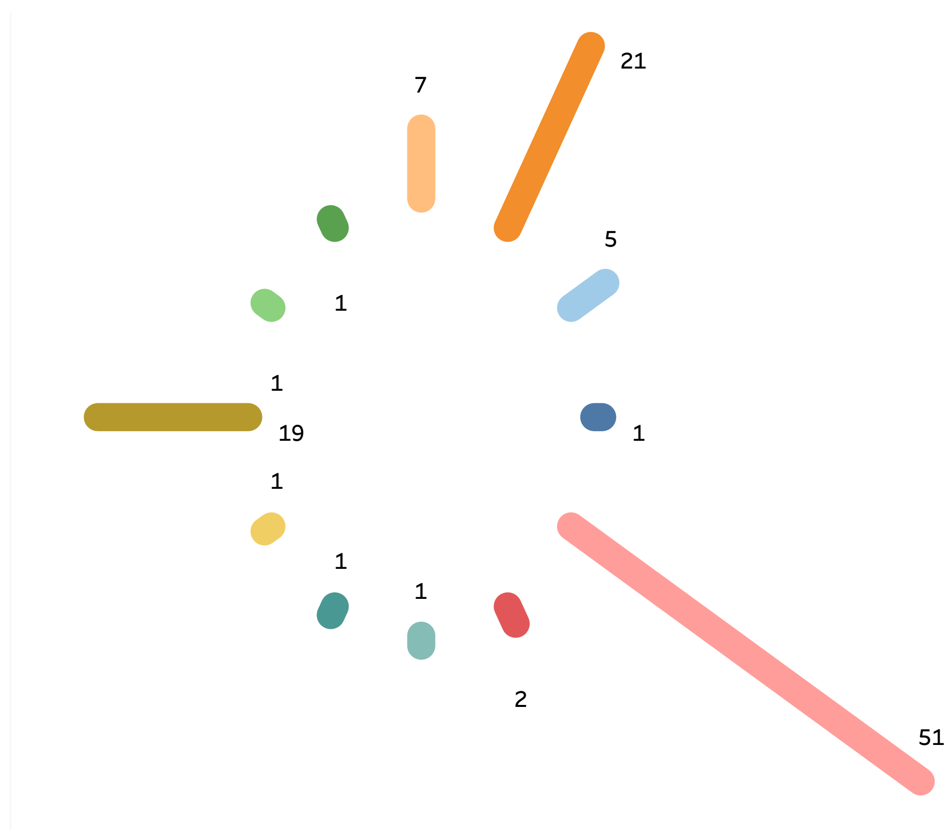
Number of Publication according to Tsunami Event



A = Banyuwangi 1994 (9)
B = Lombok 2018 (3)
C = Ambon 1674 (2)
D = Sumatra Barat 1833 (2)
E = Banda 1674 (1)
F = Bengkulu 2000 (1)
G = Biak 1996 (1)
H = Kepulauan Banda 1629 (1)
I = Bengkulu 2007 (2)
J = Halmahera 2014 (2)
K = Sumatra Barat 1797 (2)
L = Lembata 1979 (1)
M = Mentawai 2007 (1)
N = Mentawai 2009 (1)
O = Simeulue 2012 (1)
P = Maluku 1852 (1)
Q = Maluku 2004 (1)..

According to the tsunami event, the devastating Aceh Tsunami in 2004 is the big focus of research publications on tsunami hazards, even after more than a decade, the researcher still published their study about this event. The second most studied event is the recent Palu Tsunami in 2018 which grab many researchers' attention because of its unique tsunami event that made debate between scientists whether it was generated merely by an earthquake or induced by a submarine landslide. The tsunami event of the Krakatau flank collapse in 2018, Pangandaran in 2006, and Mentawai in 2010 has also been fairly studied by many researchers. Some past tsunami events across Indonesia's archipelago since the early 2000s and even old historical tsunami event has also been investigated.

Tsunami Generation Source



Tsunami Generation Source
- Banda Megathrust
- Flores back-arc
- Krakatau eruption
- Mentawai fault
- Northern Sulawaesi Thrust
- Northern Sulawesi thrust
- Palu-Koro fault
- Pasternoster fault
- Pelabuhan Ratu fault
- Sangihe fault
- Seram Megathrust
- Sunda Megathrust

One-third of the total research publication number specifically investigated the source setting of tsunami generation. Sunda Megathrust become the most frequently investigated by researchers with 51 publications because of its long and wide tectonic active area which stretched from North-western Sumatra until south of Bali Island. Followed by the Krakatau volcano in Sunda Strait, and the Palu-Koro fault in Sulawesi Island. Other tectonic sources of capable generating tsunamis in eastern Indonesia and the intraplate fault are also studied.

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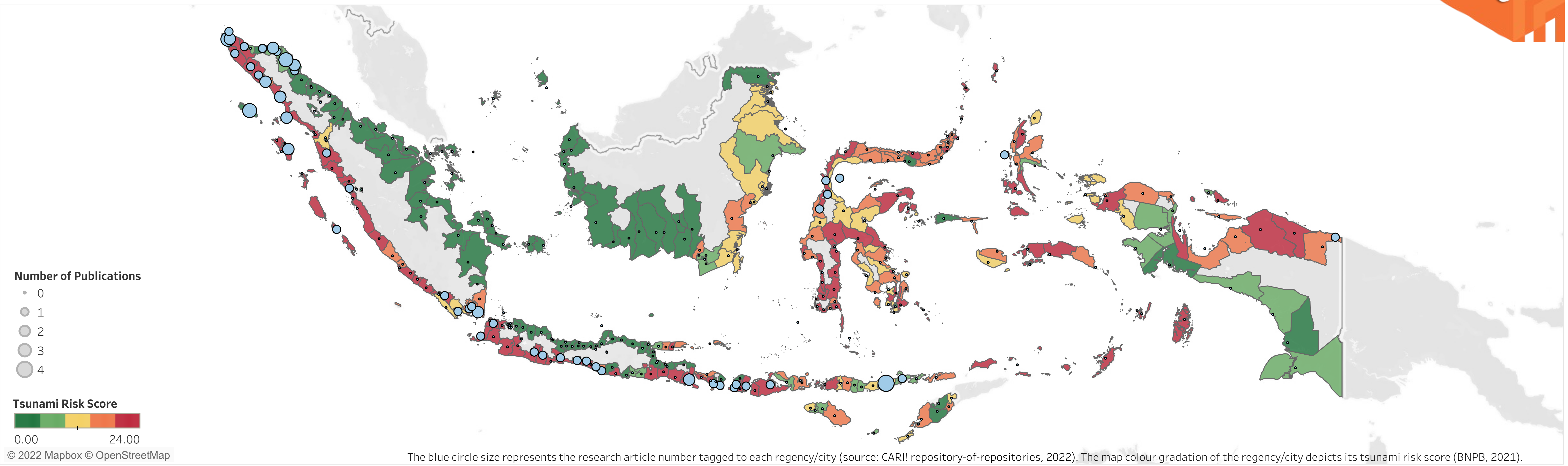
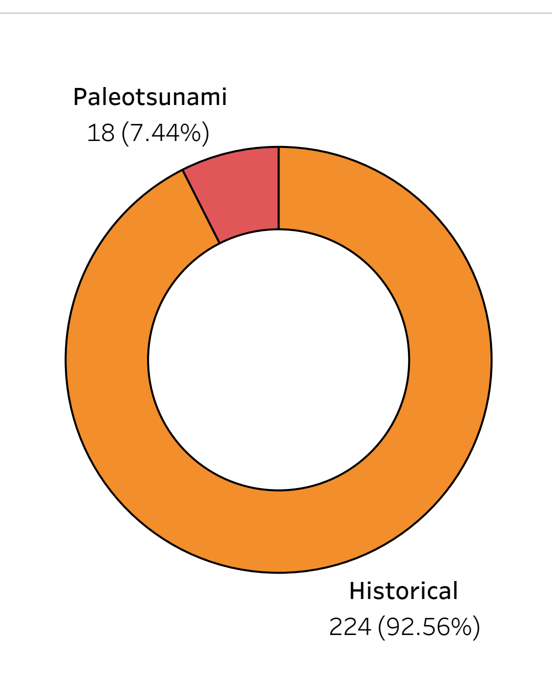
Tsunami Hazard Assessment in Coastal Districts/Cities in Indonesia



The blue circle size represents the research article number tagged to each regency/city (source: CARI! repository-of-repositories, 2022). The map colour gradation of the regency/city depicts its tsunami risk score (BNPB, 2021).

The map above shows the number of tsunami hazard assessment publications of the city/regency (depicted as a blue circle) superimposed with its tsunami risk score. It can be seen that tsunami-prone areas are located along the south coast of Sumatra, Java, Bali, Nusa Tenggara till Maluku, and most coastal areas of Sulawesi Island, Northern Maluku, and Northern Papua. This corresponds with the location of tsunami hazard research that was observed along the coast of Sumatra, Java, Bali, and Nusa Tenggara with a fair number of publications. However, the same tsunami research condition does not observe in half of coastal Sulawesi Island, South Maluku, and Northern Papua. For example, the coastal areas around the Banda trench and Seram Megathrust which suspected capable of generating tsunamis is still lack studies. This underrepresented current knowledge in those areas should raise concerns of researchers or other stakeholders to conduct a hazard assessment.

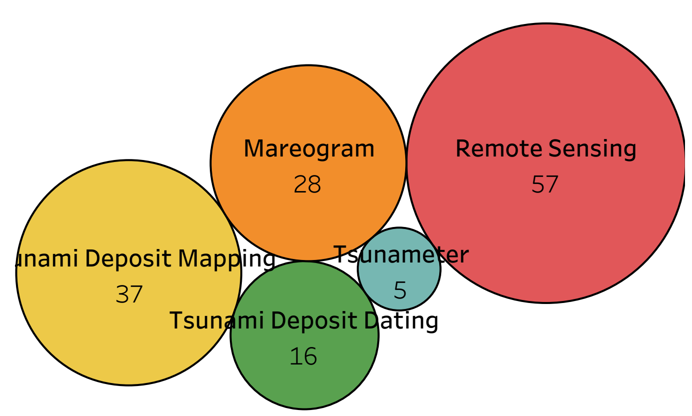
Period of Tsunami Occurrence



The tsunami has been the scientists' subject of study for centuries. There are two major classes of tsunami types based on the time occurrence of the tsunami, which is historical tsunami and paleotsunami. The historical tsunami denotes the tsunami that has been documented through eyewitness or instrumental observation within the historical record. In practice, historical tsunami ranges from manual documentation which dated back to the first tsunami written documentation from observation, and instrumental observation which dated back from the 20th century onwards, from the automatic gauge recording development. The paleotsunamis, on the other hand, are tsunamis that occurred prior to the historical record or for which there are no written observations. To successfully identify this type of tsunami, scientists need to use specific measurement methods, one of which is the tsunami sediment deposit dating to obtain the paleotsunami characteristics.

In Indonesia's case, research studies about historical tsunami occurrence consist of 93% of total publications. While research studies about paleotsunami consist of around 7% of total publications.

Tsunami Monitoring and Measurement Approach



Identifying tsunami can be done using several methods or physical tools that are installed on a specific compatible area, which can function as a tsunami detector or for monitoring purposes. The approaches include mareograph, tsunameter, remote sensing, tsunami deposit mapping and tsunami deposit dating [3]. The mareograph is usually placed around the coastal or shallow basin area and records time series signal gathered from tide gauges, pressure gauges, GPS wave gauge or any station that can possibly record tsunami signal, while tsunameter records tsunami signal and rapidly analyse tsunami height by placing bottom pressure recorder connected to satellite receiver by buoys (I.e., DART) close to subduction zones around the rims of the ocean basin [6].

Another satellite that can be used to detect tsunami is radar altimeter, which belongs to remote sensing category. This category also considers Synthetic Aperture Radar (SAR), any airborne instrument like drone or helicopter or coastal high frequency radar instrument. For general assessment of tsunami according to sedimentation processes, tsunami sediment mapping can be done, while for paleotsunami assessment, tsunami sediment deposit dating is usually conducted [4].

In doing hazard assessment in Indonesia context, researcher dominantly used remote sensing for tsunami monitoring and measurement. Followed by tsunami deposit mapping, mareogram, tsunami deposit dating, and tsunameter.

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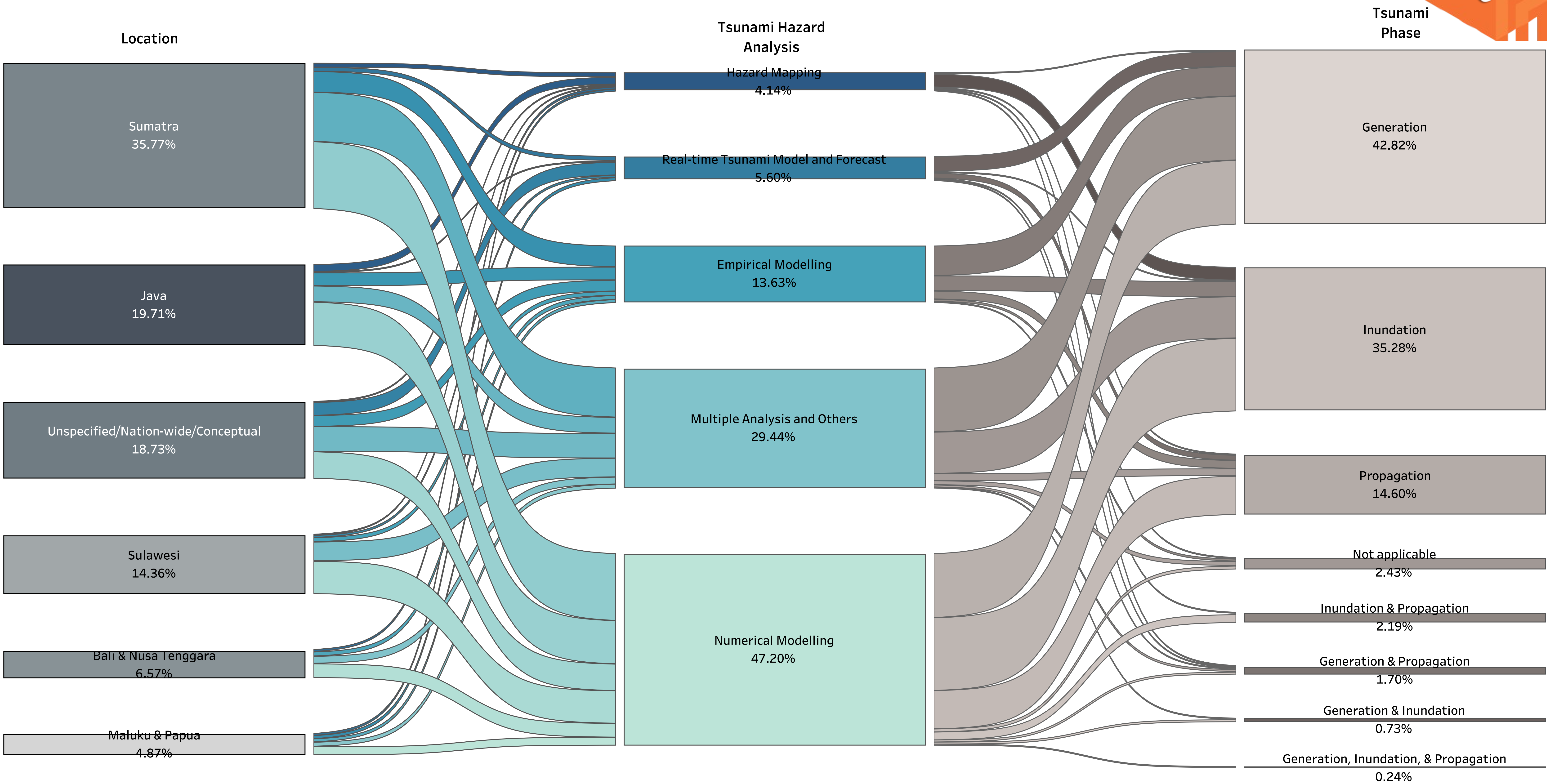
Sankey Diagram of Publications: Location to Tsunami Hazard Analysis to Tsunami Phase



The Sankey diagram is visualized proportionally to the number of publications. The larger size of the box and the wider lines indicate a greater number of publications accounted for them. The Sankey diagram illustrates the distribution of scientific publications and their relations across research locations, tsunami hazard analysis, and tsunami phase.

Review analysis of the research location revealed that the Sumatra region ranked first based on the number of research studies (147 publications), followed by Java region (81 publications), Nationwide studies (77 publications). Whilst Sulawesi, Bali & Nusa Tenggara, and Maluku & Papua regions are quite lagged compared to other regions in terms of the number of publications. Across all locations, the tsunami hazard analysis has a greater pivot for numerical modelling (194 publications). Then followed by research publications on general tsunamimultiple analysis and others hazard assessment, empirical modelling, real-time tsunami model and forecast, and the least is basic tsunami hazard mapping. Tsunami hazard numerical modelling is largely conducted to solely model the inundation phase (145 publications) and tsunami generation (176 publications). In multiple analysis hazard assessment, empirical modelling, real-time model and forecast, a greater number of publications are focused to examined tsunami generation mechanisms. While in tsunami hazard mapping, most studies are about tsunami inundation. This review shows a gap in knowledge about thorough studies in all tsunami phases conducted by all kinds of hazard analysis.

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Data source: CARI! Repository-of-Repositories (DOAJ, Scopus, & Garuda), BNPB, BMKG, and IOTIC.

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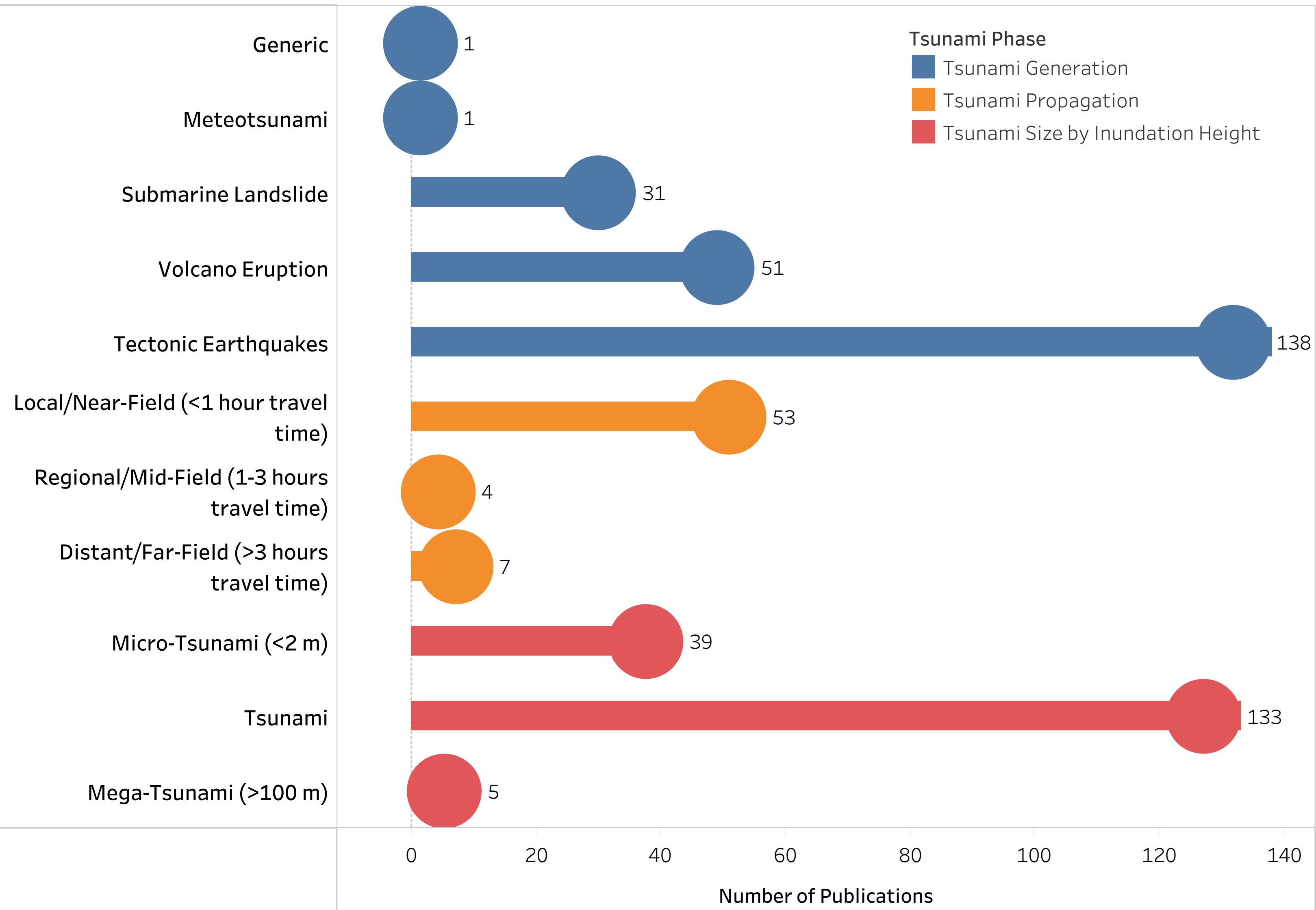
Breakdown of Hazard Assessment topic on Tsunami Phase



As have been previously mentioned, tsunami's life cycle can be divided as generation, propagation, and inundation phase. The generation phase provides analysis about how a tsunami is formed, while the propagation phase shows information about how the tsunami wave travel within the ocean basin. Usually, the propagation analysis is coupled with the maps regarding travel time, coastal amplitude, current speed/velocity, and energy directivity. The inundation phase is showing analysis of tsunami wave spreading around coastal areas, which, due to its destructive force, is usually paired with information of hazard fragility curve or hazard map.

Tsunami Generation

The generation force of tsunami has been one of the important subjects within tsunami research as it holds the key to successfully map and analyse the propagation and inundation of a tsunami. There are two major classification of tsunami generation, which are typical and atypical tsunami. The typical tsunami is the type of tsunami that are produced by tectonic earthquakes (Tsunamigenic Earthquakes), while the atypical tsunami is originated from and submarine landslides (Tsunamigenic Landslides), atmospheric disturbance (Meteorological Tsunami or Meteotsunami) and volcanic eruptions (Volcanogenic Tsunami) [1][11][12].

Tsunami Propagation

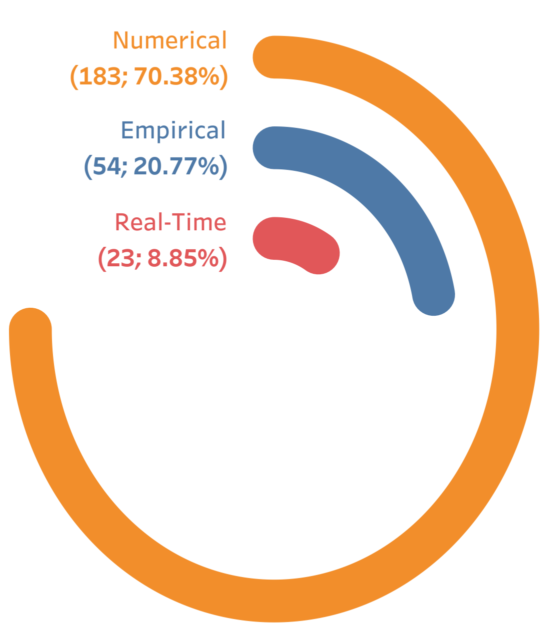
Due to the various morphology of ocean basin, the propagation of tsunami is often asymmetrical (not spreading radially), thus the travel time of a tsunami is varied. Due to that, the nearby coastal areas close to the tsunami source can receive tsunami by a matter of minutes, while distant coastal areas can receive tsunami hours after its generation [1][6]. This information is important to be understood as it is in scope for tsunami warning discussion. Various terms have been proposed to such tsunamis, such as far-field tsunami, tele-tsunami, distant tsunami, or ocean-wide tsunami to describe the tsunami that propagates far across the oceans with a travel time over 3 hours from the source. Other terms describing tsunamis that are generated locally or less than 1 hour travel time are local tsunami or near-field tsunami. In between 1-3 hours travel time, scientist often call it regional or mid-field tsunami [3].

Another way used by researchers to classify tsunami propagation is measured by the distance between source generation location and the impacted coastal area. Namely local or near-field tsunami which are generated from a nearby source within 100 km and distant tsunami or far-field tsunami originating from far away source, generally more than 1,000 km.

Tsunami Size by Inundation Height

According to several sources [1][2][5], there are three tsunami types in this category: micro-tsunami, tsunami, and mega-tsunami. Mega-tsunami has been well known for its massive wave and energy that could displace body of water to over 100m in height, while tsunamis are discernible with inundation height under 100m. The micro-tsunami, however, a kind of tsunami that is unrecognizable to human eyes, because of the low wave and inundation height. It is mentioned that tsunami as high as 1.8m can be considered as unrecognizable, thus publications that mentioned tsunami lower than 2 meters are considered micro-tsunami.

Tsunami Hazard Analysis Modelling



In assessing tsunami hazard, a series of analysis approach is used. These ranges from the general assaessment to a series of modelling approaches. The general assessment counts any information related to tsunami assessment in a general setting, which includes tsunami characteristic analysis using a set of known parameters from previous assessments, such as paleotsunami study or a case-area study [1][4]. Between the modelling methods, empirical model comprises of estimation of specific parameters using a set of statistical analysis [10]. This includes the inverse estimation of source's parameters and estimation of parameters' change, such as earthquake's rupture length, speed reduction and travel time delay.

The numerical model, on the other hand, using advanced mathematical model to simulate tsunami's parameter on a wider setting (two- or three-dimensional, wider basin, detailed resolution, etc). On the implementation, numerical model can be as simple as the Deterministic Tsunami Hazard Assessment (DTHA) that only model one scenario using a fixed set of input parameters or can be as complicated and advanced as the Probabilistic Tsunami Hazard Assessment (PTHA) that can model several scenarios at once [9]. These numerical models can be applied to every stage of tsunami life cycle, such as the source modelling, the propagation, and inundation model. When a paper discusses the creation of travel time maps, coastal amplitude maps, velocity maps, and energy directivity maps, it can be implied that the paper might be using numerical propagation model as its methodology, and when it comes to hazard curve and hazard map discussions, numerical inundation model can be expected [7][10].

A real-time model and forecast relate to the rapid but reliable model to provide real-time sea-level changes using data gathered from deep sea platform located around the subduction zones on the rim of the ocean basin [3][10]. Further, this connects to the discussion about tsunami early warning and early detection analysis.

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