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Unveiling Seismic Patterns in Kalimantan: Insights into Earthquake Events Over the Last Two Decades (2000-2024)

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ABSTRACT

Seismic activity in Kalimantan, once considered to be relatively minimal, has garnered increased scrutiny due to the presence of active fault lines, including the Mangkalihat, Meratus, and Tarakan faults. This research examines earthquake occurrences in Kalimantan from 2000 to 2024, utilizing seismic data from the USGS and analytical tools such as QGIS and Microsoft Excel. The findings reveal that earthquake occurrences are predominantly located in the northeastern and southeastern parts of the region, with magnitudes varying between 3.9 and 6.1. Notably, the year 2015 experienced a marked increase in seismic events. The results emphasize the critical need for disaster preparedness, the resilience of infrastructure, and the establishment of Early Warning Systems (EWS) to alleviate potential hazards. This study advocates for ongoing monitoring and enhanced public awareness to diminish seismic vulnerability in Kalimantan.

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1. INTRODUCTION

Seismic activity on the island of Borneo has been documented over the past few decades. According to data published by AllQuakes in 2024, the North Kalimantan region has recorded a total of 49 earthquake events since 1970, with magnitudes ranging from 2 to 6.1. In general, Kalimantan is perceived to exhibit lower seismic activity in comparison to its neighboring regions. However, the existence of active faults, such as the Tarakan fault and the Mangkalihat fault, suggests a potential for seismic events that warrants attention [1]. Research indicates that this area is not entirely devoid of earthquake risks. A study by Ninis et al. (2022) [2] successfully identified an active fault in Kalimantan that could potentially induce seismic activity. Furthermore, information from the Indonesia Re website in 2019 highlights that Kalimantan is home to numerous faults that may serve as sources of earthquakes. Earlier, Heryanto et al. (1995) [3] had recognized the surface manifestations of elongated faults within Kalimantan.

Fig. 1 Borneo Island

Kalimantan or Borneo, the third largest island in the world, is located in Southeast Asia and is divided into three countries: Indonesia, Malaysia, and Brunei. The island's geological structure is influenced by complex interactions between tectonic plates, including the Indo-Australian Plate, Sunda Plate, and Philippine Sea Plate [4]-[7]. Studies conducted successfully identified that the presence of active faults in Kalimantan has the potential to trigger seismic activity [8]. These tectonic dynamics contribute to the island's seismic activity, although Kalimantan is generally considered to be less seismically active than its neighboring regions.

The preceding discussion highlights that, despite Kalimantan not being situated directly within a subduction zone, akin to other Indonesian islands, the seismic activity in this area warrants careful consideration owing to the existence of multiple active faults [9]. Over the past twenty years, the increasing frequency of earthquakes in this region has piqued the interest of researchers, prompting them to undertake more comprehensive investigations [10].

Earthquakes represent a natural occurrence that can be examined for their potential risks and underlying mechanisms. These seismic events are characterized by vibrations of the Earth's surface, resulting from the abrupt release of energy within the Earth's crust, typically associated with the movement of tectonic plates. The energy discharged during an earthquake produces seismic waves that propagate through the Earth, leading to ground shaking. Various categories of earthquakes exist, including tectonic, volcanic, and collapse earthquakes. Measurements of earthquakes can be conducted using several scales, such as the Richter scale and the moment magnitude scale [11]. A study by Suhartono et al. (2023) investigated the earthquake risk in the Kalimantan fault region employing the Least Square method [12]. Earthquakes characterized by moderate to strong intensity have the potential to inflict significant destruction, primarily due to the direct consequences associated with the origin of the seismic activity [13]. The subsequent effects that arise following an earthquake can lead to diverse levels of risk and further intensify pre-existing damage [14]-[16].

The United States Geological Survey (USGS) is a scientific agency of the federal government tasked with the examination of the nation's topography, natural resources, and natural calamities. Specifically concerning earthquakes, the USGS is engaged in the monitoring and documentation of seismic events, evaluating their impacts and associated risks, and performing research that investigates the underlying causes and consequences of these phenomena [17]. A study featured in the Geophysical Journal International highlights the importance of comprehending the uncertainties surrounding earthquake locations for effective seismic hazard evaluation [18].

Fig. 2 QGIS Software

QGIS is a free and open-source software application designed for the visualization, management, and analysis of spatial data. It accommodates a wide range of data formats and offers tools for vector analysis, geoprocessing, and database management. These capabilities empower users to conduct thorough analyses of spatial data [9]. Microsoft Excel is widely recognized as a prominent spreadsheet application utilized for the analysis of data. Setiyanto (2023) examines the application of Excel within the realm of data science, highlighting functionalities such as error identification, elimination of duplicate entries, and management of missing data [19].

QGIS software was established in 2002, originally named Quantum GIS, and was developed by Gary Sherman. Its primary function is to provide an interface for the visualization of geospatial data [10, 20]. In their research, Lestari et al. (2019) employed QGIS for the analysis of seismicity data [21]. Research indicates that GIS tools are effective in generating risk maps for regions susceptible to earthquakes, highlighting their significance in disaster management [22]. Through the integration of various data layers, QGIS enables thorough analyses that aid in decision-making processes related to urban planning and emergency preparedness.

Given the potential for heightened seismic activity in Kalimantan in the future, it is essential to evaluate systemic interdependencies and integrate cascading effects into simulation tools or prototypes. This approach is vital for enhancing our understanding and bolstering disaster mitigation preparedness and post-disaster recovery efforts [23, 24]. Furthermore, contemporary societies face significant vulnerability to disasters, largely attributable to the intricate interconnections among various regions and infrastructure systems [25].

2. RESEARCH METHOD

2.1. Data Retrival

Fig. 3 USGS Website

To effectively analyze patterns of seismic activity, it is essential to gather accurate and pertinent data that can help identify areas at risk and facilitate early disaster mitigation efforts [26, 27]. The primary source of data utilized in this analysis is the United States Geological Survey (USGS), which offers a range of information, including the location of epicenters, magnitude, depth, and time of occurrence. This data is available for access and download in various formats, including CSV, XML, and GeoJSON.

2.2. Data Cleansing

The objective of data cleaning is to rectify inaccuracies, maintain data uniformity, and enhance the quality of analytical outcomes [28]. The initial phase of the cleaning process involves critical data validation, which ensures that values such as magnitude and depth fall within a reasonable range. Subsequently, data is filtered according to geographical location and temporal parameters. In this filtering process, only data pertaining to the Kalimantan region (defined by specific geographical coordinates) within the years 2000 to 2024 is retained.

2.3. Data Visualization

The significance of data visualization lies in its ability to elucidate patterns of earthquake distribution, the spatial relationships with active fault lines, and trends in seismic activity [29]-[31]. This capability is particularly beneficial for effectively communicating analytical results to the general public.

3. RESULT AND DISCUSSION

3.1. Data Visualization Results

- Graph of Frequency of Earthquake Occurrence in Kalimantan Island

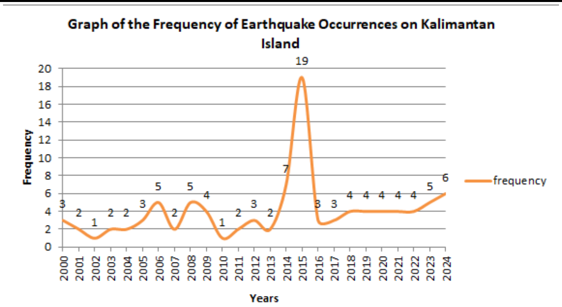

Fig. 4 Graph of Eathquake Frequency

Earthquake activity in Kalimantan is low and stable, with some peaks of activity. Peak activity occurred in 2015, which was the period with the highest seismic activity in Kalimantan, with 19 earthquakes. The average earthquake frequency is around 4-5 events per year. A stable trend emerges in the period 2018-2022, while a gradual increase is seen in the periods 2004-2006 and 2022-2024.

- Ratio Chart of Earthquake Occurrence in Kalimantan Island for the Period 2000-2024

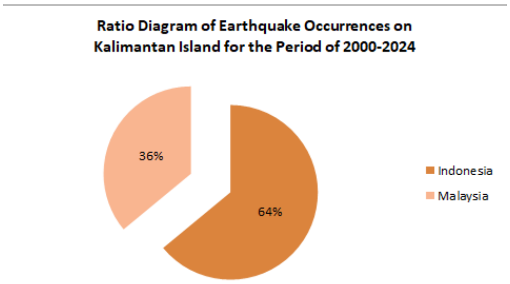

Fig. 5 Ratio Diagram

The Indonesian region dominates in the frequency of earthquake events with a percentage of 64%, while the Malaysian region with a percentage of 36%. This distribution is influenced by geological factors, tectonics, and different areas in both countries.

- Magnitude Ratio Diagram of the Occuring Earthquake

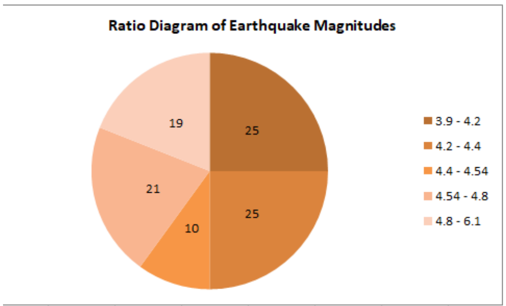

Fig. 6 Magnitude Diagram

Small magnitude earthquakes (3.9 - 4.4) are more frequent and dominate the data. Medium to large magnitude earthquakes (4.4 - 6.1) have lower numbers but are worth noting as their potential impact is more significant. The 4.4 - 4.54 range has the least frequency of occurrence (10), while the 3.9 - 4.4 category has the highest frequency.

- Earthquake Distribution Map of Kalimantan Island for the Period 2000-2024

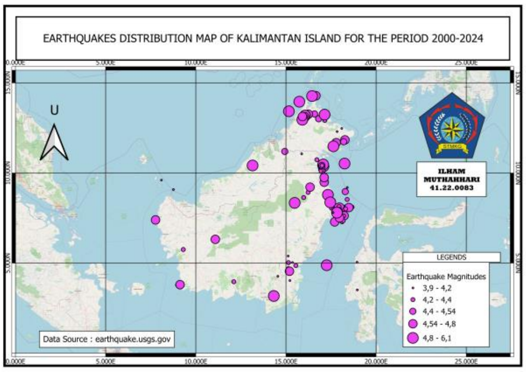

Fig. 7 Earthquake Distribution Map

The region of Northeast Kalimantan shows the highest density of earthquake activity, with many bright magenta coloured circles indicating earthquakes with significant magnitudes (4.8 - 6.1). Most of the earthquakes occurred in coastal areas and waters around the northeast. In the region of South and Southeast Kalimantan, there is a distribution of earthquakes with varying magnitudes, although the density is lower compared to the northeast. Some earthquake points have magnitudes between 4.54 and 4.8. Earthquake activity in West and Central Kalimantan are relatively rare. The small black and light purple circles indicate that most earthquakes have low to moderate magnitudes (3.9 - 4.4).

3.2. Borneo Island Faults

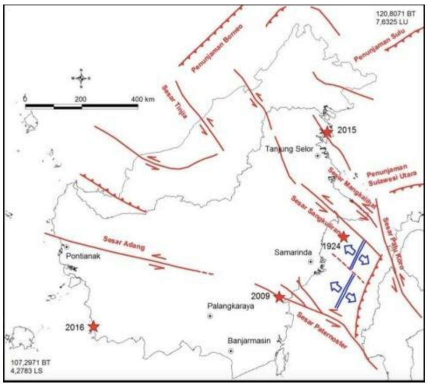

Fig. 8 Borneo's Fault Map

Kalimantan, positioned between the Eurasian and Indo-Australian tectonic plates, experiences considerable geological movement [32]. Research has indicated that the likelihood of faulting is especially notable in the island's mountainous areas [33]. Key faults identified in this region include the Barito Fault and the Kapuas Fault. The Barito Fault runs centrally through Kalimantan, extending from the northern to the southern regions along the Barito River. According to Satyana et al. (1999) [34], this fault exhibits sufficient activity to potentially trigger substantial earthquakes. Conversely, the Kapuas Fault, located in the western section of Kalimantan, aligns with the trajectory of the Kapuas River and is thought to possess a significant capacity for tectonic disturbances.

The faults located in Kalimantan are classified as ancient and are regarded as inactive; however, they may have undergone seismic activity throughout extensive geological timeframes. Notably, certain ancient faults play a role in influencing geological occurrences within the region.

The likelihood of reactivation of these faults is influenced by various factors, including regional tectonic stresses, interplate tectonic forces, and the geological properties of the surrounding rock formations. While researchers have employed seismic modeling, geological surveillance, and analysis of rock structures to assess the earthquake risk associated with these ancient faults, precise predictions regarding the timing or intensity of potential reactivation remain unattainable.

3.3. Seismic Activities in Kalimantan

Although earthquakes are infrequent in Kalimantan relative to neighboring regions, they do occur, particularly in areas near tectonic plate boundaries. Records from the Meteorology, Climatology, and Geophysics Agency (BMKG) over recent years demonstrate that Kalimantan possesses earthquake potential. Notably, the South Kalimantan Sea Island earthquake on February 5, 200 had a magnitude of 5.8, which was felt across various locations, including Laut Island, Sebuku Island, Sembilan Island, Pagatan, and Batulicin. Additionally, on December 21, 2015, at 01:47:37 a.m., a magnitude 6.1 earthquake struck the Tarakan region, occurring at a depth of 33 km and registering an intensity of MMI V-VI, followed by 26 aftershocks. Another seismic event transpired in the same vicinity on June 24, 2016, at 08:41:36, when a magnitude 5.1 earthquake occurred. The epicenter was located at coordinates 2.77°N and 110.09°E, approximately 10 km southwest of Kandawangan, Ketapang, with a hypocenter depth estimated at around 10 km and an MMI intensity scale ranging from V-VI.

The Sampit earthquake of 2023 struck at 01:21:44, with its epicenter located 25 kilometers northeast of Sampit in Central Kalimantan. This seismic event registered a magnitude of 4.3 and occurred at a depth of 13 kilometers. The tremors were experienced with a Modified Mercalli Intensity (MMI) of approximately III in the Baamang and Mentawa Baru Districts of Ketapang, as well as in other regions including East Kotawaringin and Palangkaraya. Subsequently, on February 13, 2024, at 08:22 WIB, South Kalimantan experienced three additional earthquakes with magnitudes of 4.7, 3.3, and 4.1. These quakes originated from the Meratus fault at a depth of 10 kilometers, and were sufficiently intense to inflict damage on structures in Sungkai Baru Village, located in the Simpang Empat District of Banjar Regency.

While the majority of seismic activity in Kalimantan tends to be minor and infrequently results in significant consequences, historical events underscore the necessity for local populations to maintain vigilance and preparedness for potential future earthquakes. It is crucial to enhance public awareness regarding the significance of risk mitigation strategies as part of emergency preparedness initiatives, which are vital for reducing the adverse effects of forthcoming seismic events in Kalimantan [35].

4. CONCLUSION

Kalimantan is generally regarded as a region with lower seismic activity in comparison to its neighboring areas; however, an examination of earthquake data spanning from 2000 to 2024 reveals the occurrence of notable seismic events that warrant attention. The majority of earthquake epicenters are situated near relatively active faults, including the Mangkalihat Fault, Meratus Fault, and Tarakan Fault. The eastern and northern parts of Kalimantan Island, particularly East Kalimantan in Indonesia and Sabah in Malaysia, have experienced the highest concentration of these seismic events.

The findings from this analysis have significant implications for disaster mitigation strategies in Kalimantan. They can inform the enhancement of disaster preparedness initiatives, such as the establishment of an Early Warning System (EWS) and the formulation of regional development plans that are equipped to address potential earthquake occurrences. Given the existence of active faults like the Meratus Fault, which poses a risk of substantial earthquakes, it is essential that mitigation strategies also focus on raising public awareness regarding earthquake risks and constructing infrastructure that is resilient to seismic activity in vulnerable areas.

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