Preface of destructive m<5 earthquakes in Java island, 2015-2019

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Abstract. This study aims to denote the possible casualties and damages due to the M<5 earthquake. We used the desk study of literatures to explore earthquake disaster reports. The published significant and destructive earthquakes catalogue by BMKG Indonesia along 2015-2019 noted that six events out of them in Java island due to by below magnitude 5 (M<5) earthquakes. Those are sourced in the land and shallow depth focus on the active faults region. Those earthquakes also cause human losses, that is three events out of them induce casualties, and kill two (2) people. Preliminary analysis concludes that the short distance to earthquake source and local site condition was responsible for this unexpected building damages. We suggest this events to be the lesson learned for disaster risk managers to consider the low magnitude earthquake also able to generate the high hazard on the certain seismic prone areas.

1. Introduction

The records of earthquake data in Indonesia Agency for Meteorology Climatology and Geophysics (BMKG) and global data indicate any significant increase of events, especially in recent years. As usual the means of earthquake events were 5,000 numbers annually, but since 2017 it has increased to be 7,000, even 11,920 in the 2018 [1].

Based on the tectonic setting, it can be seen from Figure 1 that Java island stands with the earthquake source in the land that is active faults which are quite densely distributed, and in the Indian Ocean, southern part of Java island, that is subduction zone namely Sunda trench or some literature is mentioned as Java megathrust, it can be seen from Figure 2 [2,3]. The earthquake hazard can affect buildings to be damaged and populations to be casualties. We find interesting information on BMKG Destructive and Significant Earthquake Catalogue that is below magnitude 5 (M<5) earthquake enables to destroy the building, even casualties [4,5].

On this article, we write the preface of destructive below magnitude 5 (M<5) earthquakes information on the Java island and its vicinity to denote the possible casualties and damages due to the M<5 earthquake magnitude. We suggest this events to be the lesson learned for disaster risk managers to consider the low magnitude earthquake enable to generate the high hazard on the certain seismic
prone areas. According to this unexpected hazard, we also propose to conduct the vulnerable reduction for people and buildings as an initial effort to reach the disaster resilience.

![Figure 1. Distribution of active faults in Java Island](image1)

**Figure 1.** Distribution of active faults in Java Island  
Source: Indonesia Center for Earthquake Studies (2017) [3].

![Figure 2. Vertical cross section of Sunda Trench, Southern Ocean of Java Island](image2)

**Figure 2.** Vertical cross section of Sunda Trench, Southern Ocean of Java Island  
Source: Earth Observatory of Singapore (2013) [6,7].

2. Data and method

We used the data from the USGS and BMKG Earthquake and Tsunami Center online repository. We used desk literature study towards the BMKG Destructive and Significant Earthquake Catalogue, and Earthquake and Tsunami Newsletter Compilation Books.

Since 1973-2012, we discover 3,678 earthquakes data in Java region. From Figure 3, it can be seen the epicenter is centering in Indian Ocean part of Sunda trench and less dense scattered in the middle of island. The various color gradation of orange, yellow, green, blue, purple and red indicates the depth transition patterns from the south to the north. The depth of epicenter is strongly correlated to steep slab angle Indian-Australian Oceanic plate beneath of the Eurasia continental plate [8]. The size of circles can be seen from Figure 3 the various earthquake magnitude on each events. Table 1 below shows the list of destructive M < 5 earthquakes in Java Island since 2015-2019.
Table 1. List of destructive M<5 earthquakes in Java Island, 2015-2019
Source: BMKG Earthquake and Tsunami Catalogue (2020)

| No. | Location | Origin Time (Western Indonesian Time) | Mag. (M) | Depth (km) | Shaking Intensity Scale | Damage & Casualties |
|-----|----------|--------------------------------------|---------|------------|------------------------|---------------------|
| 1   | 7.73 S; 111.69 N. 12 km south-east of Madiun regency, East Java | 25 June 2015 10:35:29 | 4.2 | 10 | Caruban II MMI; Nganjuk II MMI | 57 houses were damaged, 7 out of them collapsed |
| 2   | 7.25 S ;107.54 E. 15 km south-west of Bandung regency, West Java | 6 November 2016 06:44:14 | 4.2 | 10 | Pangalengan III MMI | 8 buildings were damaged, 5 out of them is residence |
| 3   | 7.22 S ;107.80 E; 21 km south-east of Bandung regency, West Java | 18 Juli 2017 12:58:15 | 3.7 | 10 | Kamojang IV MMI; Solokanjeruk II MMI | Wall of houses were cracked in Ibun and Kertasari sub-regency |
| 4   | 7.21 S ;109.65 E; 52 km north of Kebumen regency, Central Java | 18 April 2018 13:28:35 | 4.4 | 4 | Banjarnegara II MMI | 316 houses were damaged, 2104 people evacuate, 21 people injuries, 2 people die |
| 5   | 6.91 LS ;106.41 BT; 42 km south-east of Lebak regency, Banten | 7 July 2018 10:56:06 | 4.4 | 5 | Cikatomas III-IV MMI; Bayah II-IV MMI; Cisolok III-IV MMI; dan Pelabuhan Ratu II-III MMI | 31 houses were damaged |
| 6   | 6.90 LS ;106.59 BT; 101 km south-east of Bogor regency, West Java | 31 August 2019 11:24:05 | 3.4 | 5 | Ciptagelar III MMI; Sukabumi II-III MMI; Pangerangan Jatake II MMI; Cikotok II MMI dan Bogor II MMI | 9 houses were damaged in Sukabumi |

Table 1 describes each events completed with the location, origin time, shaking scale, coordinate (epicenter), depth, and damage or casualties.

Figure 3. Seismicity of Java 1973-2012
Source: United States Geological Survey (2013) [9]
3. Result and discussion

The June 25, 2015, Madiun earthquake (M 4.2), which caused a destructive shaking, is located in the 12 km south-east from Madiun central regency-East Java at 10:35:29 (Local Time). According to Figure 4, it occurred on the 10 km depth and was felt by people in the Caruban and Nganjuk (II MMI). The Madiun Disaster Management Office (BPBD) noted that 57 houses were damaged, 7 out of them were collapsed. No earthquake casualties were reported. This phenomenon may be related to Kendeng fault tectonic zone and Mt. Pandan magmatic activities [10,11].

This earthquake magnitude was low, but it caused the damage may due to shallow hypocenter and affected by local site conditions [12,13]. It is strongly possible, considering most of Madiun area is covered by unconsolidated sediment, that is alluvium deposit sourced from volcanoes activity. The damage also can be caused by topographical effects considering the Klangon village is located on the steep hill. This site condition can amplify the ground motion acceleration to be stronger [14].

In November 6, 2016 at 06:44:14 (Local Time) a destructive earthquake (M 4.2) struck Pangalengan. It is located in the 15 km south-west from Bandung central regency - West Java. According to Figure 6, it occurred on the 10 km depth and was felt by people in the Pangalengan (III MMI). The Bandung Disaster Management Office (BPBD) noted that 8 buildings were damaged, 5 out of them were residences, and 1 people were injured caused by the debris of building material. No earthquake casualties were reported.

This earthquake is categorized as the shallow depth tectonics earthquake. According to the hypocenter, this earthquake may generate by a very local-active fault named Garut Selatan “GARSELA” (South of Garut city in Bahasa Language) in the surrounding 2.5 km southern part of Cileunca lake.

The July 18, 2017, Garut earthquake (M 3.7), which caused a destructive shaking, is located in the 21 km south-east from Bandung central regency- West Java at 12:58:15 (Local Time). According to Figure 8, it occurred on the 10 km depth and was felt by people in the Kamojang (IV MMI) and Solokanjeruk (II MMI).

The Garut Disaster Management Office (BPBD) found the house wall in Ibun and Kertasari sub-regency were cracked. They also found the rooftop of the Kamojang Pertamina Geothermal Energy ex-control room had fallen. No earthquake casualties were reported. According to the hypocenter, this shallow earthquake may generate by similar to previous very local-active fault activity named GARSELA.
In April 18, 2018 at 13:44:14 (Local Time) a destructive earthquake (M 4.4) struck Banjarnegara. It is located in the 52 km north from Kebumen central regency - Central Java. According to Figure 10, it occurred on the 4 km depth and was felt by people in Banjarnegara (II MMI). The Banjarnegara Disaster Management Office (BPBD) noted that 316 houses were damaged covering 3 villages (Kasinoman, Kertosari, and Plorengan). The total number of evacuees are 2,104 people, 21 injuries, and 2 deaths.

Result of the source mechanism indicates this earthquake may generate by oblique thrust fault activity named Kalibening-Wanayasa fault. This earthquake magnitude was low, but the very shallow focus (4 km) is the reasonable factor for explaining the damage [15]. Another factor, the geological type on the certain site such as soft soil structure potentially amplifies the earthquake ground motion to be stronger [16]. This condition is well known as local site effect. The weak to moderate buildings and no earthquake-safety standard is more vulnerable to be damaged [17,18].
The July 7, 2018, Lebak earthquake (M 4.4), which caused a destructive shaking is located in the 42 km south-east from Lebak central regency- Banten at 10:56:06 (Local Time). According to Figure 12, it occurred on the 5 km depth and felt by people in the Cikatomas (II-IV MMI), Bayah (III-IV MMI), Cisolok (III-IV MMI) on Lebak regency, and Pelabuhan Ratu (II-III MMI) on Sukabumi regency. The Sukabumi Disaster Management Office (BPBD) noted that 28 houses were damaged in Sirnarasa- Cikakak sub-regency (Sukabumi), 2 houses damaged in Kábandungan sub-regency (Sukabumi), 1 house damaged in Cisolok sub-regency (Sukabumi). No earthquake casualties were reported. According to the hypocenter, this earthquake is categorized as a shallow crustal earthquake, may cause by a very local-active fault in Bayah faulting zone. Result of the source mechanism on Figure 13, it indicates this earthquake generated by rock deformation on the strike slip fault activity.
In August, 2019 a series of earthquakes magnitude less than 5 struck Bogor and Sukabumi. It is located around Mount Halimun-Salak area, 100 km approximately to south-west from Bogor central regency - West Java. These events were classified as swarm earthquake or type III on Mogi (1963) classification because there is no mainshock since the first to the last event along weeks to months [10]. The recent studies conclude that location of swarm earthquakes are only found on certain geological special sites.

According to BMKG observation, the August 31, 2019 event is the most destructive. The M 3.4 event occurred at 11:24:05 (Local Time) on the 5 km depth. It is located in the 101 km south west from Bogor central regency - West Java. It was felt by people at Ciptagelar (III MMI), Sukabumi (II-III MMI), Panggarangan Jatake, Cikotok, and Bogor (II MMI). The Sukabumi Disaster Management Office (BPBD) noted that 9 houses were damaged in Sukabumi. The total number of evacuees are 80 people [1]. Building losses in the end of the swarm series may indicate the building resilience has decreased after shaken continuously.

Result of the source mechanism indicates this earthquake may generate by oblique thrust fault activity, but there is no reference available for this fault structure location which generates this swarm events. Therefore, these 6 events were generated by newfounds faults which have not been identified in the earthquake hazard map issued by Indonesia Center for Earthquake Studies (2017).

Unfortunately, the whole area of Java island has earthquake disaster risk due to two types of seismic hazard that are active faults which distributed in the Java interior body, and Sunda trench which subduction zone Indian Australian oceanic plate beneath Eurasia continental plate in the Indian Ocean part of southern Java island [19,20]. Those active faults are able to generate felt earthquakes and damage potential caused by shallow depth meanwhile below magnitude 5 [20,21]. Theoretically, the shaking will be much stronger relevant to the increasing of magnitude (M) and the decreasing of distance (D) [22]. The distance of earthquake source (hypocenter) measured by the distance resultant horizontally in earth surface (X and Y) and towards the depth vertically (Z) [23,24].

Beside magnitude and distance, the other affected factor that is local site condition [25]. It has different conditions on each location depending on geological structure setting. The region with soft soil formation will potentially support the amplification of shaking [26]. This amplification is caused by resonance between two seismic sources that are earthquakes towards natural sites [27]. The seismic natural site can be measured using a micro seismic method [28].

On the range period 2000-2020, the series of deadly earthquakes struck Java island such as Mw 5.9 Yogyakarta earthquake May 27, 2006 (6.234 deaths); Mw 7.3 Tasikmalaya earthquake September 2, 2009 (81 deaths); Mw 6.5 Tasikmalaya earthquake December 15, 2017 (4 deaths). Moreover, historical earthquakes in some places are able to induce collateral hazard such as landslides after the Mw 7.3 Tasikmalaya earthquake September 2, 2009, liquefaction after Mw 5.9 Yogyakarta earthquake May 27, 2006, and tsunamis. The tsunami generated by tectonics earthquake hit Java island 2 times since 1990 to 2020 that are Mw 7.8 South of Banyuwangi Sea tsunami earthquake (223 deaths) and Mw 7.7 South of Pangandaran sea tsunami earthquake (668 deaths). These events are supposed to be the great lesson learned for risk studies, correlated to the multi hazard approach, especially in Java island [1].

Beside their hazards, the crowd demographic condition and the huge number of buildings in Java island are strengthening the condition to be more vulnerable. We suggest this events to be the lesson learned for disaster risk managers to consider the M<5 earthquakes potential disaster, also engage earth scientists and engineers to identify the other potential active faults.

4. Conclusion

Nowadays we tend to mark the destructive earthquake hazard only due to big earthquake magnitudes. Furthermore, the national and local documents of earthquake disaster risk analysis were developed using the worst case scenario that is using the possibly maximum magnitude of earthquakes. This study proves that the below M 5 earthquake (M<5) also enables the destructive hazard on certain seismic prone areas. Preliminary analysis concludes that the short distance to earthquake source and local site condition was responsible for this unexpected building damages. We suggest these events to
be the lesson learned for disaster risk managers to consider the certain seismic hazard region in Java island as the most densely populated and many buildings stands regarding the goals to reduce the casualties and damages.

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