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ANALYSIS OF MICROTREMOR H/V SPECTRAL RATIO AND PUBLIC PERCEPTION FOR DISASTER MITIGATION

Yusran Asnawi [1,2], Andrean Simanjuntak [1,3,5], *Umar Muksin[4,5], Syamsul Rizal [1], Muhammad Syukri [4], Mira Maisura [2], R. Rahmati [6]

[1]Graduate School of Mathematics and Applied Sciences, Universitas Syiah Kuala, Indonesia
[2] Department of Information and Tecnology Education, Universitas Islam Negri Ar-Raniry, Indonesia
[3] Badan Meteorologi Klimatologi dan Geofisika, Aceh Besar, Aceh, Indonesia
[4] Department of Physics, Faculty of Mathematics and Natural Sciences, Universitas Syiah Kuala, Indonesia
[5] Tsunami Disaster and Mitigation Research Center, Universitas Syiah Kuala, Indonesia
[6] Department of Physics Education, Universitas Islam Negri Ar-Raniry, Banda Aceh, Indonesia

*Corresponding Author, Received: 19 Feb. 2022, Revised: 05 June 2022, Accepted: 02 Aug. 2022

ABSTRACT: The NW–SE-striking Seulimeum fault in northernmost Sumatra has triggered several major earthquakes in the last decades and can thus harm the surrounding community. The microtremor HVSR method was implemented in the Lamteuba area, which is proximate to the Seulimeum fault, to analyze the possible seismic impact of numerous shallow-depth earthquakes. HVSR values were calculated for 21 sampling points. Results show that the dominant frequency is between 1 and 4 Hz, and the dominant period is 0–0.5 s; these are associated with young volcanic sediment. The areas with the highest amplification are located in the central and southern parts of the study area, with a vulnerability value (K_g) greater than 1. The K_g value of the northern part is under 1 because of its proximity to a Tertiary volcanic rock formation. About 40% of the study area is vulnerable to earthquakes, as suggested by the high susceptibility index, which is associated with soft sediment. These results are supported by the perception of the local community, which serves as a framework for acculturating the mitigation. The public perception responses show a lack of the knowledge and infrastructure needed to mitigate disasters in the area. This study also reveals a lack of actions to be taken before, during, and after a disaster. This work successfully combines seismic analysis with public perception to determine the earthquake risk level and develop a mitigation plan for the study area.

Keywords: Microtremor, Amplification, Earthquake, Public perception, Mitigation, Seismic, Disaster

1. INTRODUCTION

In June and November 2020, two M 5.0 earthquakes occurred in the northern part of the Seulimeum fault (Fig. 1). Both earthquakes, with an intensity of MMI II–IV, were generated by dextral mechanisms at shallow depths [1]. Other devastating earthquakes at fault include an M 6.5 earthquake that struck the northern part in 1960 [2,3], an M 6.0 earthquake that struck the central part in 1960 [4] and an M 6.0 earthquake that struck the southern part in 1980 [5]. People have reported severe damage and loss from past earthquakes, and Lamteuba is the most-affected area [6].

Lamteuba is a densely populated area on the Seulimeum fault and needs to be studied for disaster mitigation shortly. Tectonically, Lamteuba is proximate to the Seulimeum fault, which has been the northernmost segmentation of the Sumatera fault system since the Cenozoic [7,8]. With a length of ~100 km and a slip rate of ±2.5 cm/year, the Seulimeum fault can generate an earthquake with a magnitude above 6.0 [9].

The districts along the Seulimeum fault can be categorized as a seismic-prone zone, especially Lamteuba, which has experienced massive devastation from past earthquakes [4,10]. Therefore, a comprehensive study on the seismic microzonation of Lamteuba is urgently needed to support a disaster management program for the site [3,4,5]. In this research, we study the microtremor HVSR in Lamteuba and conduct a survey on public perception of earthquake disasters in the area. Findings show that seismic microzonation is needed to develop a disaster mitigation program for the area.

Seismic microzonation is globally used for several purposes, such as for understanding the site effect [10], subsurface properties [10,11], disaster management [13,14], and seismic hazard and geotechnical studies [14,15]. In addition, public perception of earthquakes is required as a framework for acculturating disaster mitigation [16,17]. For this study, a survey is needed because there is insufficient information about earthquake mitigation programs in Lamteuba. Furthermore, we determine the level of earthquake vulnerability in the Lamteuba area and assess the readiness of the community, especially education stakeholders, using the public perception of earthquake disasters.

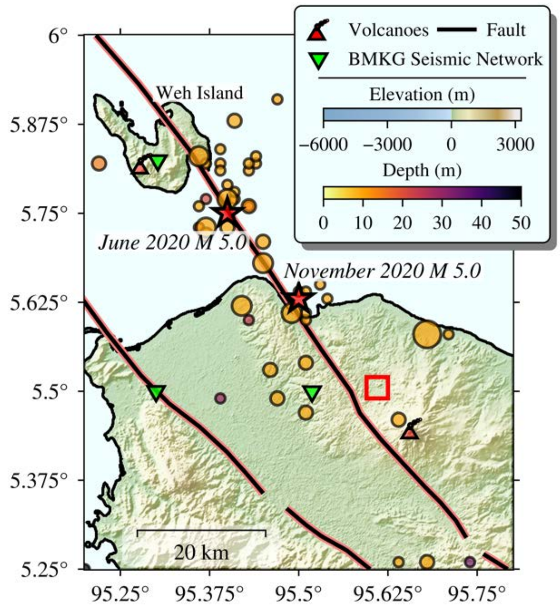

Fig. 1 Historical earthquakes near the study area that have been felt by the local people in the last decade. The red square is the study area.

2. RESEARCH SIGNIFICANCE

The initial survey yielded three main types of data: public knowledge of earthquakes, disaster vulnerability, and the need for facilities that support the disaster mitigation process in the region. According to these initial findings, micro zonation studies are needed to strengthen the seismic knowledge of various circles of society, which in turn can reduce the effects of future damage [14,23]. In addition, future collaborative research based on multidisciplinary studies is required to support a disaster mitigation program. Nevertheless, the microtremor HVSR and public perception of earthquake disasters are prerequisites for initiating and advancing mitigation studies in Lamteuba.

3. MATERIAL AND METHODS

3.1 Data Observation and Location

Twenty-one locations in the Lamteuba subdistrict were measured. The sites cover important public infrastructures, such as the district community, the district office, and schools. The study area is at the eastern part of the Seulimeum fault and lies at a distance of 5–10 km from Seulawah Agam.

The grid of the observation points was set to 200–500 m to cover the area spatially. The instrument used was a broadband seismometer recorded at a sampling rate of 100 samples per second in 30–45 min with a constant transduction factor of 800 V/m/s. The point locations were carefully selected to prevent the recording from being affected by noise from trees, sources of uniform noise (such as machine activity), and strong topographic features. The noise was classified as a transient signal that could be reduced.

Furthermore, the observation points were near public infrastructures, such as the district office and five state schools (primary schools such as SDN 1 Lamteuba, SDN 2 Lamteuba, and MIN Lamteuba, junior high and senior high schools such as SMPN 2 Seulimeum and SMAN 2 Seulimeum). We also surveyed to highlight the preparedness and knowledge of the public about earthquakes.

3.2 HVSR Method

In the horizontal/vertical spectral ratio (HVSR) method, the horizontal and vertical components of a seismic waveform are compared to determine a dominant parameter [16]. The HVSR method was developed by Nakamura [21,22] as a convenient tool for estimating natural frequencies by calculating the ratio spectrum of a recorded microtremor signal as follows:

$$\mathbf{\frac{H}{V}} = \mathbf{\frac{H_{(w)}}{V_{(w)}}} = \frac{\sqrt{\mathbf{S^2(w)_{NS}+S^2(w)_{EW}}}}{\mathbf{S^2(w)_Z}}. \quad (1)$$

In the above equation, the horizontal power spectrum is divided into north-south (NS) and east-west (EW) components, and Z is the vertical component of the waveform. The spectral ratio generally shows various peaks, which are caused by multiple reflections and refractions of incident waves [17]. H/V peaks are empirically an estimation of Rayleigh waves, which dominantly occur at higher frequencies.

Each site has an individual, isolated frequency, which is influenced by subsurface conditions, such as soil thickness, density, and compactness. Through the ratio, a dominant parameter can describe the vulnerability (K_g) in an area. The vulnerability (K_g) from Nakamura [21,22] can be calculated as follows:

$$\mathbf{K_g} = \mathbf{\frac{A^2}{F}}. \quad (2)$$

K_g is useful for identifying areas with weak and poor soil resistance, seismic vulnerability levels, and the possibility of damage that may be heightened by the macroseismic intensity and ground shaking [19].

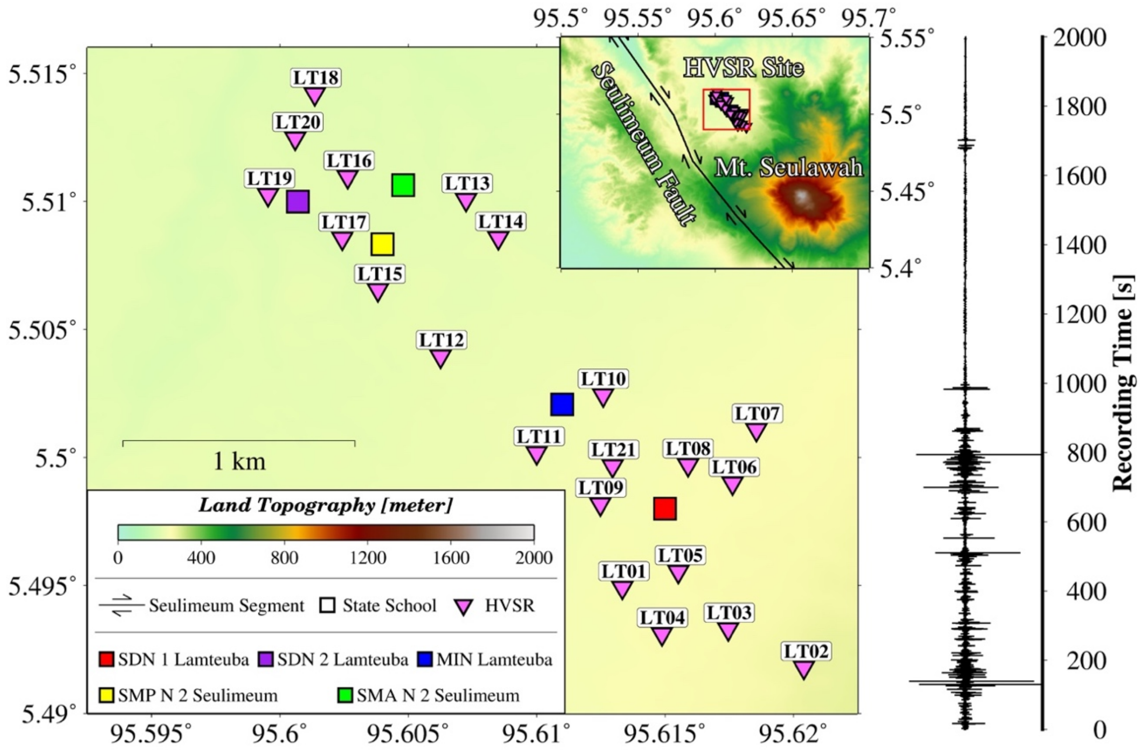

Fig. 2 Survey location in the Lamteuba subdistrict, 21 sampling points, and a sample seismic recording of the vertical component of site LT12 in the 2000s.

3.3 Geologic and Tectonic Settings

The geological setting of the study area, as shown in Fig. 2, is dominantly influenced by local tectonic activity with major fault movement in the right lateral direction [6].

Geomorphologically, the study area is in high-topography regions that are characterized by mountains and steep hills [8]. Lithologically, the study area has been composed of volcano-sedimentary rocks (Lamteuba Volcanic Group) since pre-Tertiary [4,5,8]. It consists of volcanic products from the eruption of Seulawah Agam, such as tuff, breccia, and ash-flow comprising tuffaceous sandstones, conglomerates, and mudstones [20]. These products are considered rock materials based on the classification of the Indonesian National Standard [21].

Young alluvial and volcanic structures, including flat-topped hills, lie along the entire western edge. A flat-topped hill follows closely to the Seulawah Agam, figuring a fault surface structure, namely, the Seulimeum fault. The branch faults control the area in the NW–SE direction. The morphology in the study area is subdued because the rock structure is strongly fractured [20].

The study area is cut by an active fault in the NW–SE direction parallel to the Aceh fault. The rock is compact, but some areas with claystone are highly fractured. The fracture can locally generate impedance contrast between the dense rock and young sediment. Some rocks are influenced by quaternary alluvial sediment that can generally be classified as prone soil.

3.4 Respondents' Data

Data were collected using a public survey. The respondents were divided into three groups based on their background: students from elementary to high school, teachers and headmasters, and community leaders. This study involves 85 students accompanied by 20 teachers from five schools. Among school officials, headmasters and teachers are important, given that schools have removed lessons related to disaster mitigation [22].
Risk education is a long process that transcends the knowledge-sharing stage; it is accompanied by an understanding of choices and preparedness actions to be implemented to recover during disasters [23]. The last group was from the community and involved several civil servants and farmers. Community leaders are vital because they play a crucial role, such as by giving suggestions and recommendations to the local people.

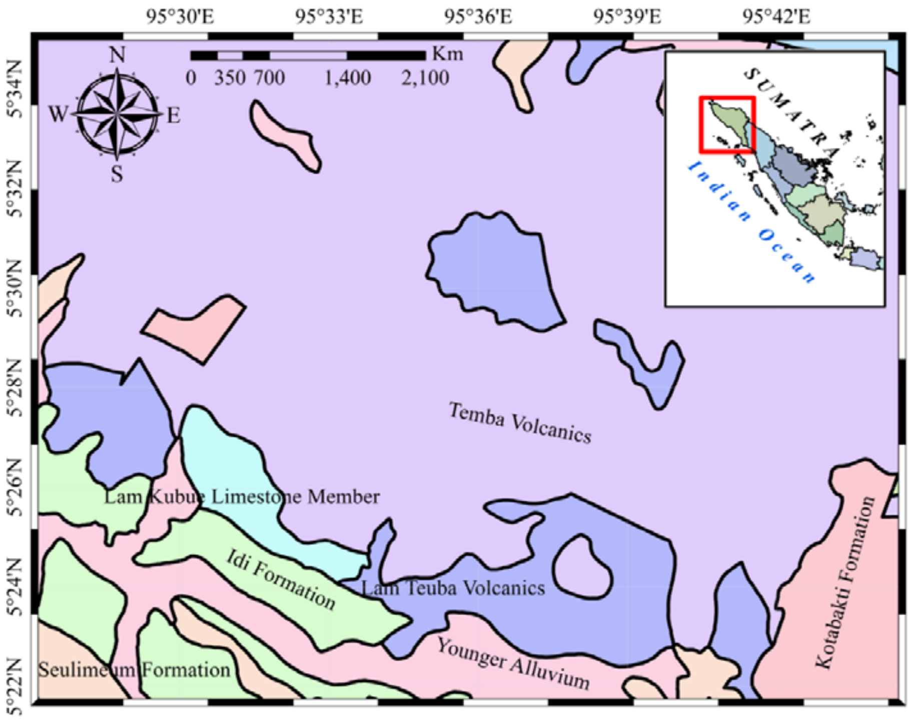

Fig. 3 Geological map of the study area, which mostly consists of volcanic rock and sediment.

4. RESULTS AND DISCUSSION

We started our analysis by examining the waveform quality and removing transient effects with anti-triggering by comparing the short-term average (STA) and long-term average (LTA) between 0 and 30 s. Then, the data were filtered between 0.5 and 15 Hz. Each component was windowed in 20 s steps with a 5% cosine taper. Smoothing was performed to refine the pattern by using the Konno–Ohmachi method [24,25] and obtaining the HVSR with the logarithmic window function. The parameter results were relatively uniform at all sites: frequency of 1–5.5 Hz, period of 0–1 s, amplification of 0–1.8, and vulnerability of 0–2.4.

The soil classification and type were determined based on Kanai and Tanaka's model [26]. Such classification is important for highlighting the geological properties of Lamteuba. The classification was based on the microtremor parameters of each measurement point, such as the dominant frequency, dominant period, amplification, and vulnerability index. The dominant frequency generally illustrates the condition of the soil, which is quite soft and has alluvium and mud in the study area.

Then, the interpolation results of the microtremor parameters at all sites were mapped to elucidate the spatial conditions in the study area (Fig. 4).

a. Spatial Analysis of HVSR Parameter

We used interpolation to identify spatial differences and obtain a clear area that has a dominant parameter. The interpolation results are frequency map, period map, amplification map, and seismic vulnerability. The information from the maps corresponds to three different recordings (from northern, southern, and central parts).

At site LT16 (northern part), the soil is compact, with a 4.885 Hz frequency and a low amplification of 0.5. As for the southern part, the parameter values at LT05 are almost the same as those at LT06, thus indicating a similarity in rock properties. In the central part, LT11 has low parameter values due to the presence of sedimentary rock, which is less compact than the rocks at LT16 and LT05.

The dominant frequency is relatively uniform, ranging from 1 to 6 Hz. Frequency maps may be associated with topography, geological conditions, and bedrock depth. A smaller frequency indicates a greater bedrock depth. In the study area, the central part may have a deeper bedrock compared with the northern and southern parts. The amplification factor, as the peak HVSR, ranges from 0.3 to 1.5, as shown in Fig. 4.

The dominant factor in amplifying the seismic waveform on the ground surface is the amplification factor. The highest amplification can be found in the northern and southern parts, which have higher topographies. The distribution of high amplification in the study area may be associated with low topographies, but it is not influenced by the dominant frequency, and no empirical correlation is established for both parameters.

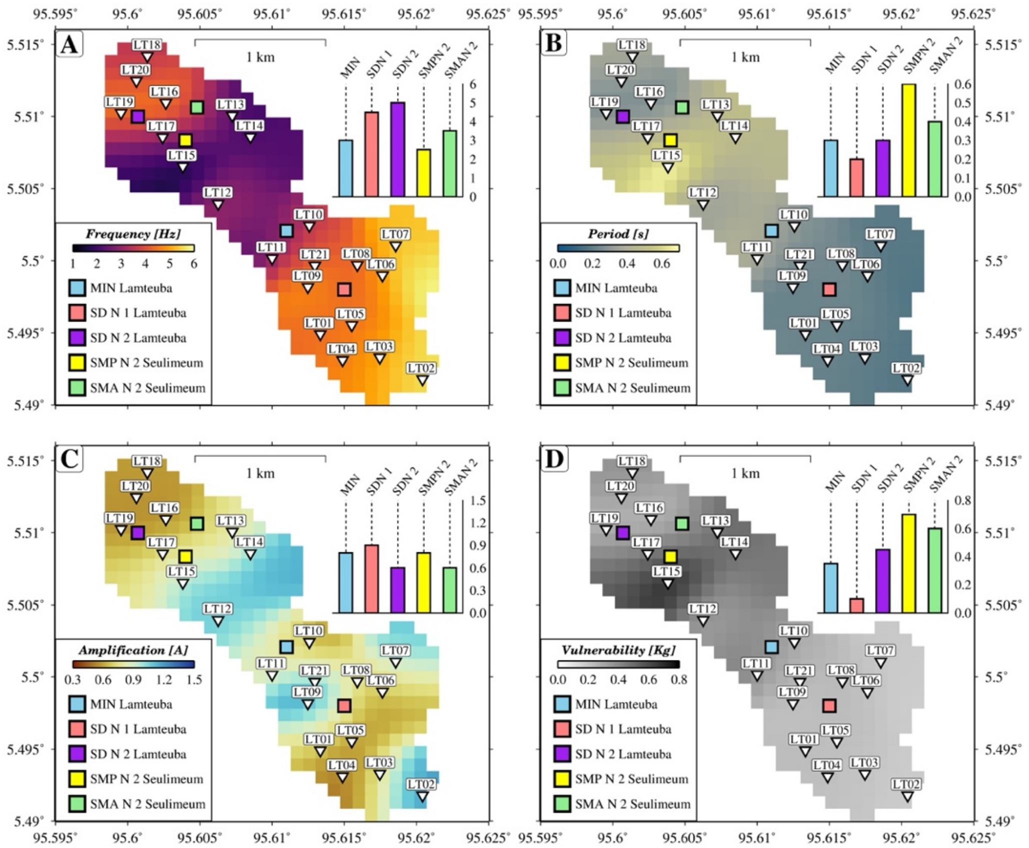

Fig. 4 Spatial interpolation of (A) dominant frequency, (B) dominant period, (C) amplification, and (D) vulnerability for all sampling points.

Variations in the physical properties of rocks, such as shear modulus, damping ratio, and density, also influence the amplification factor. By contrast, the density and saturation state of the bedrock are insignificant. The saturation of the soil layer may affect the amplification factor. Thus, the geological condition has a dominant influence on the amplification variation. Low density and saturation can amplify a surface wave and generate a massive shake when traveling through a poor structure.

Amplification, determined from the HVSR (Fig. 4), is debatable because there is no specific correlation between the ratio and the spectral amplification from strong-motion sensors. Moreover, the northern part, which has a low amplification value, may be recommended as a location for strong-motion sensors. The vulnerability (K_g) from the HVSR is important for identifying areas of potential damage.

Knowledge about potential damage is important to support disaster risk reduction shortly. Many earthquakes cause massive damage because the building is poor and not connected to the site response and properties. As stated in previous studies [13,15,20,22], the distribution value of K_g corresponds to potential damage. The K_g parameter also reflects local side effects and can be used as an indicator in selecting earthquake-prone areas [28]. The K_g values in the northern area are higher than those in the southern area. In particular, the northern sites are weak zones that may fail during an earthquake. The awareness of people in such a high-vulnerability area, where many buildings are located, should thus be enhanced.

b. Survey Results

Most of the infrastructure in the study area is in a region with high vulnerability. We conducted a scenario-based survey to gain insights into the local community's knowledge of disasters. The survey generated various answers regarding the respondents' levels of knowledge of earthquakes.

c. Teachers

The educators consisted of teachers from elementary school (SD), madrasah ibtidaiyah (MI), junior high school (SMP), madrasah tsanawiyah (MTs), and senior high school (SMA). Eighty percent of the respondents do not have any information about past earthquakes, as shown in Fig. 5. Information access is poor due to the inferior network connection in the study area. This finding conflicts with their responses about their knowledge. Specifically, 90% of the respondents reported knowing the definition of a disaster, and 60% stated having adequate knowledge in this regard. Thus, the teachers need to be further educated through several workshops that will provide added information about earthquake disasters.

d. Students

The students gave significantly varied responses between one and other related questions. All of them had never heard of natural disasters that occurred in 1964. Nonetheless, they have a sufficient understanding of the types of disasters and adequately understand the steps to be taken before, during, and after a disaster. Half of the students were able to answer questions on disaster mitigation.

e. Disaster Mitigation Management

In the survey, we asked the respondents about having a disaster mitigation management system (Fig. 6). This system includes the provision of evacuation signs. It also has an early warning system, which is supposed to alert people if conditions show a potential disaster, the availability of medication, and health personnel, including the Red Cross Teen (PMR). Ten percent of the respondents are aware of evacuation signs. However, 90% believe that there are no signs provided within the area.

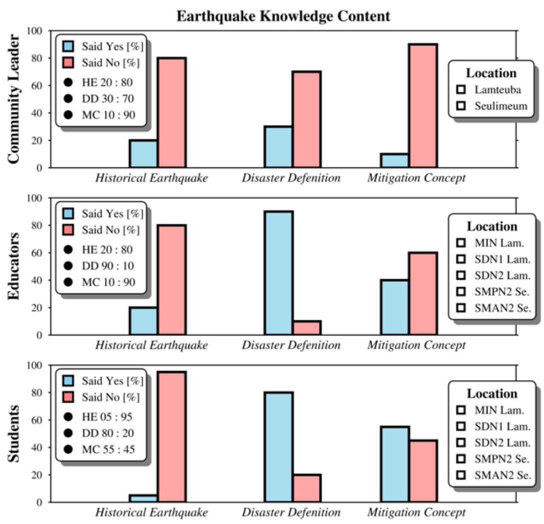

Fig. 5 Public perception survey results from community leaders, educators, and students about their knowledge of earthquakes, such as details on historical earthquakes, the definition of disasters, and the concept of mitigation.

This result differs from those of students and educators; an average of 48% of them believe that signs are provided. Regarding medical facilities, 90% of the educators and community leaders believe that the area has better disaster information and availability of medication. Furthermore, 60% of the students know about such facilities.

The survey also inquired about disaster education, field simulation, early warning system, disaster act, and human response.

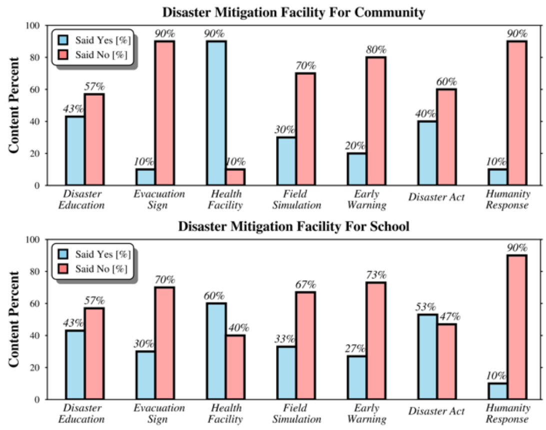

Fig. 6 Community leaders', educators', and students' knowledge of the concept of disaster mitigation and suitable facilities for the community and the schools.

On average, more than 60% assert that there is no alarm system in the area. Educational institutions should help reform school curricula to make them a good starting point in linking education and a disaster mitigation program that will be beneficial in the future [29].

Disaster signs and vulnerability maps are needed to direct the community to safe zones [30]. In addition to evacuation signs, an early warning system should be installed within the area as part of the disaster mitigation system. This will inform the community of potential earthquakes [31]. Furthermore, this research clearly shows a lack of information about disaster mitigation in the Lamteuba region.

The results of this study successfully provide disaster learning by combining microzonation and public perception. Our findings offer basic knowledge of earthquake disasters and what the public needs to support mitigation programs. A recommended direction of further research is the use of a seismic subsurface analysis method to determine the rock properties in the study area. A suitable evacuation program and practice based on vulnerability and subsurface conditions will reduce earthquake damage shortly.

5. CONCLUSIONS

Microtremor parameters showed that the central part of Lamteuba has weak soil and high seismic vulnerability. Low amplification can be found in the northern part, which contains a rock formation. The public perception survey suggested that a mitigation program needs to be implemented before, during, and after a disaster. Earthquake parameters and probability should be disseminated quickly. The awareness of educators, students, and the local community has to be improved based on disaster and evacuation signs. Furthermore, the government should enhance the infrastructure in the area according to its geological conditions. An awareness attitude and an ideal mitigation concept will help save individuals.

6. ABBREVIATIONS

HVSR = Horizontal/Vertical spectral ratio
Qvtl = Volcanic rock of Lamteuba
EW = East–west component
NS = North-south component
STA = Short-term average
LTA = Long-term average
PMR = Palang Merah Remaja (Red Cross Teen)
SMP = Sekolah menengah pertama (junior high school)
SD = Sekolah dasar (primary school)
MI = Madrasah ibtidaiyah (Islamic primary school)
MTs = Madrasah tsanawiyah (Islamic junior high school)
SMA = Sekolah menengah atas (high school)

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