The microzonation of vulnerable earthquake zone in Sorowako city using microtremor

M Karnaen¹, D A Suriamihardja¹, A Maulana¹, and A Jaya¹

¹Hasanuddin University, Jalan Perintis Kemerdekaan KM 10, 90245, Makassar, Indonesia.

E-mail: muh.karnaen@gmail.com

Abstract. Micro-tremor analysis has been used on micro-zonation studies for Sorowako City area. This study is of importance since Sorowako City closes to the Matano Fault as an active seismic area. The city has been developed through mining and agriculture activities, despite prone to be vulnerable to earthquake hazards. This vulnerability increases due to heterogeneous local settlements and public facilities with non-engineering structures to support buildings design. This study aims to conduct micro-zonation over the vulnerable area from earthquake hazard covers an area of 121.3523° E – 121.3692° E and 2.5185° S – 2.5299° S. The acquisition data used portable seismograph instrument comprising of 14 observation points. The obtained signal data was then processed using gypsy software to determine the resonance factor, rock hardness level, and \( K_g \) Index. The results were formulated in three conclusions concerning vulnerability factors. The first factor is resonance phenomena. This vulnerable area caused resonances located along the Street of Merapi’s settlement with a natural frequency of 0.68 Hz that resonates with seven large earthquakes of Matano Fault ranged in the interval of 0.65 – 0.82 Hz. The second factor is a cause of vulnerability which is considered to be the existence of soft rock composition with predominant frequency under 1 Hz that includes areas along Street of Merapi’s Settlement, ship harbor, Magani Traditional Market, and bus station. The third factor is vulnerability of the areas viewed from the \( K_g \) index which gave value of greater than 30 \( K_g \) for areas of Kibait Church, Street of Merapi’s Settlement, Al Ikhwan Great Mosque, and the adjacent area of Lake Matano. The latter is the result of combining frequency and amplitude of micro-tremor waves.

1. Introduction

The City of Sorowako is growing rapidly owing to endowed high regional income. The income is derived from the mining and agricultural products around it. There are nickel mining companies that have been operating since 1977 [1]. The progress of complete City infrastructures accompanies the development of this City. This trend has invited and involved a large number of migrants who have come from different regions looking for a better life and settled in the City. While the development of the City continues well, it is necessary to remind that there exists a chance of disaster occurs that will happen at any time forward. Historically, the most dominant disaster in the city is related to the occurrences of the earthquake.

Needless to say, that earthquake is one of the natural phenomena causing damages mostly to buildings in this city. Although logically that the most damaged area is on the surrounding of the earthquake source, as a matter of facts there are some places away from the faults but also suffered
severe damages. The local rock formations could influence this anomaly. The same situation also occurs as vulnerable area of earthquake disaster around Matano Fault noted at data from Meteorological Climatology and Geophysical Agency [2].

Matano fault has a high level of earthquake activity [3]. The frequency of earthquake in this area is very high and even caused some big earthquakes which caused the damages to the area of the city. This fault passes through several regencies and cities in Sulawesi Island, caused consequently it needs to be aware of its existence [4]. The highest vulnerability is in Sorowako City because due to the most densely populated residential area than any other locations. Shortly, this City becomes the object of studies concerning the damage caused by a major earthquake [5].

Historically, there have been four times significant earthquake (in the years of 2011, 2012, 2014, and 2015) shaking the City of Sorowako [5]. All of these earthquakes came from the source along eastern Matano fault activity. But the vibration is felt in all parts of the City Sorowako even destroyed the settlements and public facilities. Characteristic of the damage to the City is not uniform because having differences in ground structures. The difference of damage needs to be further investigated by several methods. Required research that can provide information on how the urban conditions in the earthquake disaster. Micro-zonation is a preliminary study that can be a guide to give earthquake disaster vulnerability maps [6]. This mapping is a reference as mitigation that needs to be done. The mitigation will provide an evacuation map that guides people around the City. This paper intends to micro-zonation the vulnerable areas due to the earthquake in Sorowako City at 121.3523° E - 121.3692° E and 2.5185° S – 2.5299 S.

Micro-zonation to be done in this study is an analysis based on micro-tremor method. Although this method is quite easy and inexpensive, it is effective to determine the vulnerable zone in an area [7]. An object from micro-tremors is weak ground motion with an amplitude between 1 and 10 µM that generated by natural processes [8]. Micro-tremor was used to obtain qualitative information on a vulnerable area [9].

The micro-tremor analysis provides information on resonance, the softness of the soil, and the $K_g$ index associated with the vulnerable area. The area that resonates with the macro earthquake wave is a vulnerable zone [10]. Soft soils associated with high predominant period are vulnerable areas [9]. The higher of $K_g$ index the associated with vulnerable area [11]. The $K_g$ index can be identified by using natural seismic waves involving dominant frequency variables ($f_o$) and spectral amplitude $A_o$ [12].

2. Review of Related Studies
Micro-tremor is one of the geophysical methods based on passive seismic activity caused by noise resulting from local activities such as tides, wind, seismic, traffic, and industry [13]. The micro-tremor method was used to research local site effect by a Japanese scientist, it related to more serious damage [9]. Micro-zonation based local site effect through micro-tremor data was proposed for Mexico City earthquake damage evaluated [6].

Resonance is a phenomenon that causes severe damage in the event of a major earthquake; this observation was done in the earthquake M. 4.6 Missouri in 1991 [14]. The resonance can be approximated by micro-tremor method comparing natural waves with earthquake waves at the site [15]. Resonance studies have been conducted in Mexico City where Distribution of damage shows high and low anomalies within the City, even shocks are felt strongly in tall buildings [16].

Earthquake disaster occurs when the seismic force exceeds the limits of the strength of ground and structures. It is necessary to know the durability of ground and structures against earthquake [17]. The durability of the ground can be identified by the micro-tremor method. The ground responses are calculated regarding the predominant period [15]. Beroya in Laoag City, Philippines gives the soil classification of the dominant period is hard soils with small periods and soft soils in high dominant periods [9]. The predominant period can be stated the following table below.
Table 1. Soil classification based on predominant period

| Soil Classification | Predominant Period |
|---------------------|--------------------|
| Zone I              | Hard               | 0.8 > P             |
| Zone II             | Medium             | 1.0 > P > 0.8       |
| Zone III            | Soft               | 1.5 > P > 1.0       |
| Zone IV             | Very soft          | P > 1.5             |

Characteristic of surface ground affecting earthquake damage can be grasped by precise measurement [17]. HVSR technique fits very well to describe micro-zonation [13], and dynamic characteristics of ground and structures [18]. The vulnerability indices can express by:

\[ K_g = \frac{A_o^2}{f_o} \]  

(1)

where 
\[ K_g = \text{Vulnerability Indices} \]
\[ A_o = \text{Amplification factor} \]
\[ f_o = \text{Frequency} \]

3. Framework for This Study

People in the City of Sorowako must observe earthquakes because it causes building damages and injuries. Micro-zonation becomes very important in delineating seismic hazard zones within and around City [19]. This study provides an overview of micro-zonation with micro-tremor technical analysis approach. Maximum hazard zones have occurred due to resonance on the Mexico City in the earthquake of 19 September 1985 [16]. The study about how micro-tremor measurement can be used as hazard mapping and micro-zonation based predominant periods in Laog City, Northern Philippines [9]. Vulnerability indexes called K values \((K_g)\) give a chance to estimate the earthquake damage before the earthquake occurs, it has been applied in Turkey with the result show K value is high where the damage risk is high. Therefore, for the framework for this study can be list as below.

![Figure 1. The Conceptual of Framework for This Study](image-url)
4. Data and Method

The data used was primary data. The acquisition was made in the City of Sorowako precisely on the southern part of Lake Matano. Fourteen micro-tremor observation points were determined between the lake port and the airport. Location of the distribution point close to the City facilities such as offices, places of worship, bus terminals, and markets (Figure 1). Data acquisition using TDS type portable seismograph with a duration of 30 minutes at each point was conducted on 14-15 September 2017.

The data of significant earthquakes near this area was used for resonance study. It was secondary data from BBMKG database Region IV Makassar in the year 2009-2017. We obtained seven earthquakes event include parameters of earthquake occurrence time, the position of the epicenter (latitude and longitude), depth, magnitude, and frequency (table 2). From the large earthquake that has been determined the waveform was recorded at the nearest station to the source of the earthquake. In this process one of the stations owned by BMKG was selected namely LUWI station located in the city of Luwuk. In addition to close to the source of the earthquake this station also has a position perpendicular to the Matano Fault which is the cause of large earthquakes in this location.

Table 2. List of Seven Great Earthquakes around Matano Fault

| No | Date      | Time    | Latitude | Longitude | Depth | Magnitude | Natural Frequency |
|----|-----------|---------|----------|-----------|-------|-----------|------------------|
| 1  | 2/15/2011 | 13:33:55| -2.47    | 121.55    | 34    | 6.2       | 0.65             |
| 2  | 12/3/2014 | 27:05.5 | -2.86    | 122.39    | 10    | 5.9       | 0.65             |
| 3  | 4/16/2012 | 17:49.5 | -2.63    | 121.85    | 10    | 5.8       | 0.69             |
| 4  | 4/16/2012 | 01:16.1 | -2.61    | 121.92    | 7     | 5.4       | 0.82             |
| 5  | 4/27/2012 | 29:39.6 | -2.55    | 121.86    | 10    | 5.4       | 0.64             |
| 6  | 5/1/2012  | 59:43.4 | -2.65    | 121.95    | 20    | 5.4       | 0.41             |
| 7  | 7/28/2015 | 38:48.3 | -2.76    | 122.39    | 10    | 5.3       | 0.71             |

5. Method of Processing

Processing methods for this micro-tremor require some software that is TDS, Geopsy, Microsoft window, Microsoft office, and surfer program. Data processing begins with an analysis of field measurement results stored in TDS with the mini-seed format. This measurement is a recording of natural waves at a specified point taking into consideration the location of minimal noise from the activity of the surrounding population. If any activity has a significant effect on the recording, it will be deleted in the next process.

The data is then processed by the HVSR method in the program of Geopsy software. In this process, the noise can be removed to get the original signal without noise from the local acts. To get more objective wave data then processed HVSR method with an automatic menu option. If the method of processing the delete noise is done by manually, it will be subjective results. The result is the predominant frequency and spectral amplification (A_o) and then are mapped in the surfer program.

The frequency at the observation point will be compared with the large earthquake (M>5.0) occurring in the Matano Fault to obtain resonance. The predominant period from frequency reverse became qualitative information on subsoil conditions and site classification. K_g Indices derive from Amplification factor (A_o) and natural frequency (f_o) (equation 1). The micro-zonation of earthquake disaster vulnerability is determined, thus the evacuation map is designed for the surrounding population for earthquake disaster mitigation.

6. The Result of Vulnerability by Resonance Area, Soft Rock Area and K_g Indices

Micro-zonation based on micro-tremor data has been done by using the HVSR method of measurement of signal in the field in Sorowako City. Micro-tremor data has been obtained from the measurements made at some point that has a strategic position on the part of the City. Recording performed at 14 points has a duration of 30 minutes. The results of the recording are a list in the table 3 below.
Table 3. The Result of Micro-tremor Processing

| No | Longitude (degree) | Latitude (degree) | Location | Frequency ($f_0$) | Period (s) | Amplification ($A_0$) | $K$ indices ($K_g$) |
|----|--------------------|-------------------|----------|------------------|------------|----------------------|-------------------|
| 1  | 121.3526           | -2.5201           | Western Tambora street | 1.05          | 0.95            | 3.96                | 15.21             |
| 2  | 121.3519           | -2.5243           | Nuha Community Health Centre | 1.33          | 0.75            | 2.55                | 4.81              |
| 3  | 121.3521           | -2.5261           | Sumantri Brojonegoro street | 1.20         | 0.83            | 3.55                | 10.21             |
| 4  | 121.3555           | -2.5284           | Along Street of Merapi’s Settlement | 0.68       | 1.47            | 5.92                | 58.02             |
| 5  | 121.3572           | -2.5253           | Al Ikhwan Great Mosque | 1.69         | 0.59            | 8.17                | 41.01             |
| 6  | 121.3571           | -2.5238           | Sport Area | 1.01          | 0.99            | 4.99                | 24.01             |
| 7  | 121.3570           | -2.5220           | Muslim Clothing Store | 1.07         | 0.93            | 6.17                | 37.21             |
| 8  | 121.3608           | -2.5220           | Ship harbor | 0.86        | 1.16            | 5.58                | 37.81             |
| 9  | 121.3620           | -2.5239           | Settlement near the estuary | 1.07       | 0.93            | 3.99                | 15.21             |
| 10 | 121.3598           | -2.5278           | Bus Station | 0.98        | 1.02            | 4.68                | 23.51             |
| 11 | 121.3590           | -2.5297           | Airport | 1.65        | 0.60            | 3.39                | 6.81              |
| 12 | 121.3536           | -2.5243           | Kibait Church | 0.88        | 1.13            | 6.48                | 51.20             |
| 13 | 121.3586           | -2.5260           | Magani Market | 2.12        | 0.47            | 3.91                | 7.24              |
| 14 | 121.3573           | -2.5267           | Butcher shop | 1.18        | 0.84            | 3.91                | 13.83             |

The results of micro-tremor measurements performed at 14 points in Sorowako City, acquired the value of the natural frequency from 0.68 to 2.12 Hz. The phenomenon of resonance often occurs during earthquakes. The occurrence of resonance is strengthened if that the medium propagation has the same frequency as the frequency of earthquake waves. This resonance will cause a much larger amplitude due to oscillation at the time of earthquake propagate in the ground surface. Based on the dominant frequency map of the research results, the low frequency is at point 4 (0.68 Hz) at along Street of Merapi’s Settlement. This point has a value equal to eight large earthquakes (0.65 - 0.82 Hz) that occur around Matano Fault (table 2). Thus the zone has a precondition for the occurrence of resonance phenomenon if an earthquake occurs.

The next vulnerability aspect is rock hardness. The zone that has a high hardness of rock is a safety zone when shaken by an earthquake. While the zone that has the composition of the soft rock is a zone that is vulnerable to earthquake shocks. Soft rock zone can be seen from the high predominant value that is at point 4 at along Street of Merapi’s Settlement (1.47 s), point 8 at Ship Harbor (1.16 s), point 10 at Bus Station (1.02 s) and point 12 at Kibait Church (1.13 s). The $K_g$ index is a zone of seismic vulnerability that involving two variables that are frequency and amplification factor. Based on $K_g$ index, there are four zones are vulnerable. It has values above 30 $K_g$ around point 4 at along Street of Merapi’s Settlement ($58.02K_g$), point 5 at Al Ikhwan Great Mosque ($41.01K_g$), point 7 at Muslim Clothing Store ($37.21K_g$), point 8 at Ship harbor, and point 12 at Kibait Church ($51.29K_g$).
Figure 2. [A] The Observation points, [B] Soft Rock Area, [C] Resonance Area, [D] Kg Index Area, with the description of vulnerability area in Sorowako City that red is high, green is medium and yellow is low.

7. Discussion
From the research results, several variables have been obtained from the micro-tremor analysis. These variables are the dominant frequency values, amplification factors, and soil susceptibility in Sorowako City. In relation to the earthquake micro-zonation of disasters, several aspects need to be considered as a disaster mitigation action. Mitigation actions include discussions of vulnerable earthquake zones associated with resonance factors, rock hardness, and soil susceptibility indexes in the city of Sorowako. The evacuation of whole cities or even regions is an important problem. Because of the complexity of the system, an analytic solution to this problem seems to be hard. Therefore, a microscopic multi-agent simulation for the city with all its inhabitants has been developed [20]. An evacuation model describes relationships between the pedestrian and the scenario and decisions taken by the pedestrian himself during the evacuation procedure is developed [21].

From the research results, some data has been processed by researchers to be made mitigation action both structural and non-structural. As a structural mitigation measure, it is advisable to make earthquake-resistant buildings in the vulnerable area to earthquake disasters around the pier, at along Street of Merapi’s Settlement, around the Al Ikhwan highway, as well as around the Kibait church. While non-structural mitigation action one of them is the evacuation path of the population in case of a big earthquake in Sorowako City. Evacuation zoning is very important for disaster prevention. The evacuation path is shown in figure 3 below.
From the picture above there are several roads that will be passed by residents in Soroako city in case of a big earthquake. The vulnerable zone is settlement near Lake Matano, at along Street of Merapi’s Settlement, Masjid al Ikhwan, and around Kibait Church. It is recommended to the local government to make an evacuation route around the highway immediately. The destination point for evacuation is 3 places, around Community Health Centre, south of Magani market, and north of Soroako airport.

8. Conclusion
From the results of data processing and discussion, it can be concluded that several factors cause some areas in Sorowako vulnerable to earthquake disaster. Factors that cause these vulnerabilities are resonance, rock hardness, and soil susceptibility index. Each zone has various vulnerability values. The resonance phenomenon occurs in the area of point 4 at along Street of Merapi’s Settlement because it has a natural frequency of 0.68 Hz which coincides with a large earthquake frequency range of 0.65 to 0.73 Hz. The susceptible zone with soft rock composition is present at point 9 near the estuary (0.86 Hz), Point 13 of Magani Market (0.88 Hz), and Field near the terminal (0.88) Hz. A high soil susceptibility index with values above 30 $\mathbf{K}_g$ is found in the Kibait Church, at along Street of Merapi’s Settlement, the Great Mosque, and around the pier.

The evacuation map provides information that the high vulnerability value is at the point 12 Kibit churches and the point 4 at along Street of Merapi’s Settlement. This zone needs attention so that in case of earthquake it is necessary to evacuate immediately to stay away from adjacent buildings to get to the open. To reduce the adverse impacts of both casualties and material, the high vulnerability zone requires the construction of buildings that are resistant to earthquakes.

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