Seismic Hazard Measurement of Earthquake Swarms Activity Based on Horizontal Vertical to Spectral Ratio Analysis (HVSR) in West Halmahera, Indonesia

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Seismic Hazard Measurement of Earthquake Swarms Activity Based on Horizontal Vertical to Spectral Ratio Analysis (HVSR) in West Halmahera, Indonesia

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Abstract. The swarm earthquake that occurred in West Halmahera which recorded a lot resulted in damage to houses in several rural areas. Although human casualties are not too significant, they affect the stability and capacity of an area in terms of regional development. Mapping of seismic hazard zone is a solution to minimize the impact that will be caused by the earthquake. The purpose of the study is to initial mapping seismic hazard zoning based on Horizontal Vertical to Spectral Ratio (HVSR) analysis. The estimated values of the fundamental frequency range from 0.0 Hz up to 4.9 Hz increases with decreasing depths of basement rock. Regions with the lowest dominant frequency value are South Ibu sub-District, this shows that the area has a large sediment thickness and is a vulnerable area of high. Amplification value range of 4.7 – 51, where the higher the amplification value, the thickness of sediments. The highest amplification value area is Jailolo sub-District and is an area that has a high risk of damage if shaken by an earthquake. This shows that areas that have high amplification values are areas that have the greatest potential for damage due to earthquakes. Analysis obtained from the results of the data shows that the topographic influence is also very significant with the earthquake waves that occur.

1. Introduction

West Halmahera is one of the areas in North Maluku with the highest and unique earthquake vulnerability. This is because the area is located in the convergence of three main plates, the Eurasian plate, the Pacific plate and the Australian Plate, and small plates such as the Philippine plate, Sangihe plate and Halmahera plate. The intensity of the earthquake is centered in the Jailolo area which is the capital of West Halmahera Regency and the center of community activity. Earthquakes in the Jailolo area are dominated by earthquakes with a type of swarm which has a small magnitude character with a very high frequency of occurrence and lasts a long time and is not accompanied by a strong earthquake as the main earthquake [1].

The earthquakes that occurred in Jailolo, West Halmahera were not only sourced from the Maluku Sea Plate but also local earthquakes in the waters of the Jailolo bay and around the Jailolo Mountain. Vibrations felt around Mount Jailolo include shallow earthquakes and cause damage to regional infrastructure. Earthquake events, especially the Tectonic Earthquake in Jailolo, West Halmahera in the last few years, have resulted in damage to houses in several rural areas. Although human casualties are not too significant, they affect the stability and capacity of an area in terms of regional development. It was recorded that the earthquake in 2015, which was 2.385 houses was severely damaged, 1.902 were damaged, and 5.149 were slightly damaged. This is due to the limited level of vulnerability and infrastructure that has a greater earthquake impact [2].

Seismic activity in the Maluku Sea is dominated around the coast of West Halmahera. Significant earthquakes in the area. The distribution of seismic activity in West Halmahera is shown in the figure below:

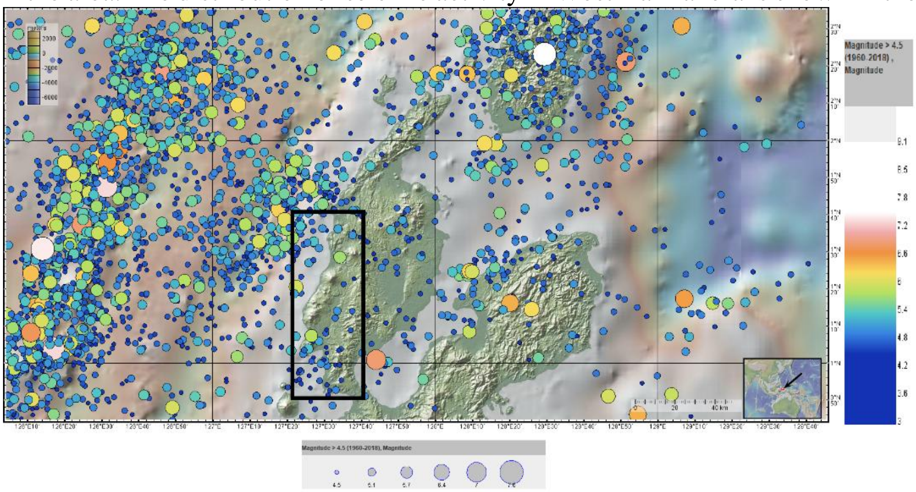

Figure 1. The epicenters of earthquake swarm area of West Halmahera, Indonesia (Data Source: usgs.gov)

Earthquake that has a large and seismic level with an unclear period of time are called earthquake swarm [3]. Earthquakes are expected to come from the pressure of a moving plate and produce a deformation in the rock due to the growing pressure, that's when the earthquake occurs. The earthquake that occurred in Jailolo is influenced by normal faults but is also centered on the Jaiolo mountain which is an old volcano that is inactive and underdeveloped. The cause and trigger of the Jailolo swarm are rocks that burst and propagate laterally. For Jailolo area it is indicated that Jailolo volcano has active magma activity and is expected to carry out research related to volcanic hazards [3] Based on the data obtained that Gunung jailolo is classified as an active volcano although the manifestations and eruptions that occur are not documented in historical records. this volcano can erupt in the Holocene [4].

Mapping of earthquake hazards is a solution to minimize the impact that will be caused by the earthquake. Information on land characteristics and local geology is needed to determine the level of vulnerability of seismic hazard in the West Halmahera area. Microtremor method with Horizontal Vertical Spectral Ratio (HVSR) analysis is a method used to predict subsurface responses based on the dominant period (T) and soil amplification (A) values. This HVSR method is easy to apply and is environmentally friendly to an area with a dense population.

2. Tectonic Setting

Tectonic background in Maluku Sea, one of which is the earthquake in 2014 with a magnitude of 7.1 SR [5]. Figure 1 shows tectonics from the research area [5].

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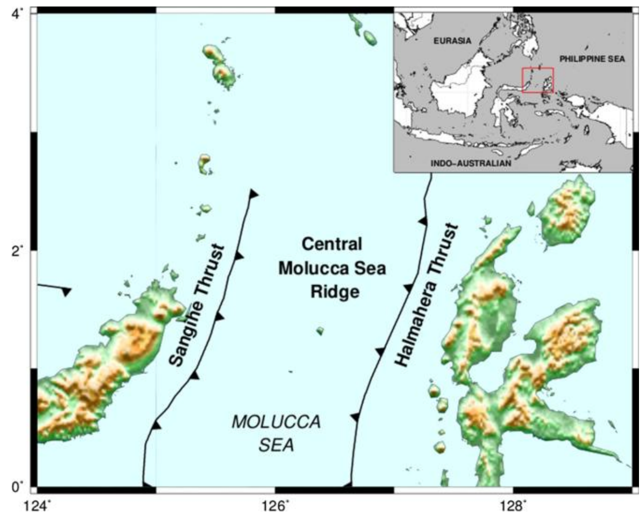

Figure 2. Tectonic Background in Maluku Sea [5]

Maluku Sea is a collision zone with tectonic conditions with the most complex seismicity and is a collision interaction between the Sangihe Archipelago arc that moves eastward with the Halmahera Archipelago arc towards the West [6]. Active volcanoes in the Halmahera arc are produced due to subduction from the Northeast of Maluku [7].

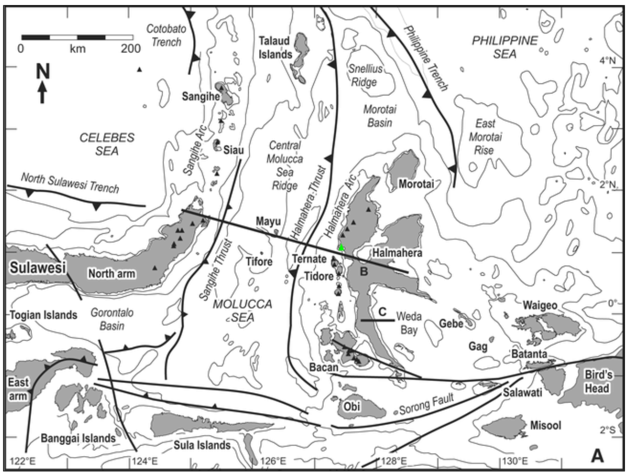

Figure 3. Major tectonic of the Molucca Sea [8]

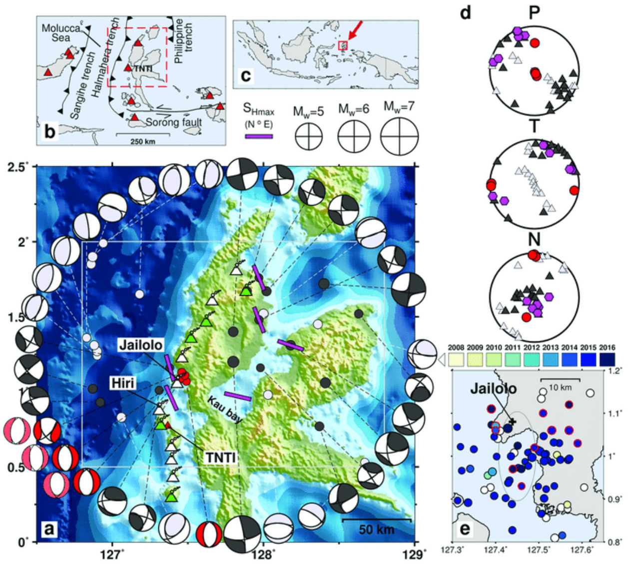

Figure 4. Map of the focal mechanism Halmahera [3]

Jailolo volcano does not have fumarolic, but the emergence of hot springs and hot steamy soil [9]. Earthquake swarm in Jailolo caused severe damage and collapse of houses and buildings in villages located on the south side of Jailolo volcano (Jailolo, Saria and Bobanehena village) and minor damage occurred at Idamdehe caldera. There is a crack along the coastline near Bobanehena and Saria which is indicated as a new hot spring [10]. Figure 5 is a Jailolo mountain located south of the western Halmahera volcanic arc.

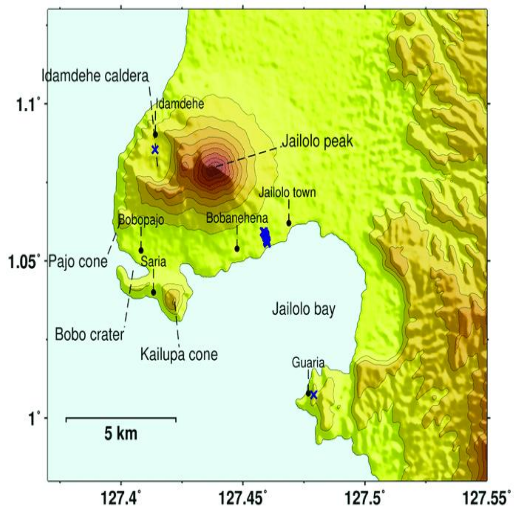

Figure 5. Map of Main Structure in Jailolo Volcano [3]

Swarm earthquakes in the Jailolo volcano occur in a relatively long time, which is more than 2 years starting from 2015 to 2016. It is suspected that there is magma activity, swarm earthquake period, and composition [11, 12].

3. Potential Seismic Hazard

Seen from the tectonic order, the Jailolo area is very vulnerable to earthquake disasters. Earthquake data BMKG records earthquake disasters that occurred in 2015-2016 resulting in damage to infrastructure.

Geological studies show that the Jailolo area is a series of young volcanic mountains. Earthquakes that occur from plate movements, active faults and other types of complex earthquakes. The source of the earthquake due to plate movement includes the Mayu ridge zone (Maluku sea plate), Sangihe earthquake zone and Halmahera-Irian earthquake zone. While the source of the active fault earthquake is the Sorong fault and the complex earthquake source includes the earthquake zone of the Obi fragment and the earthquake source zone of the Banggai-Sula fragment.

Based on data from the North Maluku Disaster Risk Assessment 2016-2020, the West Halmahera region includes a high potential earthquake hazard (BNPB, 2016). The description of the level of earthquake disaster risk in the North Maluku region based on the Disaster Risk Assessment can be seen in the figure below:

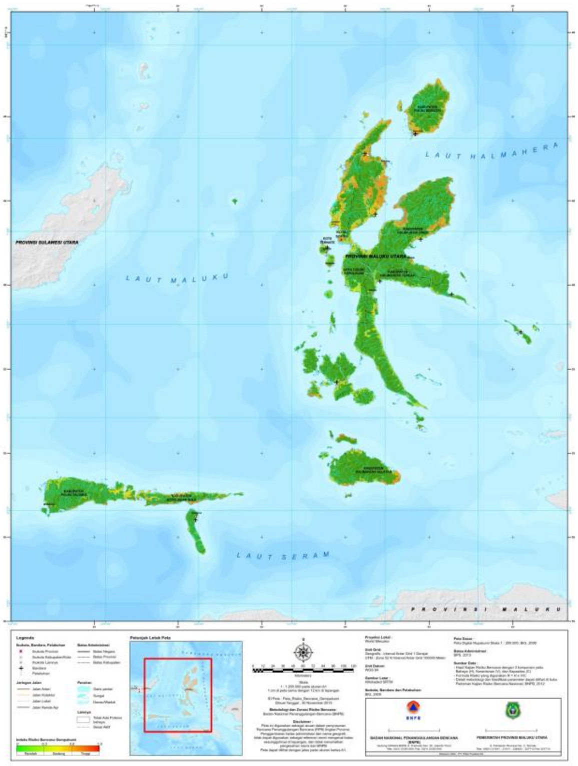

Figure 6. Earthquake Disaster Risk Map in North Maluku

4. Method

The primary data used are seismic wave data (microtremor) as measured by a TDS-303S (Digital Portable Seismograph-three component) seismometer with a sampling frequency of 100Hz. Seismic data obtained were 57 points scattered in West Halmahera (Figure 7). In this research, we use HVSR method or called as the Nakamura technique (1989). The method used in this study is the microtremor method, where this method utilizes ambient waves that appear around the location or also called local earthquakes which are used to determine some characteristic parameters of soil dynamics. Microtremor data processing is assisted with Matlab, surfer, and ArcGIS programs. Data that is processed to produce fo value, Ao.

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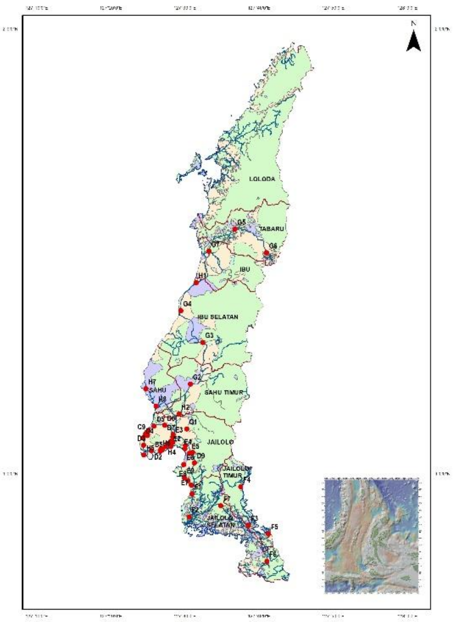

Figure 7. Distribution of microtremor measurements at West Halmahera

Table 1. Microtremor Measurement Point in West Halmahera

No	Point Code	Date	Latitude	Longitude	Location
1	B1	13 July 2018	1,0538	127,4474	Bobanehena
2	B2	13 July 2018	1,0552	127,4486	Bobanehena
3	B3	13 July 2018	1,0556	127,4458	Bobanehena
4	B4	13 July 2018	1,0531	127,4483	Bobanehena
5	B5	13 July 2018	1,0503	127,4442	Bobanehena
6	C1	14 July 2018	1,0972	127,4172	Idamdehe
7	C2	14 July 2018	1,0874	127,4152	Idamdehe
8	C3	14 July 2018	1,0865	127,4147	Idamdehe
9	C4	14 July 2018	1,0856	127,4152	Idamdehe
10	C5	14 July 2018	1,0886	127,4136	Idamdehe
11	C6	14 July 2018	1,0902	127,4141	Idamdehe
12	C7	14 July 2018	1,0917	127,4132	Idamdehe
13	C8	14 July 2018	1,0931	127,4134	Idamdehe
14	C9	14 July 2018	1,0895	127,4123	Idamdehe
15	C10	14 July 2018	1,0874	127,4108	Idamdehe
16	D1	15 July 2018	1,0608	127,4676	Gufasa
17	D2	15 July 2018	1,0514	127,4243	Payo
18	D3	15 July 2018	1,0638	127,4066	Bobo-Idamdehe
19	D4	15 July 2018	1,0803	127,4052	P. Damar Tour
20	D5	15 July 2018	1,1066	127,4300	Marinbati
21	D6	15 July 2018	1,1087	127,4541	Taboso
22	D7	15 July 2018	1,0879	127,4729	Loku Kie
23	D8	15 July 2018	1,0699	127,4719	Gamlamo
24	D9	15 July 2018	1,0240	127,5208	Sidangoli-Jailolo street

25	D10	15 July 2018	1,0478	127,5165	Sidangoli-Jailolo street
26	D11	15 July 2018	1,0633	127,5005	Bukumatiti
27	E1	16 July 2018	1,0668	127,4662	Jalan Baru
28	E2	16 July 2018	1,0725	127,4674	Sokonara
29	E3	16 July 2018	1,0830	127,4722	Hatebicara
30	E4	16 July 2018	1,0560	127,4992	Todowangi
31	E5	16 July 2018	1,0455	127,5091	Tuada
32	E6	16 July 2018	1,0203	127,4970	Motui
33	E7	16 July 2018	0,9741	127,5139	Buku Bualawa
34	E8	16 July 2018	0,9841	127,5063	Buku Maadu
35	E9	16 July 2018	0,9910	127,4980	Tauro
36	F1	17 July 2018	0,9546	127,5156	Tataleka
37	F2	17 July 2018	0,9025	127,5089	Sidangoli Gam
38	F3	17 July 2018	0,8836	127,6422	Tetewang
39	F4	17 July 2018	0,9706	127,6249	Akelamo Kao
40	F5	17 July 2018	0,8643	127,6872	Pasir Putih
41	F6	17 July 2018	0,8030	127,6837	Braha
42	F7	17 July 2018	0,9276	127,5804	
43	G1	18 July 2018	1,1006	127,5036	Porniti
44	G2	18 July 2018	1,2014	127,5119	
45	G3	18 July 2018	1,2951	127,5395	Ibu selatan
46	G4	18 July 2018	1,3664	127,4901	Ibu Utara
47	G5	18 July 2018	1,5495	127,6117	Ibu Utara
48	G6	18 July 2018	1,4963	127,6832	Ibu Utara
49	G7	18 July 2018	1,5002	127,5534	Ibu
50	H1	19 July 2018	1,4296	127,5247	Ibu
51	H2	19 July 2018	1,1338	127,4863	Sahu
52	H3	19 July 2018	1,0669	127,4596	Gufasa
53	H4	19 July 2018	1,0608	127,4556	Galala
54	H5	19 July 2018	1,0419	127,4073	
55	H6	19 July 2018	1,0527	127,4438	
56	H7	19 July 2018	1,1909	127,4116	Todahe
57	H8	19 July 2018	1,1519	127,4345	Sangaji (Sahu)

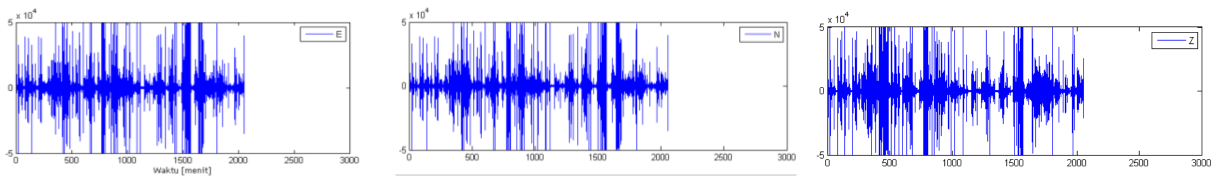

Figure 8. Time chart (microtremor record at West Halmahera)

5. Result

Based on the results of the observations of the ambient waves at 57 points, the three components of the wave component direction Nort – South (N-S), East – West (E-W) and vertical (Z) are obtained. The results of the analysis using the HVSR method will produce a graph of the relationship between H / V and frequency (Figure 9). The value of amplification (A_o) and the dominant frequency (f_{dom}) obtained from the

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graph will be interpolated so that it can be used as a contour of the values of Amplification (A_o), Frequency (f_{dom}) and Dominant Period (T_{dom}) in the study area.

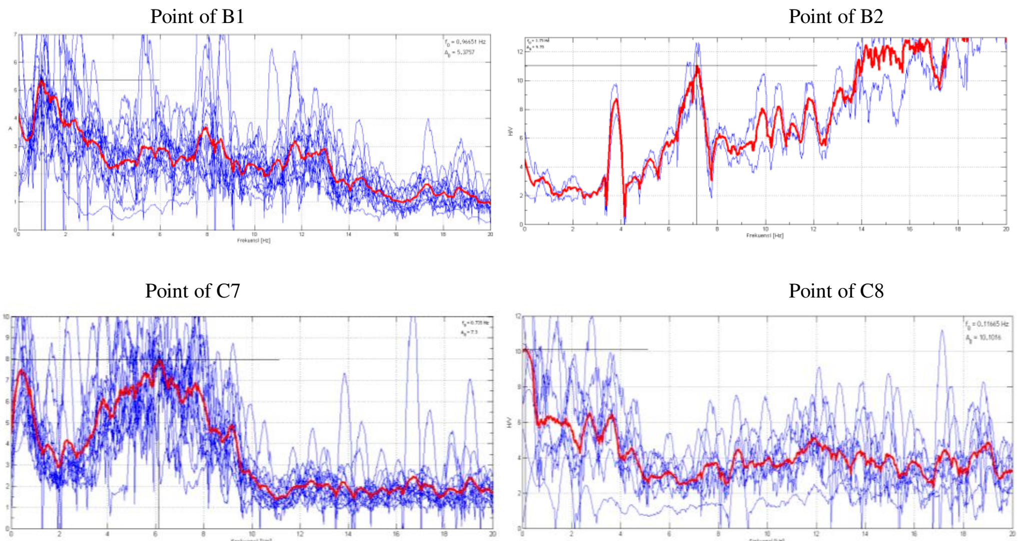


Figure 9. Example of multiple and broad peak graphs of spectra ratio (H/V) curves

The graph of the relationship between H/V and frequency indicates that there is a significant lateral variation in the thickness of the underground or sedimentary structures. Contour maps of dominant frequency values (f_0) in the West Halmahera area vary from 0.0 - 4.9 Hz (Figure 10). From the observation point, around 65% of the regions have a low value of f_0 or less than 1 Hz. The region with the lowest dominant frequency value is the South Mother district, this indicates that the area has a large sediment thickness and is a high-risk earthquake area. Areas with the highest frequency of the dominant frequency will be lower if in areas with deeper basement depth. The dominant frequency becomes higher when in area with shallower basement depths [13].

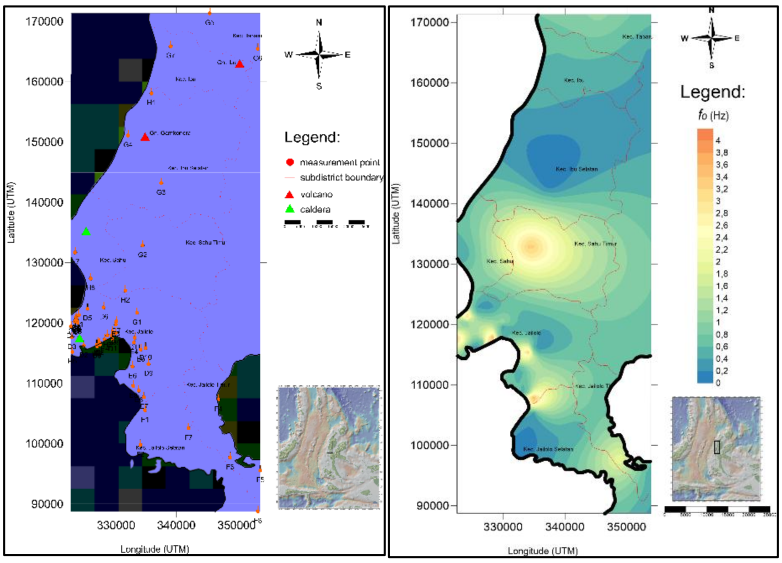


Figure 10. Contour map of dominant frequency (*fo*) in West Halmahera

The amplification value is affected by the wave velocity, the greater the wave velocity, the smaller the amplification value, and vice versa. The value of amplification is closely related to the level of rock density, increasing the value of amplification, the rock will be reduced in density or soft. Contour maps for amplitude H/V (A_0) ratios in West Halmahera (Figure 11) show varying values around 4.7 - 51. The highest amplification area is located at point D10, Jailolo sub-district and is an area with high damage risk. If shaken by an earthquake.

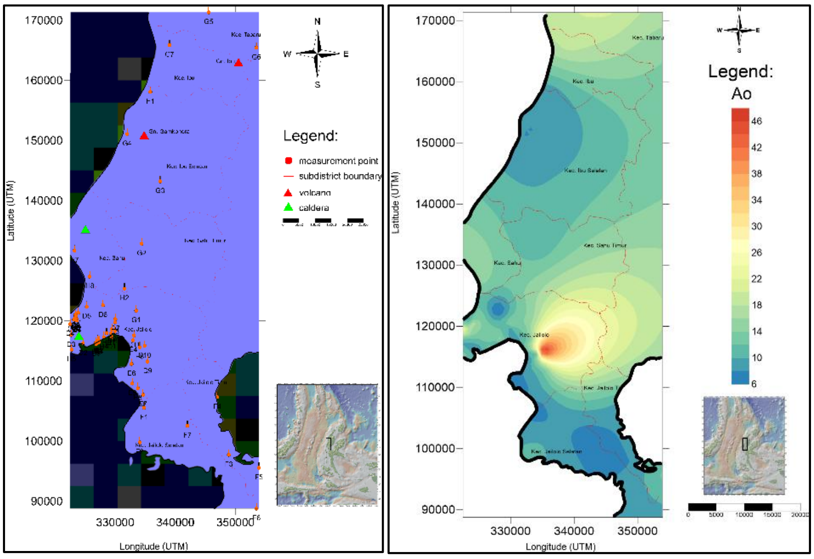
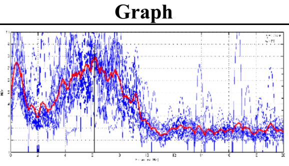
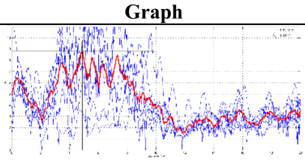
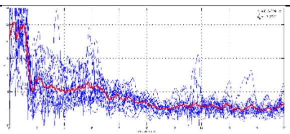
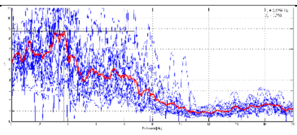


Figure 11. Contour Map of amplitude ratio (*Ao*) in West Halmahera

The influence of topography is very significant with the incoming earthquake waves so that there are some buildings that are damaged and not damaged even though in the same area or still in one village (Table 2).

Table 2. Comparison of HVSR charts on damaged and undamaged village buildings

Point	Damaged		Point	Not Damaged	
	Graph	Building		Graph	Building
B1			B4		
C2			B3		

6. Conclusions

1. The dominant frequency value (f_0) in the West Halmahera area varies from 0.0 - 4.9 Hz. Regions with the lowest dominant frequency value are South Ibu sub-District, this shows that the area has a large sediment thickness and is a vulnerable area of high.

2. The amplitude ratio of H / V (A0) in the West Halmahera area shows varying values around 4.7 - 51. The highest amplification value area is Jailolo sub-district and is an area that has a high risk of damage if shaken by an earthquake.

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Acknowledgments

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