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Mapping the fissure potential zones based on microtremor measurement in Denpasar City, Bali

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Abstract. Denpasar City and its vicinity considered as the areas with excessive ground water exploitation and high earthquake intensity. These conditions will cause these area potential with land subsidence which is triggering ground fissures. This research aims are to mapping the fissures potential areas based on microtremor measurement in Denpasar City and its vicinity. Ground fissures will happen if the land subsidence occurs in the areas which have different bedrock height beneath its sedimentary layer. The height of bedrock is determined by reducing surface elevation with the sedimentary layer thickness. This sedimentary layer thickness obtained from microtremor measurement using HVSR method, and Shear wave velocity (V_S) obtained from microtremor array measurement which is analyzed by Spatial Auto Correlation (SPAC) method. The result from HVSR method as well as Peak Ground Acceleration (PGA) value are then analyzed to get ground shear strain value, which is the soil surface strain and its effect when earthquake occurs. Based on the bedrock map, it can be estimated that the bedrock layer forms structure in the southern part of the research areas and the potential fissuring area due to the massive ground water exploitation is in the west Denpasar Subdistrict. In addition, based on the bedrock map and ground shear strain value which combined with Simple Additive Weight (SAW) method, there are two areas having fissuring potential, i.e west and south Denpasar Subdistricts.

1. Introduction

Denpasar city and its vicinity were considered as the main tourism destination in Bali with rapid development and high water consumption. Almost 30% water supply in Denpasar city provided by government water department from ground water exploitation [1]. Beside that, hotel and tourism business had their own ground water exploration well to fulfil their water needs, this area also have high earthquake intensity, about VI-VII MMI [2]. This condition can cause sedimentary layer compaction at these areas and land subsidence will occurs. Land subsidence is the ground elevation lowering phenomenom caused by soil compaction related to ground water depletion or earthquake. Ground water loss that fills the space between soil grains can cause sedimentary layer compaction and land subsidence will occurs. Earthquake can also caused by the land subsidence when earthquake

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shake the saturated or partially saturated soil then increase pore water pressure and decrease effective soil stress causing water came out from the soil. This called liquifaction phenomenom. Land subsidence that occurs in small area which has different bedrock height beneath sedimentary layer (high slope of bedrock) will increase the horizontal strain of sedimentary layer and triggering ground separations or fissures [3].

The bedrock height (Z_B) as the main parameter that cause fissure when land subsidence occurred. It could be investigated using drilling borehole but it is expensive and slow. Microtremor measurement as one of the geophysical techniques can be used as an alternative that allow investigation in wide area and reduced both time and cost of investigations. Microtremor is all ground vibration not due to earthquake or explosion [4]. Source of microtremor originated from daily human activities such as factory machinery movement, motor, cars, people walking; and natural phenomenon such as rain, wind, ocean waves, and variation in atmospheric pressure [5]. Shelley et.al [3] showed that sharp step of bedrock derived from microtremor related to fissures that occured in Mexico city and the measurement can used to predict the area of next fissure will occur. Microtremor measurement is used to map sedimentary layer thickness, which is the layer on bedrock, and it measurement can be very useful and accurate in mapping small variation in shape and geological structure of bedrock [6]. Sedimentary layer thickness obtained using microtremor measurement using equation

$$H = \frac{V_S}{4 f_0} \tag{1}$$

where H is sedimentary thickness, f_0 is the dominant frequency of sedimentary layer obtained from single station microtremor measurement, and V_S is the shear wave velocity of sedimentary layer obtained from array microtremor measurement.

Single station microtremor measured 3 components of microtremor on sedimentary layer and was analysed using Horizontal-to-Vertical spectral ratio (HVSR) method. This method was proposed by Nakamura [7]. Dominant frequency of sedimentary layer known from H/V curve that obtained by dividing the average spectra of horizontal components by vertical component of microtremor signal. This calculation can eliminate the influence of source effect and also can determined soil amplification factor (A) when earthquake occur since H/V curve exhibits a good agreement with H/V curve from earthquake recording. Further analysis using dominant frequency and amplification, Nakamura [8] using these values and peak ground acceleration or PGA (α) of bedrock layer [9] to determine ground shear strain value (γ), which is the soil surface strain value, calculated by equation

$$\gamma = \frac{A^2}{f_0} \times 10^{-6} \times \alpha \tag{2}$$

Fissures will occur in area which has ground shear strain values about 10^{-4}-10^{-2} [8]. Daryono [10] showed that fissures in Yogyakarta caused by earthquake in 2006 occured in an area which has high ground shear strain value.

Array microtremor measured vertical component of microtremor to estimate a subsurface layered-earth structure and shear wave velocity (V_S) profiles on the assumption that microtremor consist of predominately of Rayleigh waves [5]. Spatial autocorrelation (SPAC) method is widely used for array microtremor data collection, processing and analysis. This method gives good result but need less recording station and shorter dimension arrays measurement compared with the other method. The spatial autocorrelation (SPAC) method was first introduced by Aki [4] that uses the spatial and time stationaries of microtremor to calculate average spatial coherency ($\bar{c}$) over different stations separations that has the shape of zero order Bessel function (J_0) show by equation

$$\bar{c}(f) = J_0\left(\frac{2\pi f r}{V_S(f)}\right) \tag{3}$$

where *r* is seismometer separation distance. The coherency curve is fitted to Bessel function by iterative inverse modelling to obtained shear wave velocity of sedimentary layer [11].

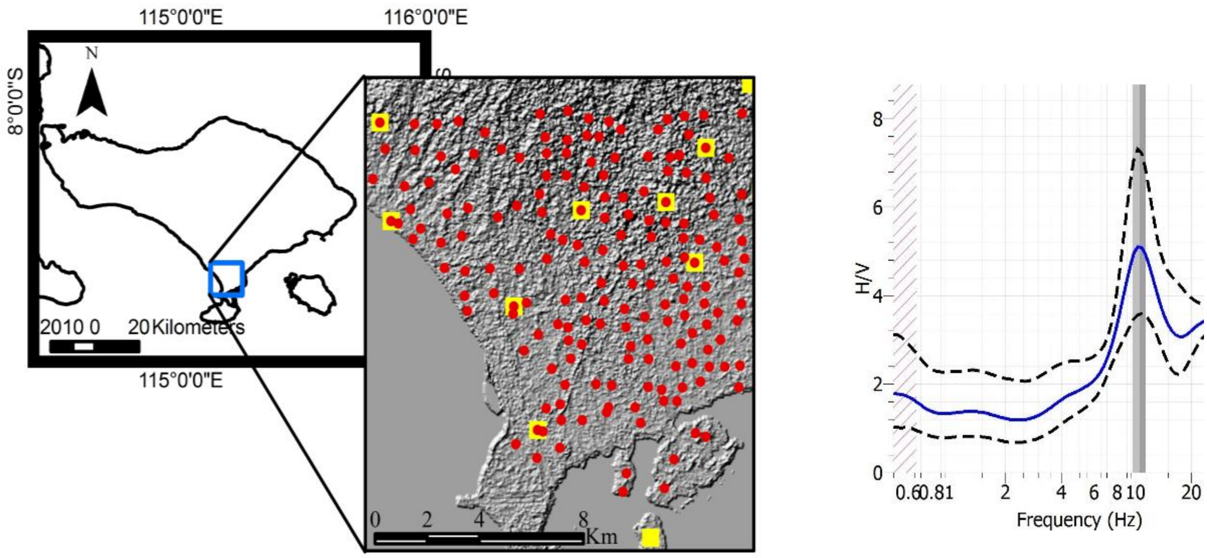
In this work, we developed microzonation of fissure hazard when earthquake and excessive ground water exploration happens. Microtremor measurements was derived to mapped the bedrock height as the main parameter to determine fissure potential zone when excessive ground water exploitation happen and using simple additive weight analysis. We combine the map of bedrock height and ground shear strain value as parameters to determine fissure potential zone when the earthquake happen. SAW is a multicriteria analysis method that combines some data parameter (attributes) into one decision output. This decision output calculated by multiply the alternative of each attribute with the attribute value, then sum the multiply value for all attribute [12].

2. Geological Setting

Geological setting in the middle and south part of the area are included in Buyan-Bratan and Batur volcanic formation (Qpbb) comprises Holocene age that consist of tuff and volcanic mudflow. South part of the area is included in alluvium formation comprises Holocene age that consist of sandstone, clay stone, shale stone, and mix of rivers, seas, and lake precipitations [13].

3. Single Station Microtremor

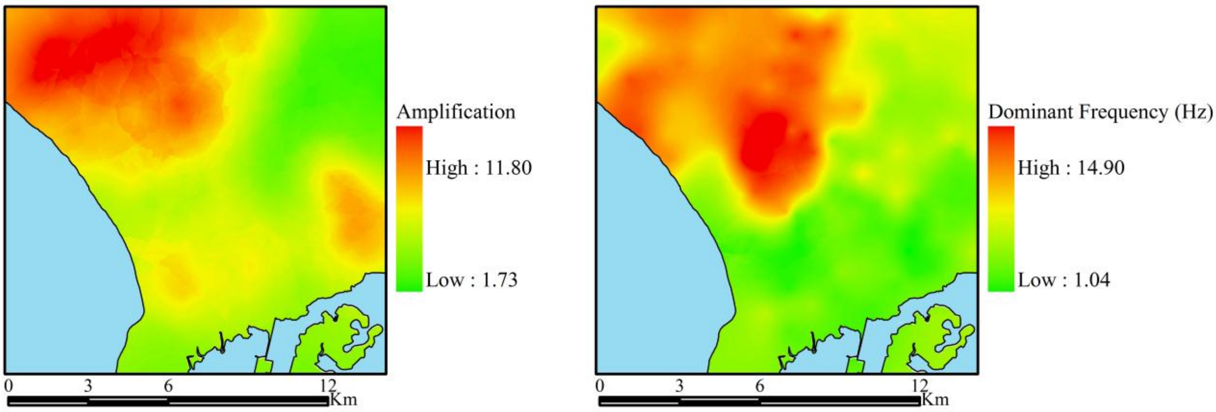
Single station microtremor measurements of 176 sites (figure 1.a) used Mark L4-3D seismometer were carried out over Denpasar city and its vicinity from May - June 2014 and October - November 2014. The HVSR method has been applied on data that were acquired, selected, processed according to the recommendations of Sesame European Project and computed using geopsy free software. Before the spectra computation, the window length for each data was set to a period of 15 seconds in order to capture low frequency of H/V peak curve at a sampling rate of 100 samples per second and 5% cosine taper value. Geopsy software were used to compute the mean and linear trend of all windows, then transformed into Fourier spectra and smoothed by Konno and Ohmachi one with b=15.



(a) (b)

Figure 1. (a) Distribution of measurement points, the red dots are single station microtremor points and yellow squares are array micretremor points. ASTER GDEM map from USGS, (b) H/V curve of point A001.

Most of the H/V curve results show very clear single peak (figure 1.b) with amplitudes that related to amplification value about 1.73-11.80 (figure 2.a). This amplification value could be correlated with a quite clear impedance contrast between bedrock and overlying sedimentary layer. A predominant peak at dominant frequency about 1.04–14.90 Hz appears at research area. Distribution of dominant frequency (figure 2.b) present high dominant frequency value on northern part and small dominant frequency value on southern part. It represents that sedimentary thickness become thicker from northern to southern part since the dominant frequency have negative correlation with sedimentary thickness based on equation 1.



(a) (b)

Figure 2. (a) Amplification map, (b) Dominant frequency map.

4. Ground Shear Strain

The ground shear strain calculated using equation 2 and figure 3 show the distribution of its value. The parameter that used for PGA calculation are the hipocenter and magnitude of 6.41 *Mw* earthquake that occoured in July 14, 1974. The result of PGA calculation in this research area are about 49.03-65.13 gal. The distribution show that based on Isihara's classification [8], almost all the area have high fissure vulnerability because it has ground shear strain value about 10^{-4}-10^{-2} (yellow colour). The West Denpasar subdistrict (green colour) have low ground shear strain value because this area has low amplification value (low contrast of sedimentary layer and bedrock) and high dominant frequency value that represent thin sedimentary layer.

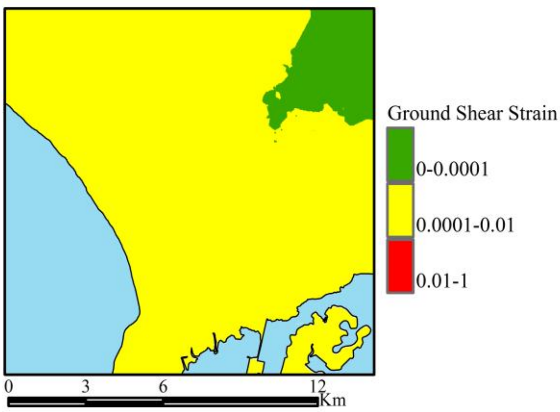


Figure 3. Ground shear strain distribution map.

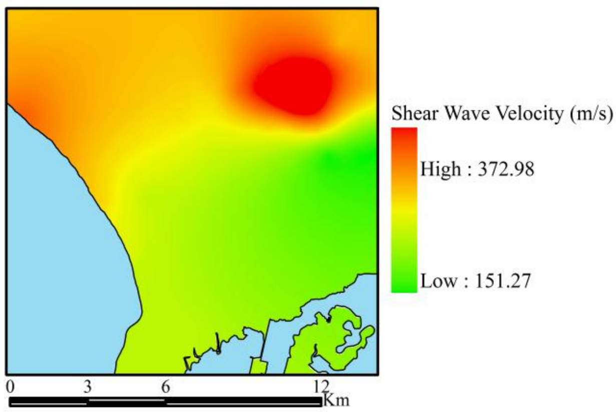


Figure 4. Sedimentary layer shear wave velocity map.

5. Array Microtremor

Array microtremor measurements of 13 sites (figure 1) used 4 OYO seismometer 1134 model were carried out over Denpasar city and it is vicinity from May - June 2014 and October - November 2014. The measurement used triangular array configuration, with seismometer distance (*r*) 2 m, 5 m, 7 m, 10 m, and 20 m for each sites. The duration of the measurement are 20-45 minutes depend on the seismometer distance and its sampling rate are 100 samples per second. The SPAC method has been applied on the acquired data, then processed and computed using geopsy, spac2disp and dinver which are included in geopsy free software package. Shear wave velocity of sedimentary layer resulted from SPAC method (figure 5) then interoplated to obtained sedimentary layer shear wave velocity map. The depth value haven't used for the further analysis because the inversion of homogen sedimentary layer assumption would resulted far estimation from real depth but the shear wave velocity was well estimated compared to borehole measurement [11]. Sedimentary layer shear wave velocity map (figure 4) showed that southern part of the area has lower shear waves velocity than northern part of the area. This condition was caused southern part are alluvium sediment that is weaker than northern part which are Buyan-Bratan volcanic sediment.

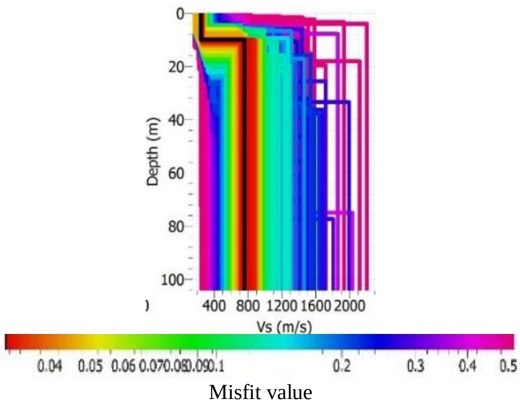


Figure 5. sedimentary layer shear wave velocity of point A01 resulted from SPAC method

6. Bedrock Morphology

The bedrock morphology of the area (figure 6.a) estimated by reducing the surface elevation from USGS Aster GDEM map with the distribution of sedimentary thickness calculated using equation 1. The bedrock morphology results has compared with drilling result [14] (figure 6.b, figure 6.c, figure 6.d). A-A' and C-C' profiles show that the bedrock morphology has good correlation with the drilling result. B-B' profile show bad correlation of bedrock morphology with the drilling result. It happen because the area around B-B' profiles has large dominant frequency value about 1.90-4.35 Hz that represents high variation of sedimentary thickness at this area. A detailed measurement is needed in this area. Figure 6.a shows that southern part of the area has low bedrock height (green colour), located in south part of the area between Mengwi subdistrict, West Denpasar subdistrict and South Denpasar subdistrict. This bedrock height contrast with the other area around it and we predict that the bedrock formed a basin structure. Soebowo et. al [14] named this basin structure as south basin of Bali and this basin predicted as the result of faulted graben in south Bali. We estimated the fault orientation that resulted the graben by the dashed blue line showed in figure 6.a.

7. Estimation of Fissure Potential Zone

Slope of bedrock map (figure 7) show the high fissure potential zone when excessive ground water exploration happen is West Denpasar Subdistrict which has slope value >45^0 (red area) and located at basin structure. Medium fissure potential zones are West and South Denpasar subdistrict, a part of East Denpasar subdistrict and Mengwi subdistrict. High and medium fissure potential area located in pedestrian area included in Buyan-Bratan formation and small area of alluvium formation. Almost all the area has fissure potential when excessive ground water exploitation happen because from Bali hydrology map [15] was known that bedrock height are lower than ground water height except the northern part of this area which has ground water heigh 25-35 m.

Fissure potential zone when earthquake happen (figure 8) has been estimated based on the bedrock slope value and ground shear strain value which both of them combined using simple additive weight method. High fissures potential zones when earthquake happen are in the West Denpasar subdistrict, South Denpasar subdistrict and small east part of Kuta subdistrict. Fissures can occur at this area because from hydrology map of Bali [15] shows that the surface elevation gap with ground water height is less than 5 m. This condition can trigger liquefaction when earthquake happen and causing fissure because it has high ground shear strain value and high slope of bedrock.

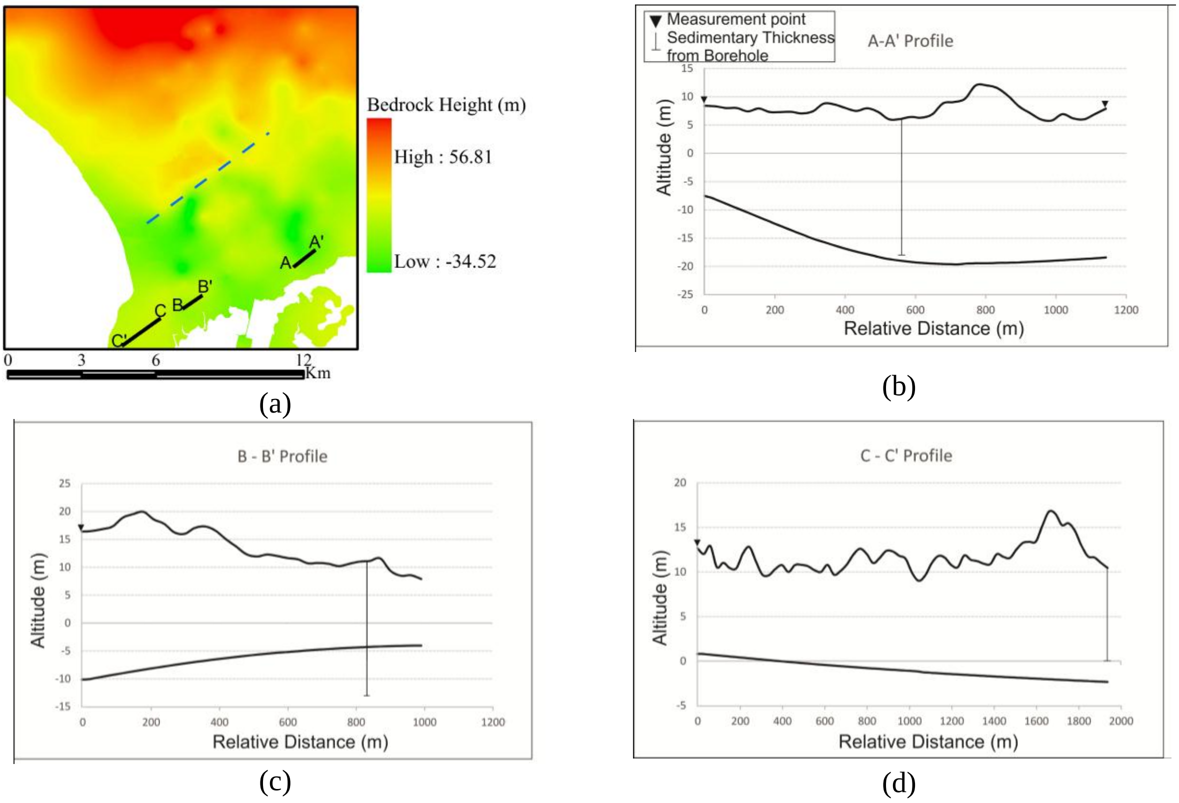


Figure 6. (a) Bedrock height map, dashed blue line show the predicted fault, (b) A-A' (c) B-B' (d) C-C' cross sections showing the subsurface structure profile.

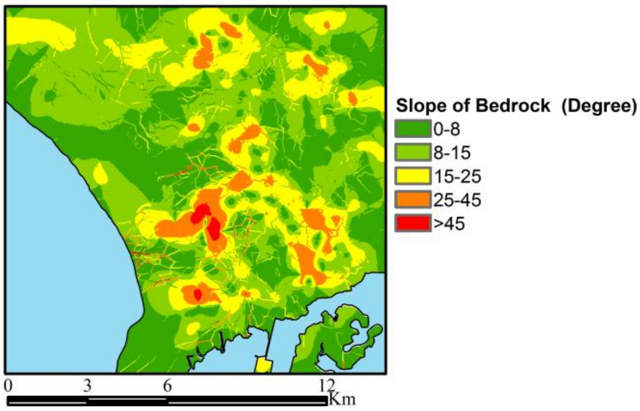


Figure 7. Slope of bedrock height map.

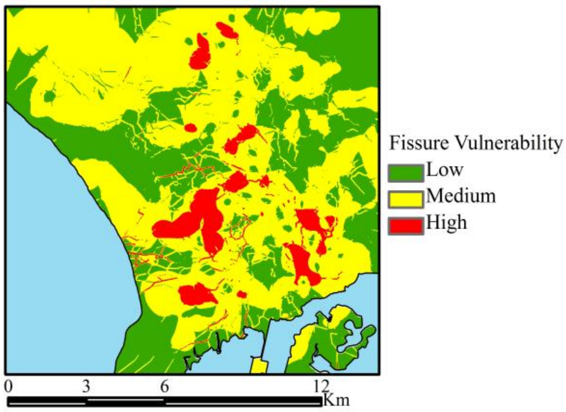


Figure 8. Fissure potential map when earthquake happen

8. Conclusion

In the present research, microtremor analysis have been carried and the fissure potential zone of the research area have been determined. Our result confirm the suitability of microtremor analysis as geophysical method to explore the geological setting especially in sedimentary layer. This analysis can also well estimate the bedrock morphology underlying the sedimentary layer. In addition, we has estimated the fissure potential zone that can be used for fissure and seismic hazard assesment. As the results, there are two areas having fissures potential, i.e West and South Denpasar subdistricts.

Acknowledgement

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