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Analysis of Lombok 2018 earthquake effects on surface deformation process based on time lapse microgravity data (case study: east Lombok and central Lombok regencies)

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Abstract: Fault activities was detected during periods of 2016 to 2018 which presented by land subsidence in East Lombok and Central Lombok regencies during this period. In order to find out the impact of the earthquake which occurred from July to August 2018, time lapse microgravity anomaly before and after earthquake was compared, i.e. time lapse microgravity anomaly 2016 to 2018 period and 2018 to 2019 period. Measurements were carried out at about 80 points which distributed in both of regencies. Time lapse microgravity anomalies periods of 2016 and 2018 show positive values at all measurement points and deformation analysis revealed that subsidence occurred at all study areas. The results of the time lapse microgravity anomaly data processing between the periods of 2018 to 2019 show the opposite one. The results of data analysis and processing of time lapse microgravity anomaly during period 2016 to 2019 shows the deformation process on the surface before the earthquake Lombok and it was stopped due to the events of the Lombok Earthquake in 2018. The earthquake that generated by the thrust fault mechanism causing elevation change of the research area in Central Lombok Regency and East Lombok, an event of uplifting occurred.

Keywords: Lombok earthquake, subsidence, thrust fault mechanism, uplifting

1. Introduction

Research on fault activities on the island of Lombok has been carried out since 2016. During the period 2016 to 2018 using the microgravity and GPS method, fault activity has been detected [1]. The fault activity is detected signed with the changes in value of observed gravity (Gobs) during the time interval, here after referred as time lapse microgravity anomaly, and the vector shift of GPS measuring points.

Phenomena that occur due to the fault activity of one of them is the case of land subsidence in the area of research [2]. Time lapse microgravity anomaly is superposition of anomaly due to shallow and deep sources as shown by equation (1) [3]

$$\left(g_{obs(1)} - g_{obs(2)}\right) = G\int_0^{\infty}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \frac{\Delta\rho\left(\alpha,\beta,\gamma,\Delta t\right)}{\left[\left(x-\alpha\right)^2+\left(y-\beta\right)^2+\left(z-\gamma\right)^2\right]^{3/2}} d\alpha d\beta d\gamma + \left(c_1 - c_2\rho\right)\Delta h \quad (1)$$

Where, $g_{obs(1)}$ and $g_{obs(2)}$ are the gravity observation values of the first and second measurement, G is universal gravity constant, Δρ is density contrast value , (α, β, γ) and (x, y, z) are coordinate of anomaly body and measurement point respectively, Δt is time interval between first and second measurement, c_1 is free air anomaly constant (=0,30876 s^{-2}), c_2 is bouguer correction constant (=0,04193 $cm^3.gr.s^{-2}$), and Δh is the elevation change of the first and second measurements. Anomaly due to deep source is shown by the first term of right segment of equation (1) is caused by subsurface dynamics and anomaly due to shallow source is shown by second term is caused by vertical deformation on the surface called a land subsidence.

Land subsidence could effort by many factors i.e. groundwater extraction, induced by the load of constructions, natural consolidation of alluvial soil, and tectonic activities [4]. In Lombok Island natural consolidation and tectonics activities are significant factors affected the land subsidence. To get an information about land subsidence, value of time lapse anomaly due to shallow source has to separate from total time lapse anomaly.

Method of anomaly separation that used in this research is striping filter, which need an input thickness, depth, and contras density of shallow and deep layer [5, 6]. To extract shallow anomaly spectrum, filter stripping for a can be written as:

$$S\left(u,v\right) = \left(1+\alpha\beta\left(u,v\right)e^{-k\xi}\right)^{-1} \quad (2)$$

Where, $\alpha = \frac{\Delta\rho_d}{\Delta\rho_s}$, $\beta = \frac{1-e^{-kt_d}}{1-e^{-kt_s}}$, and $\xi = h_{t_d} - h_{t_s}$, which α is density comparison, β is thickness comparison (t) and ξ is the difference of depth between the shallow and deep layers.

In the period of July to August 2018 Lombok is shocked by at least 6 earthquakes with a magnitude of more than 5 Richter scale (RS) as shown in **table 1**.

Table 1. Parameters of Lombok earthquakes 2018 which has magnitude more than 5.0 RS [7]

Date of event EQ	Magnitude (RS)	Position of hypocentre	Depth of EQ source (km)
29 July 2018	6.4	116.508E, 8.324S	14.0
05 August 2018	6.9	116.436E, 8.260S	31.0
09 August 2018	5.9	116.208E, 8.394S	10.0
19 August 2018	6.3	116.576E, 8.325S	7.9
19 August 2018	6.9	116.626E, 8.324S	25.0
25 August 2018	5.5	116.425E, 8.425S	9.2

Based on the location and depth of the hypocentre, this earthquake is a type of shallow earthquake due to the Fault Activity of the Flores Back Arc Thrust. The results of the analysis of the source

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mechanism show that this earthquake is generated by rock deformation with a thrust fault mechanism [8]. These earthquakes will affect the deformation process which has been observed before.

2. Methods

Research was done at area about (50 x 30) km2, with a measurement station of 80 units spread in central Lombok and East Lombok Regencies as shown in figure 1. Measurements were made 3 times, in August 2016, April 2018, and June 2019 using gravity meter Scintrex Autograv CG-5 as shown in figure 1 and figure 2.

Figure 1. Data acquisition location (unscaled) [9]

Figure 2. Scintrex Autograv CG-5 gravimeter [10]

Surface deformation analysis using striping filter with input in the form of subsurface structure analysis based on gravity data in 2016. Analysis was carried out on time lapse microgravity anomalies data periods 2016 - 2018, 2018 - 2019, and 2016 - 2019. The stage of processing data was shown in **figure 3.**

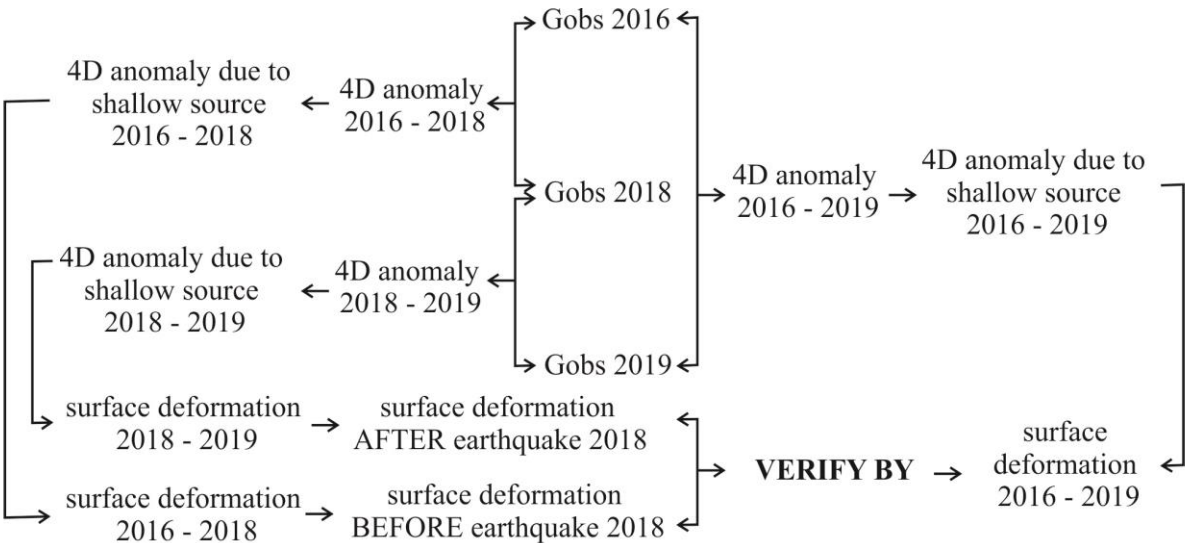

Figure 3. Stages of processing data to analyse an effect Lombok Earthquake 2018 on surface deformation

3. Results and Discussions

Time lapse microgravity anomalies periods of 2016 and 2018 show positive values at all measurement points. The results of time lapse anomaly separation show that time lapse anomaly due to shallow source is about (6 – 30) □Gal. Conversion the anomaly resulting surface deformation as land subsidence of 2 to 10 centimetres occurred at all study areas as shown in figure 4. Land subsidence that occurred due to natural consolidation, geologically research area composed of young rocks (Quaternary aged), and triggered by tectonics activity of Lombok Island.

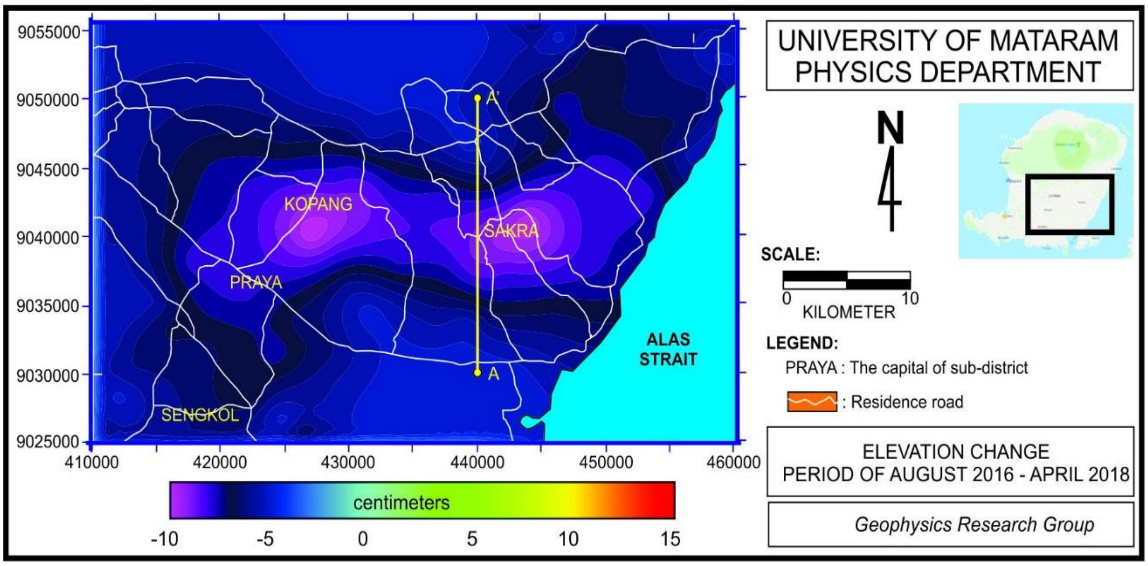

Figure 4. Elevation change period of August 2016 to April 2018

The time lapse microgravity anomaly data processing between the periods of 2018 to 2019 show the opposite one, most of the study areas have negative anomalous due to the shallow source. Negative change values, which mean Gobs which measured in 2019 are less than Gobs 2018. The results of surface deformation analysis show that uplifts happened at all study areas ranging from 0.5 to 13 cm as shown in figure 5.

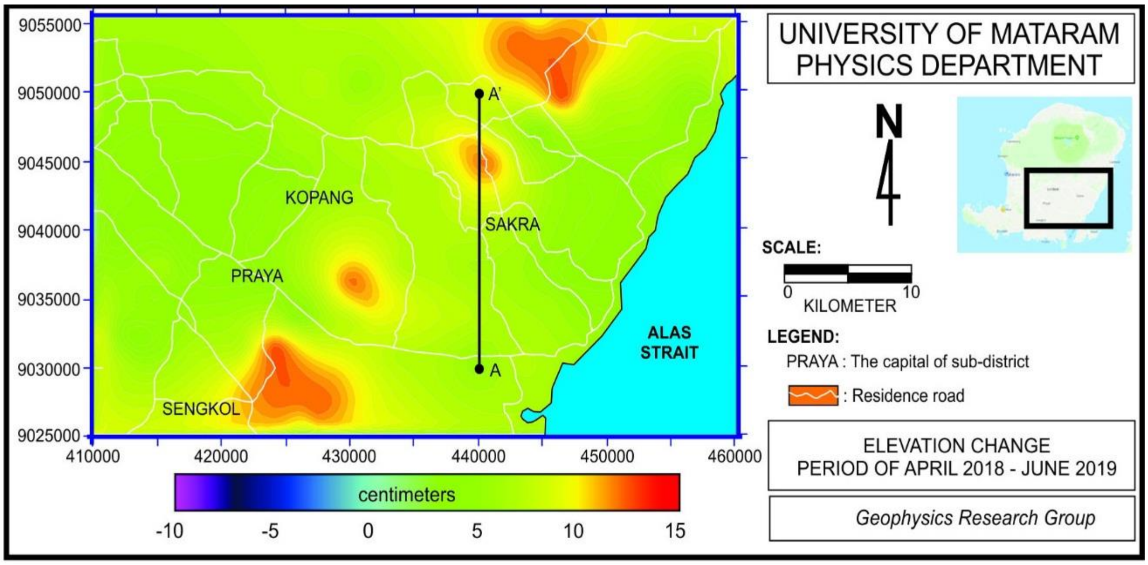

Figure 5. Elevation change period of April 2018 to June 2019

Change of Gobs value along period of 2016 to 2019 is superposition of change values along period of 2016 to 2018 and 2018 to 2019. Time lapse anomaly was founded due to shallow source in this period was -26 to 14 μGal and this value is an anomaly due to the elevation change as much ass -5 to 9cm, refer to fig. 6.

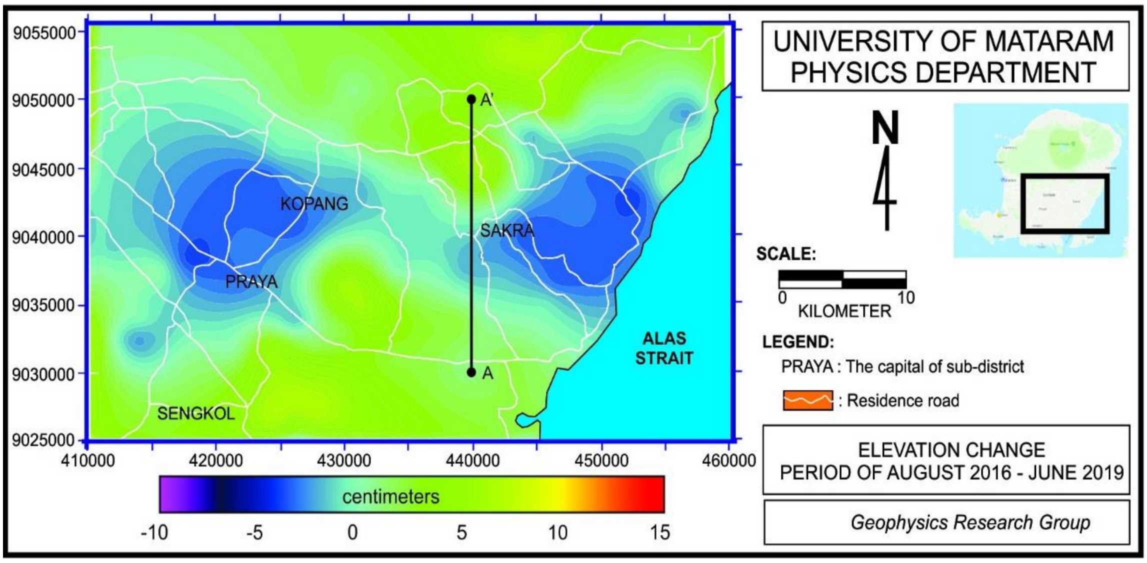

Figure 6. Elevation change period of August 2016 to June 2019

To see the impact of the 2018 earthquake also made a cross section AA' as shown in figures 4, 5, 6. Time lapse anomalies along period of 2016-2018 in AA' cross section are positive, shown in figure 7, as well as the results of filtering produce anomaly due to shallow sources is also positive. This is because land subsidence (change in negative elevation), shown in figure 8, results in Gobs 2018 value greater than 2016.

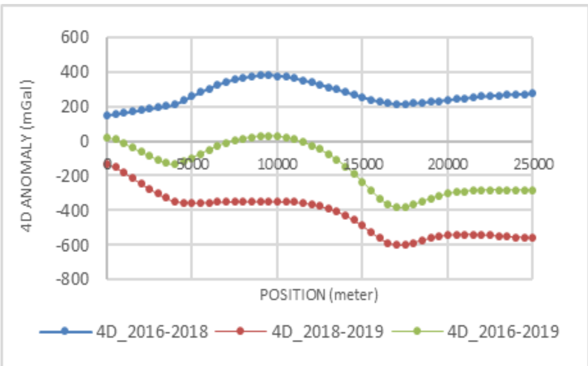

Figure 7. Time lapse (4D) microgravity anomaly periods of 2016 to 2018, 2018 to 2019, and 2016 to 2019 along cross section AA'

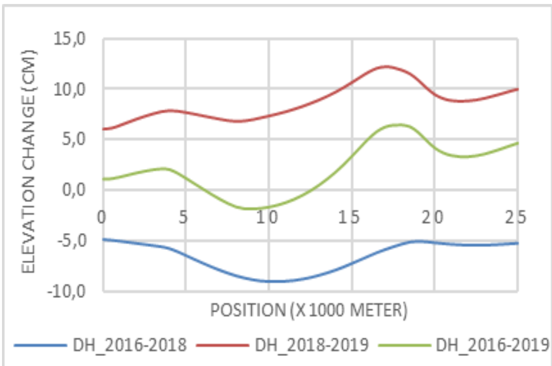

Figure 8. Elevation change periods of 2016 to 2018, 2018 to 2019, and 2016 to 2019 along cross section AA'

Based on figure 7, 8 and also figure 5, in the period 2018 - 2019 the opposite situation occurs. The time lapse anomaly value in this period is negative. The results of filtering with striping filters produce negative values as well, indicating that on the cross-section AA', and most areas of the study, an uplifting process occurs.

Change of elevation along periods 2018 to 2019, which dominated by uplifting process as impact of earthquake not able to restore the state to the condition before the earthquake. This can be seen in Figure 8 that the change in elevation along period of 2016 to 2019, in cross section AA still leaves a negative elevation changes (subsidence) in some places.

The earthquakes as stated in table 1 are all centred north of Mount Rinjani, and with regard to their location and hypocentre depth, this earthquake is a type of shallow earthquake due to the Fault of Back Arc Thrust activity. Results of the analysis show the mechanism of the source of these earthquakes, earthquakes generated by the deformation of the rock with the upward movement mechanism (thrust faults). The mechanism of the upward movement in the northern part of Lombok Island will affect the southern part which is also somewhat pushed up by the Indo Australia plate. The impact pressure from the north and south of the island of Lombok looked forming anticline structure, with a peak around Praya, Kopang, and Sakra, as shown in Figure 6. The uplifting process due to tectonic activity (earthquake) was impact natural deformation on the surface, which is land subsidence.

4. Conclusion

Lombok earthquakes on July to August 2018 significantly affected to deformation on the surface. Surface deformation as land subsidence which happen before earthquake occurred, was stopped due to earthquake and become an uplifting.

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