Microgravity method to monitor subsidence in Kota Lama area Semarang

Supriyadi\textsuperscript{1*}, Khumaedi\textsuperscript{1}, Sugiyanto\textsuperscript{1}, Jefta Heparona\textsuperscript{1}

\textsuperscript{1}Department of physics, Faculty of Mathematics and Natural Sciences, Universitas Negeri Semarang, Indonesia

*Corresponding author: supriyadi@mail.unnes.ac.id

Abstract. The purpose of this study was to monitor the subsidence that occurred in the Kota Lama. The method used is the micro gravity method. Measurements were carried out 2 times in the period May and September 2017. The anomalous data obtained time lapse microgravity anomaly which were the weight difference between the period of September and May. This anomalous data still contains anomalous sources of groundwater leve changes which are then corrected with rainfall data for that time interval. Finally anomaly data were obtained which were the target of the study in the form of microgravity anomaly data due to subsidence. After being converted with a constant free air correction resulted in a maximum subsidence of 0.3 cm or 3 mm occurred in the north and south of the Kota Lama.

1. Introduction

The microgravity method which is the development of gravity with its characteristic repetition at the same point with a certain time interval, for example on changes in gravity values in the rainy and dry seasons using a careful gravimeter in the Gal order and accurate elevation measurements by Allis and Hunt [1]. Why was this method chosen because the results of previous studies showed satisfactory results. Following are various surveys that use this method, Monitoring geothermal reservoirs, oil and gas [2], Monitoring oil and gas reservoirs due to oil production activities and gas or water injection has been carried out since 1983 and continues to grow until now [3], Observation of activities volcano in the form of magma movement and surface deformation by Jousset et al [4].

Application of microgravity methods related to the environment has also been carried out by Lyness [5], Branston and Style [6] monitor land subsidence in the mining area. In Indonesia, subsidence research using this method has been carried out by several researchers, including Supriyadi et al [7] implementing a time lapse microgravity method for monitoring subsidence in Semarang. Abidin et al [8] examined land subsidence in coastal cities of Semarang (Indonesia) characteristics, impacts and causes. Detecting subsidence using gravity method in Jakarta and Bandung Area by Setyawan et al [9], Minardi et al [10] which analyzed the decrease in groundwater level and subsidence using time lapse vertical gradient methods in Jakarta.

The purpose of this study was to monitor subsidence in the Kota Lama Semarang. This location was chosen because it has become a tourist area with its distinctive features of ancient Dutch colonial buildings. Based on previous research states that the lower Semarang area including the Kota Lama has experienced subsidence [11,12,13]. The potential for occurrence of subsidence in this area needs to be monitored to maintain the existence of ancient buildings that exist.
2. Methods

Before measurements in the field, create a model of the subsidence relationship with groundwater level change using the advanced method. As the study [14] states that micro gravity anomaly between two different periods of mathematics are expressed by equation (1)

\[
(g_{\text{obs}(2)} - g_{\text{obs}(1)}) = \int_{0}^{\infty} \int_{0}^{\infty} \int_{0}^{\infty} \Delta \rho(\alpha, \beta, \gamma, \Delta t)(z - \gamma) [x - \alpha]^2 + [(y - \beta)^2 + (z - \gamma)^2]^{(2/3)} d\alpha d\beta d\gamma + c_i(h_2 - h_1) \tag{1}
\]

where \( g_{\text{obs}(2)} \) and \( g_{\text{obs}(1)} \) are the gravity measured at the study site on \( t_1 \) and \( t_2 \), \( G \) is gravity constant, \( \Delta \rho \) is density change, \( \alpha, \beta, \gamma \) is density coordinate, \( x, y, z \) coordinate mass point, \( \Delta t \) time interval measurement, \( h_1 \) is elevation at measurement \( t_1 \), \( h_2 \) is point elevation at measurement \( t_2 \), and \( c_i \) is Terrain Correction constant. Equation (1) shows that the difference in gravity values from measurements or time lapse microgravity anomaly is caused by changes in the density of subsurface masses that are related to groundwater level changes and subsidence. The meaning of equation (1), if the source of the anomaly groundwater level is reduced it will be obtained by the source of the anomaly due to subsidence, and vice versa.

Gravity measurements were carried out at 17 points spread across the study site using gravimeter sintrex CG-5. Measurements were made in two periods, namely March and September 2017. After the data was collected, it was followed by making an initial correction of Tide correction to reduce tidal effects, Drift correction to reduce the fatigue effect of the gravimeter device. After the initial correction is carried out followed by further correction. This correction is adjusted for the purpose of the study to obtain microgravity anomaly caused by subsidence. For this purpose, the time lapse microgravity anomaly data must be corrected with data on groundwater level changes related to rainfall. The relationship between groundwater level change and rainfall is expressed in the following equation (2).

\[
H(t) = H_1 + \alpha \Sigma_n R_n \exp\{-c(t - t_n)\} \tag{2}
\]

where \( H(t) \) is the initial groundwater level, \( t \) is time, \( t_n \) is th time \( n \), \( \alpha \) is the absorption constant (\( \alpha = 0.00932 \)), \( c \) is the evaporation constant (\( c = 0.00985 \)) and \( R_n \) is precipitation in the nth month. After obtaining changes in groundwater level from precipitation, we can obtain time lapse microgravity anomaly due to groundwater level changes as stated in equation (3)

\[
\Delta g_w = 2 \pi G \rho_w \phi \Delta H \tag{3}
\]

where \( \Delta g_w \), \( G \), \( \rho_w \), \( \phi \), \( \Delta H \), respectively are gravity anomaly (mGal), water density (gr/cm\(^3\)), porosity (%), and groundwater level change level (meter).

3. Results and Discussion

In the beginning, modeling of changes in gravity values due to changes in groundwater level. By assuming porosity of the rock (groundwater reservoir) of 30% then any change in groundwater level of 1 meter causes gravity changes 12,579 \( \mu \)Gal as shown in Figure 1.
Next is the modeling of time lapse microgravity anomaly caused by subsidence and groundwater level changes. In this model groundwater level reduction is used (Figure 2). It is assumed that subsidence occurs at coordinates 2500-3500 m, the magnitude is at $t_0 = 0$ and $t_1 = 10$ cm. For groundwater level reduction occurs at 3000 - 6000 m the amount of 1.5 m with the position of the groundwater at $t_0 = 20$ m and $t_1 = 21.5$ m. The maximum response combined with gravity anomaly due to subsidence and groundwater level decrease ($A + B$) is 30,706 $\mu$Gal.

The results of gravity measurements in the May and September 2017 periods at the study location (Old City) were expressed qualitatively with contour maps (Figure 3a and Figure 3b). In general the maximum gravity values are in the middle and south which are 16.7 mGal in the May period, and 16.8 mGal in the September period.
Figure 3. Gravity values measured for May (a) and September periods (b)

Time lapse microgravity anomaly is obtained by calculating the difference in microgravity values in the period September with the period May for each measuring point. Furthermore, the anomaly values obtained are expressed qualitatively as in Figure 4. There are two values, positive in the middle, west and south. Negative values are in the north. In the condition of microgravity anomaly between times it is caused by two sources of anomaly, namely, subsidence and groundwater level decrease.

Figure 4. Time lapse microgravity anomaly for May-September 2017 period

In accordance with the purpose of this study to obtain anomalies due to subsidence, a reduction in the microgravity anomaly data was carried out over time to minimize the influence of the source of anomalies on changes in groundwater depth by using rainfall data. Based on equation (2) the precipitation value ($\Delta H$) will be obtained which can then be calculated the magnitude of the microgravity anomaly between times which has been corrected with precipitation data using equation (3). Rainfall data during 2017 is as shown in Table 1 below. The amount of precipitation value ($\Delta H$) is 0.184 mm which is related to groundwater level decrease which give time lapse microgravity anomaly of 0.0023 mGal. Time lapse microgravity anomaly corrected by rainfall qualitatively as in Figure 5.
### Table 1. Rainfall data for the period from May to September

| Stasiun               | Mei (mm) | Juni (mm) | Juli (mm) | Agustus (mm) | September (mm) |
|-----------------------|----------|-----------|-----------|--------------|----------------|
| Klimatologi Semarang  | 105      | 190       | 32        | 15           | 129            |
| BMKG Maritim Tanjung Mas | 97      | 91,4      | 28        | 2            | 39             |
| Candi                 | 146      | 92,2      | 62        | 0            | 176            |
| Tlogosari             | 81       | 95        | 23        | 0            | 99             |

Source: BMKG Central of Java

**Figure 5.** Time lapse microgravity anomaly corrected rainfall

Based on Figure 5, it can be seen that the time lapse microgravity anomaly is positive. This means that the source of the anomaly in the form of groundwater level changes has been reduced, so that there is only a source of subsidence anomalies that are the target of this study. To calculate the amount of subsidence, then the time lapse microgravity anomaly data each rainfall corrected point is converted by dividing free air correction constant of 0,3086. The final result is the amount of subsidence in the Kota Lama as shown in Figure 6.

**Figure 6.** The subsidence map in Kota Lama is based on the results of gravity measurements for the period May-September 2017

Based on Figure 6, it is known that subsidence has occurred in the Kota Lama for an interval from May to September 2017. The greatest occurrence of the occurrence of the northern and southern parts is 0.3 cm or 3 mm. In the middle of the location in general there is very little subsidence that occurs 0.1 cm or 1 mm, so that it can be said that there is no subsidence. This result is supported by research conducted...
by Heri at al. [15] who stated that subsidence occurring in lower Semarang, including the Kota Lama continued to increase between 2008 - 2016.

4. Conclusion
The micro gravity method can be used to monitor subsidence. To use this method, it starts with making an anomalous object model that is the target of research. Using gravimeter with accuracy in microGal. Gravity survey is done at least 2 times with a certain interval according to your needs. Corrections made are initial corrections, namely tide correction and drift correction and further correction to minimize the source of anomalies groundwater level changes. The application of this method in Kota Lama shows that there has been a maximum subsidence of 3 mm in the north and south part.

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