Analysis of Time Lapse Microgravity Anomaly Data Case Study in Kota Lama Tourism Area Semarang Indonesia

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Abstract. Time lapse microgravity survey has been carried out in Kota Lama Semarang using the Gravimeter Scintrex CG5 on January 2019 and July 2019 with a total of 75 points spread evenly at research field. There are three possible values of gravity anomaly between time, positive, negative, and zero does not change. The results which is an anomaly which is known as time lapse microgravity anomaly show that maximum positive 0.29 mGal in the north and south, and minimum negative -0.11 mGal in northeast and southwest. For the time lapse microgravity vertical gradient anomaly show that maximum positive 0.0013 mGal in west, center, east, and minimum negative -0.0082 mGal in north and south. Conclusion are rainfall data throughout the study range show a downward trend and calculation of groundwater reduction using this data obtained a groundwater level decrease an average of -3.63 mm.

1. Introducing

Gravity method is one of the oldest methods in geophysics, but its application to sources of anomalies near the surface and those related to the environment is not as intensive as applications for geodynamic studies or exploration in the estimation of relatively large geological structures. This is due to the accuracy of the anomaly still in the order of mGal or $10^3 \mu$Gal. Whereas in terms of gravimeter devices, an accuracy of 10 $\mu$Gal was achieved in the early 1970s, but the accuracy of the readings is entirely dependent on the accuracy of the operator because the gravimeter still uses a mechanical reading device.

The time lapse microgravity method is a development of the gravity method with its fourth dimension being time. The principle of this method is measuring gravity repeatedly both daily, weekly, monthly and yearly using a careful gravimeter in the order $\mu$Gal and meticulous elevation measurements. Any changes or differences in the results of observational gravity in the first period with the next period are called microgravity anomalies. Changes in observation gravity can be caused by dynamics around very points, such as changes in the depth of the ground water level and subsidence.

In line with the rapid increase in digital technology in the late 1980s, the problem of reading accuracy can be increased by the use of digital reading systems. At the end of 2000, LaCoste & Romberg released a full digital gravimeter called graviton with an accuracy of 1 $\mu$Gal and semi digital gravimeter which is the development of LaCoste & Romberg type G which is equipped with a digital reading system with an accuracy of 1-5 $\mu$Gal. Early in 2002 Scintrex also issued a full digital gravimeter called Scintrex Autograv CG5 with an accuracy of 1 $\mu$Gal. With the availability of digital gravimeter systems in full or semi-digital, the obstacles associated with tools for observing changes in the gravity field in the order $\mu$Gal can be removed.
An increase in gravimeter accuracy and development of digital systems, the application of gravity methods for sources of anomalies near the surface and those related to the environment and for monitoring purposes are increasingly being used, including for monitoring geothermal reservoirs, oil and gas. The process of steam production and water injection in geothermal reservoirs must be monitored properly with the aim that the geothermal reservoir remains stable, steam production is stable so that the geothermal reservoir can last long [2]-[6].

Utilization of microgravity for monitoring, including the following: survey of geothermal potential in Mount Ungaran [7], monitoring of volcanic activity [8]. Utilization for monitoring environmental quality, for example the potential for subsidence zones in Jakarta [9]. Kennedy conducted a survey of changes in subsurface mass [10]. Monitoring changes in surface water depth [11]

Based on the description above, this study aims to analyze the time lapse microgravity data in the tourism area Kota Lama Semarang. From the analysis of the data it is expected that microgravity anomalies will be obtained time lapse anomaly. This anomaly data is related to the source of the anomaly that is the target of this study.

2. Method

In this study using the time lapse microgravity gravity method between time, which is measuring the gravity at the same point with a certain time interval, namely January and July 2019 with the number of 75 points that are spread evenly in the study location (Kota Lama area). The tool used is autograv CG-5 gravimeter. Stages of method as follows:

2.1. First

Before measuring gravity at the research location, modeling is done first. Modeling aims to determine the various values of micro-gravity anomalies over time produced by different sources of anomalies. For modeling the source of the anomaly and the magnitude of the anomaly caused by using some Equations according to needs.

a. Equation which states the water level depth housing with an intermittent microgravity anomaly [12] which is stated by Eq.1.

\[
\Delta g_n = 41.93 \rho_n \phi \Delta l
\]

where: \(\Delta g_n\), \(G\), \(\rho_n\), \(\phi\), \(\Delta l\) each is the change in gravity value due to changes in groundwater level depth, general gravity constant, water mass density (gr/cm3), porosity (%), and change in depth groundwater level (meters).

The amount of precipitation will affect changes in groundwater level. In the rainy season the groundwater level will be at its maximum value and then gradually decrease with the change of seasons. Changes in groundwater level can be calculated based on the Eq.2.

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

where \(H_1\) is groundwater level at first, \(t\) is time, \(t_n\) is nth time, \(\alpha\) is absorption constant (0.00932), \(c\) is evaporation constant (0.00985), and \(R_n\) is precipitation in the month.

b. Modeling time lapse microgravity anomaly using Eq. 3 is used for this purpose [13]

\[
g_{\text{ob2}}(t_2) - g_{\text{ob1}}(t_1) = \int_{0}^{\infty} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \frac{\Delta \rho(x, y, z) \Delta d}{(x-a)^2 + (y-b)^2 + (z-c)^2} dxdydz + c_1(h_2 - h_1)
\]

where \(g_{\text{ob2}}\) is the observational gravity of measurements at \(t_2\), \(g_{\text{ob1}}\) is the observational gravity of measurement at \(t_1\), \(G\) is universal gravity constant (6.67x10^{-11} m^3/kg/sec^2), \(\Delta \rho\) is density change, \(\alpha, \beta, \gamma\) is density coordinate, \(x, y, z\) is the measuring point coordinate.

Eq.3 shows that the difference in the gravity value of the measurement results due to changes in subsurface mass density associated with changes in the depth of the ground water level and subsidence
2.2. Second
Perform gravimetric calibration to ensure that the tool can be used for research. The gravimeter used has accuracy in µGal with the intention of being able to measure changes or small anomalies.

2.3. Third
Determine the location and position of the measuring point. For the necessity of measuring gravity over time, the location of the measuring point is sought to be stable and predicted not to experience physical damage during the study.

2.4. Fourth
The next step is to measure gravity and a measurement period has been planned in the next period. The next interval usually uses the season guidelines, which are the rainy season and the dry season. Note The sequence of points to measure the gravity is recorded, and in the measurement of the next period the order of points in a loop must be the same as the previous period.

2.5. Fifth
In the same way at each point, the measurement is repeated by placing the gravimeter at a height of 25 cm.

2.6. Sixth
Make an initial correction ie tide correction using Eq. 4 and drift correction with Eq. 5 every day after measurement in the field [14]-[17].

\[
tide = G(r)\left[ (c/R)^4 \left( \sin^2 \theta_m + \frac{1}{3} \right) + \frac{1}{6}r/c \left( \frac{5}{3} \cos 3 \theta_m + 3 \cos \theta_m \right) \right]
\]

where \( tide \) is tide correction, \( G(r) \) is Universal gravity constant, \( c \) is average distance to the month, \( R \) is earth’s diameter, and \( \theta_m \) is zenith angle of moon.

\[
\text{drift}_n = \frac{(t_n - t_1)}{(t_N - t_1)} (g_N - g_1)
\]

where \( \text{drift}_n \) is drift correction, \( t_n \) is reading time at the nth station, \( t_N \) is reading time at base station (end looping), \( t_1 \) is reading time at base station (initial looping), \( g_N \) is tidal-corrected gravimeter reading at base station (end of loop), and \( g_1 \) is tidal-corrected gravimeter reading at base station (initial looping).

Tide correction is done to eliminate the gravitational influence of objects outside the earth like the moon and the sun, which changes with latitude and time. In practice, tidal correction is done by measuring the gravity value at the same station (base) at a certain time interval. Then the gravimeter reading is plotted against time to produce an Equation used to calculate tidal correction. This tidal correction value is always added to the gravity reading.

Drift correction is due to differences in gravity readings from the same station at different times, which is caused by the shock spring of the gravimeter during the transportation process from one station to another. To eliminate this effect, gravity data acquisition is designed in a closed circuit (loop), so that the magnitude of the deviation can be identified and assumed to be linear at a certain time.

2.7. Seventh
Finally, make further corrections, which include elevation correction, correction of changes in groundwater level depth. At this stage the aim is to obtain anomalous sources (research targets), and proceed with analysis of gravity anomaly data between times.

3. Results and Discussion
General research results include (1) modeling, (2) measurement results, and (3) analysis of measurement results. Explanation of each result as follows:
3.1. Response anomaly modeling

Using Eq. 1 and assuming rock porosity (groundwater reservoir) of 30%, any change in groundwater level of 1 meter during an interval of time causes time lapse microgravity anomaly 12,579 µGal as shown in Figure 1.

Using Eq. 2 and the model parameters used in the form of a three-layer earth model extending horizontally with the physical properties as follows:

a. Layer 1 in the form of clay has a thickness of 10 m and \( \rho = 1.9 \text{ gr/cm}^3 \)

b. Layer 2 is sand with \( \rho = 2.0 \text{ gr/cm}^3 \). Aquifer porosity is 30%, changes in mass density due to a decrease in groundwater level \( \Delta \rho = -0.3 \text{ gr/cm}^3 \)

c. Layer 3 is clay with a thickness of 10 m and \( \rho = 2.1 \text{ gr/cm}^3 \)

It is assumed (a) that subsidence occurs at coordinates 2000 until 4000 m, the magnitude of which is at \( t_0 = 0 \) and \( t_1 = 10 \) cm. For the decrease in ground water level occurs at coordinates 2500 until 3500 m a ground water by 1 m with a ground water level position at \( t_0 = 30 \) m and \( t_1 = 31 \) m. The maximum response time lapse microgravity anomaly caused subsidence and groundwater level decrease is 30,856 µGal (Figure 2).

It is assumed (b) that subsidence occurs at coordinates 2500 - 4500 m, the magnitude of \( t_0 = 0 \) and \( t_1 = 10 \) cm, and the increase is assumed to occur at coordinates 2500 - 4500 m at 2.5 m with ground water level at \( t_0 = 30 \) and \( t_1 = 27.5 \) m. The maximum response of time lapse microgravity anomaly subsidence and groundwater level increase 63,546 µGal (Figure 3).

3.2. The result of observation gravity

The gravity measurement data was carried out in January 2019 which is shown in Figure 4. The gravity measurement value in January with a minimum gravity of 978118.44 mGal and maximum gravity of 978118.88 mGal, while the value of the gravity measurement in July 2019 is shown in Figure 5 with a minimum gravity of 978118.62 mGal and a maximum of 978118.88 µGal.
In Figure 4 and Figure 5 shows the areas that have low observed gravity values have a higher topography such as the western part of the city on Mpu Tantular street and the north side of Tawang Station which is shown by blue to dark blue images. On the other hand, regions that have high observational gravity values have low topography as shown almost evenly distributed in the Kota Lama which is shown by green to pink imagery. In the January 2019 measurement shown in Figure 4, and the July 2019 measurement shown in Figure 5, there is a significant difference in the contour pattern which is caused by several factors, one of which is due to the increase in the rock density which causes the elevation at a measurement point bias can increase or reduced. Changes in gravity values from the period January 2019 to July 2019 can be seen in Figure 6 below.

**Figure 4.** Observation gravity value on January 2019  
**Figure 5.** Observation gravity value on July 2019

Based on Figure 6, can be seen measurement points or areas that have increased or decreased the value of the observed gravity. The results of observational gravity measurements from the period January 2019 to the period July 2019 showed a value that was almost the same as the average gravity value of the earth, namely 980000 mGal or 9.8 m/s². Furthermore, the gravity measurement data for each period is corrected to obtain a simple bouguer anomaly contour map in January 2019 and July 2019. The corrections used to reduce the factors that affect the gravity value are float correction, tidal correction, and Bouguer correction on the observed gravity value. The next stage was to determine the value of gravity anomalies in the study area with Oasis Montaj software to describe the contours of the study area.

### 3.3. Microgravity vertical gradient

The value of the vertical gradient microgravity anomaly in the January 2019 period (Figure 7) shows the value -0.0039 to -0.0063 mGal/cm. The southern part of Kota Lama such as on the Sendowo street and the northern part around the Pengapon street have an anomaly range of vertical gravity gradient values of -0.0039 mGal/cm until -0.0030 mGal/cm indicated by gradations of blue. Most of the Kota Lama Region has a vertical gradient gravity anomaly value of -0.0030 mGal/cm to -0.0063 mGal/cm.
The value of the microgravity vertical gradient on July 2019 (Figure 8) shows the value of -0.004 until -0.0015 mGal/cm. The southern part of Kota Lama such as on Sendowo street and the northern part around Tawang street have an anomaly range of -0.004 mGal/cm until -0.0032 mGal/cm indicated by gradations. Most of the Kota Lama region has a vertical gradient gravity anomaly value of -0.003 mGal/cm until -0.0015 mGal/cm.

Difference in the gravity gradient microgravity between the two periods will be obtained time lapse microgravity vertical gradient anomaly values (Figure 9) shows the change in the value of the vertical gravity gradient anomaly. The southeast area of the Kota Lama area around Sendowo and Cendrawasih street and points that show gradations of pink and green experience anomalous vertical gradient gravity values of positive values of 0.0002 mGal/cm to 0.0013 mGal/cm, while the points that point to gradations of green to blue such as on Tawang Street have decreased the vertical gravity anomaly values of -0.0006 mGal/cm to -0.0082 mGal/cm.

In general, the results of the measurement and analysis above are simplified as in Table 1 below. This table will make it easier to help during research on time lapse microgravity, repetition of gravity shifts at the same point at certain intervals, usually in different seasons, namely the rainy season and the dry season.
Table 1. Relationship between time lapse microgravity – time lapse microgravity vertical gradient and groundwater level

| No | Time lapse microgravity (TLM) | Time lapse microgravity vertical gradient (TLMVG) | Explanation                  |
|----|-------------------------------|-----------------------------------------------|------------------------------|
| 1  | +                             | +                                            | Groundwater recharging, subsidence |
| 2  | +                             | -                                            | groundwater decreasing, Subsidence |
| 3  | -                             | -                                            | Groundwater decreasing       |
| 4  | 0                             | 0                                            | Stable, no change            |

Furthermore, using gravity data and the vertical gradient of gravity for each period, between time and Table 1, it can be explained that in some research zones in the Kota Lama area there are potential subsidence and subsidence. Remembering this latest condition that the Kota Lama area has been revitalized to become a tourist visiting area and paving is done to prevent flooding (Figure 10). This condition directly affects the results of the study. Based on Eq.3, it can be explained that the time lapse microgravity anomaly to monitor subsidence occur less effectively, given that paving causes elevation of surface at Kota Lama and its surroundings to change. This surface’s elevation change affects the elevation of each measuring point. Changes referred to the initial height used as a reference increasingly high.

![Figure 10. Paving in Kota Lama Semarang to prevent flood](image)

In addition to subsidence other information obtained based on Eq. 2 is a groundwater level decrease that occurred in the Kota Lama as indicated by microgravity anomaly and vertical gradient microgravity anomaly is negative value. In addition, rainfall (Figure 11) that occurred during the January-July 2019 in Kota Lama showed a declining trend. Based on the calculation of rainfall data from January to June 2019 using Eq.2, the results of groundwater level decrease of -3.63 mm.

![Figure 11. Rainfall data from record station located around Kota Lama](image)

4. Conclusion

Based on the results of the study it can be concluded, that the measurement of repetitive gravity at the same point in the Kota Lama provides valuable anomaly information (+) caused by subsidence, (-) caused by a groundwater level decrease, and (0) no change occurred. For the January to July 2019 research period in Kota Lama based on microgravity and vertical gradient data, there was no
subsidence, this is because when the research was conducted revitalizing the Kota Lama made it difficult to monitor the subsidence, the gravity measurement point experienced a change in elevation. However, using rainfall data can be attributed to a groundwater level decrease which gives an average of -3.63 mm.

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