# Modeling response Time Lapse Microgravity Vertical Gradient (TLMVG) anomaly due to fluid volume changes of sub surface and its implementation in Kota Lama Semarang

**Supriyadi [1,\*], Khumaedi[1], Sugiyanto[1], M Ikhsan[1] and Sarkowi [2]**

[1] *Physics Department, FMIPA, Universitas Negeri Semarang-Indonesia*
[2] Geophysics Engineering, Lampung University-Indonesia

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

**Abstract.** Modeling of time lapse microgravity anomaly have done. The modelling was done with two ways are first gravimetri position on the earth's surface, and second position at a height of 25 cm from it. The first model shows for 30 % rock porosity than any change in groundwater within depth 1 meter causes gravity change 12,579 μGal. The second model show that reduction of groundwater wil reduce time lapse microgravity vertical gradient (TLMVG) anomaly. Reduction of groundwater will provide TLMVG negative value (-) and reverse groundwater give positive value (+). It was concluded that in the Kota Lama during the range of March to September there was no subsidence, but there was a decrease in groundwater level of 1.449 m

## 1. Introduction

The gravity method is one of the most widely used geophysical method to geodynamic and exploratory studies in geological structure estimation. The time lapse microgravity method is the development of gravity methods with the characteristic of measuring gravity at the same point at the time interval, usually measuring during the rainy and dry seasons. The increase in gravimeter accuracy and the development of digital systems, the application of gravity methods to the source of surface and environmental-related anomalies and for monitoring purposes are increasingly being used. This method have been widely used, for example: gravity changes is seasonally due to hydrologic changes at Cap Pele that reach 10 μGal [1]. There is good correlation between gravity value changes with rainfall data [2]. The rainfall, changes in groundwater depth and gravity in the geothermal area of Oguni Japan that gained a relationship between changes in rainfall and changes in the depth of groundwater in the area [3]. Butler began by combine gravity methods and gradient techniques to detect tunnels and springs to Shallow exploration in Manatee Florida [4]. The gravity survey along the South Sunrise Bowling Green Kentucky road to detect an underground cavity [5] and the measurement results obtained a low anomalous response of 250 μGal relative to about that located above its. The study of gravity change relationships with change in rainfall and ground water flow at Kirkkonummi, Finland [6] and the results showed a change positive gravity in the southern part of the study area that correlates with direction groundwater flow in the area. The gravity method to determine groundwater potentiality and the structural elements at The North Western Part of Sinai, Egypt [7]. The gravity method to determine subsurface structures, groundwater aquifer around Cairo–Belbies Desert road [8].

This study intends to describe the modeling of anomaly response of microgravity over time due to changes in groundwater depth. For this purpose two models are created, namely gravity measurements

on the earth's surface and gravity measurements with a height of 25 cm from the surface of the earth. Changes in the depth of ground water in a place are affected by: season, the amount of rainfall, groundwater extraction and others. Modeling for knowing groundwater change is very difficult to achieve good results because of the complex hydrogeological conditions, such as: soil type, soil structure, aquifer porosity and others. Schon stated that the response gravity due to changes in groundwater depth can be calculated using Bouguer slab correction approach is not up to include porosity factor [9] (equation 1)

$$\Delta g_w = 2\pi G \rho_w \varphi \Delta h \tag{1}$$

$$\Delta g = 0{,}3086 \Delta h \; (mGal) \tag{2}$$

where $\Delta g_w$, $G$, $\rho_w$, $\varphi$, $\Delta h$ each is a gravity value change due to changes in groundwater depth, common gravity constants, density of water mass (gr/cm$^3$), porosity (%), and changes in groundwater depth (meters). In the fact that gravity changes are a manifestation of changes in the surrounding rocky period. Change the rocky period can be caused by several things, namely the composition of elements its formers, its internal structure and binding [10]. Filling element relatively easy to lose rock is water. Changes in water or fluid filling the pores of the rock causes a change in the total mass density of the rock. To find out the relationship TLMVG and change of mass density is performed by calculating the MVG of the object spherical. MVG response of a spherical object model [10].

$$g = \frac{4}{3}\pi G \rho a \frac{z}{(x^2 + z^2)^{1/2}}$$

$$\frac{\partial g}{\partial z} = \frac{4}{3}\pi G \rho a \left( \frac{1}{\left(x^2 + z^2\right)^{3/2}} - \frac{3z^2}{\left(x^2 + z^2\right)^{5/2}} \right) \tag{3}$$

where $\frac{\partial g}{\partial z}$ is microgravity vertical gradient (MVG). Equation 2 shows that if the radius and depth of the sphere remain, twhen the gravity gradient of gravity is only affected by mass density. Decrease the mass density causes a decrease in the MVG and vice versa. TLMVG anomaly is the difference of the gradient value vertical current period with previous as shown equation 3 and 4. This model shows the characteristics of gravity response (g) are MVG and TLMVG gradient caused by the reduction of groundwater and groundwater affixes. This model shows the characteristics of gravity response (g) for MVG and TLMVG caused by the reduction of groundwater and groundwater affixes.

$$\frac{\partial g(x,z,\Delta t)}{\partial z} = \frac{4}{3}\pi G a \left( \frac{1}{\left(x^2 + z^2\right)^{3/2}} - \frac{3z^2}{\left(x^2 + z^2\right)^{5/2}} \right)(\rho) \tag{4}$$

$$\frac{\partial g(x,z,\Delta t)}{\partial z} = \frac{\partial g(x,z,t_2)}{\partial z} - \frac{\partial g(x,z,t_1)}{\partial z} \tag{5}$$

$\frac{\partial g(x,z,\Delta t)}{\partial z}$ is TLMVG, If the TLMVG negative indicates a decrease density, positive value is increase density. The measurement scheme of MVG is made from three legs specially designed with a height that can be arranged (Figure 1). TLMVG is the difference between the second measurement MGV and the first measurement MVG.

**Figure 1**. Measurement of gravity vertical gradient

## 2. Methods

This synthetic data simulation aims to know the TLMVG due to groundwater level decline. Physical model parameters used are a three-tier earth model extends horizontally with physical properties as follows first layer is a clay having a thickness of 10 m and $\rho = 1.9$ gr/cm$^3$, second layer in the form of sand (aquifer) with a thickness of 40 m and $\rho = 2.0$ gr/ cm$^3$. The aquifer porosity is 30%, the change in the closing period due to the taking groundwater is $\Delta\rho = -0.3$ gr/cm$^3$. third layer is clay with $\rho = 2,1$ gr/cm$^3$. It is assumed that groundwater level decreases occur at coordinates 4000-6000 m with groundwater level decline is: $t_1 = 0$ m, $t_2 = 5$ m, $t_3 = 10$ m, and $t_4 = 15$ m

The physical model used for groundwater level increase is similar to the physical model of groundwater level decline, but at the initial condition ($t_1$) due to groundwater retrieval excessive decline in groundwater forms a cone with depth 20 meters at coordinates of 4000-6000 meters. At time $t_2$ (pumping stopped) recharge groundwater on the aquifer up to 5 m and 10 m on $t_3$.

For justification of modeling result used rainfall data, the depth of groundwater level is strongly influenced by rainfall, at the time of rain the ground water table will rise slowly and fall down suddenly when dry. [3] have done gravity observations, rainfall, groundwater level depth in the area The Oguni Japan geothermal field is getting a relationship between changes in rainfall, groundwater depth and gravity measurable. To find the relationship of changes in groundwater level depth due to changes in rainfall is done using the approach empirical using the equations given by [3] as follows:

$$H(t) = H_i + \alpha \sum{}_n R_n \exp\{-c(t - t_n)\} \tag{6}$$

where $H_1$, $t$, and $R_n$ respectively is the initial groundwater depth, time, rainfall, whereas $\alpha$ and c are related constants with evaporation and soil properties. The results of rainfall measuring and the depth of groundwater level is further plotted on the chart to get values of $H_1$, $\alpha$ and c.

## 3. Results and Discussion

Model of objects and TLMVG response shown in Figure 2 and Figure 3. For the case of groundwater level decline, simulation results show that the groundwater level decline will reduce the MVG value. Groundwater level decline will provide TLMVG value is negartive. In case of groundwater recharging, simulation results show that groundwater recharging causes an increase the MVG value. The groundwater recharging will provide TLMVG value is positive.
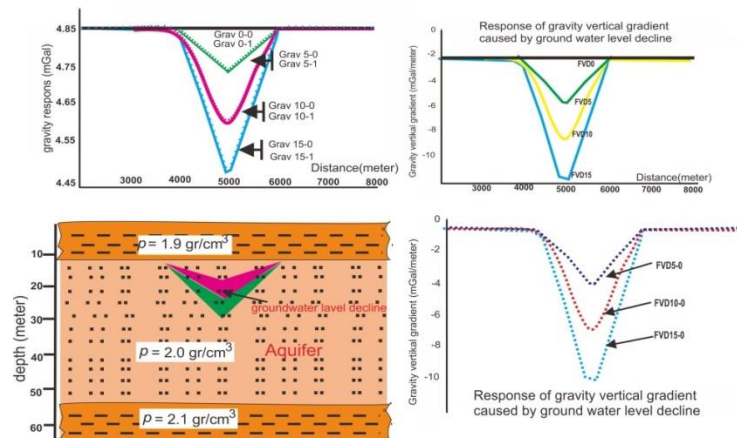
**Figure 2**. Rosponse TLMVG anomaly caused by groundwater level decline
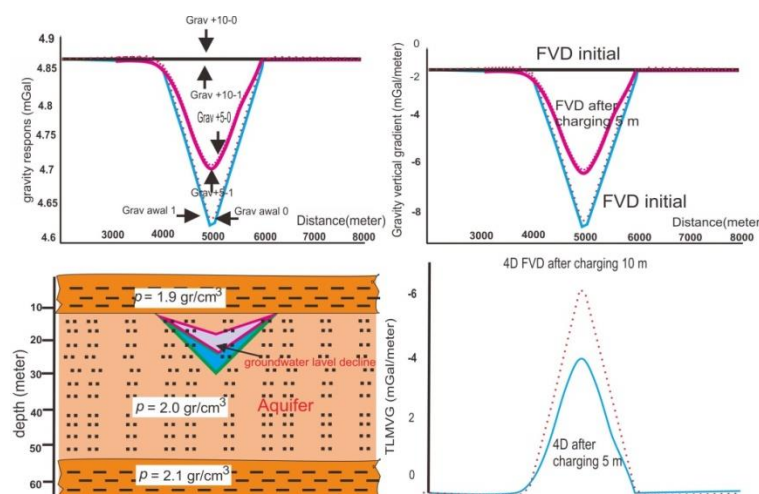


**Figure 3**. Rosponse TLMVG anomaly caused by groundwater level increase

Based on the vertical gradient characteristics due to the decline in groundwater level can be used to identify recharge or dicharge area. Area which has a TLMVG positive indicates the area of groundwater recharge and vice versa area with a TLMVG negative indicates a groundwater discharge area (Table 1).

Measurement and calculation of microgravity in Kota Lama Semarang city for some period as in Figure 4, it can be seen that the largest range value in the March period (Figure 3a) and the September period 2018 (Figure 3b) are in the Blenduk church area and its surroundings. The interval value of microgravity is 978118,69-978118,79 mGal. Furthermore, contour of TLM anomaly data (Maret-September) Figure 3c is negative in all research areas with a maximum value of -70 mGal. This shows that changes in the value of micro observation gravity are caused by a decrease in groundwater level. As stated by Kadir[12] that the difference in the value of the microgravity is caused by changes in subsurface mass density associated with changes (decrease or increase) of the depth of the groundwater level and subsidence. At the time of measurement between March and September, there was no indication of a subsidence in the Kota Lama. The anomaly of TLM are dominated by a decrease in groundwater level.

**Table 1**. Characteristics of the time lapse microgravity- time lapse microgravity vertical gradient (TLMVG) and its relationship to change depth of groundwater level [11]

| 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 |



(a)



( b)



(c)
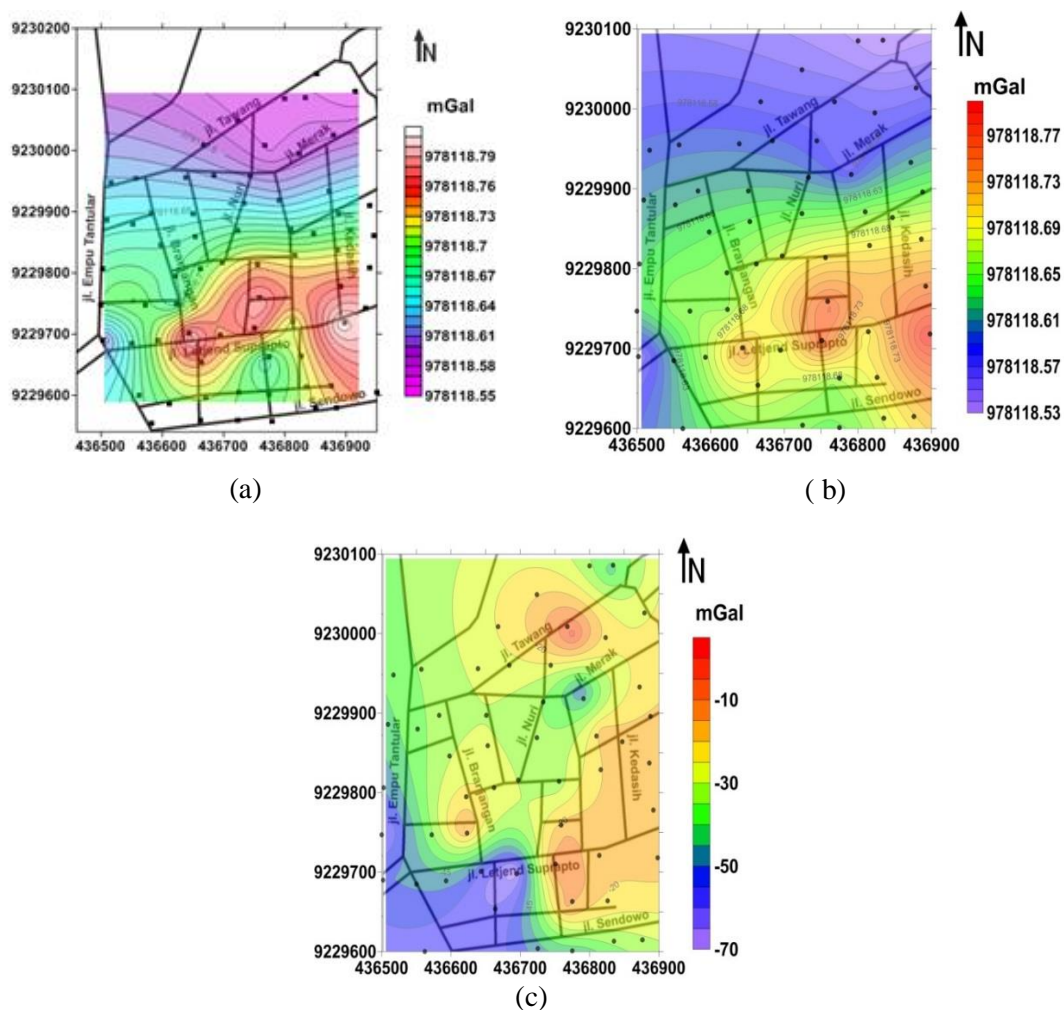
**Figure 4.** Contour map of microgravity value on (a) March, (b) September 2018, (c) anomaly TLM (Maret-September)

To ensure that changes in the microgravity values that occur due to a decrease in groundwater will be validated by (1) rainfall data during gravity measurements, and (2) TLMVG data measured directly at the same point as gravity measurements. Explanation of both as follows:
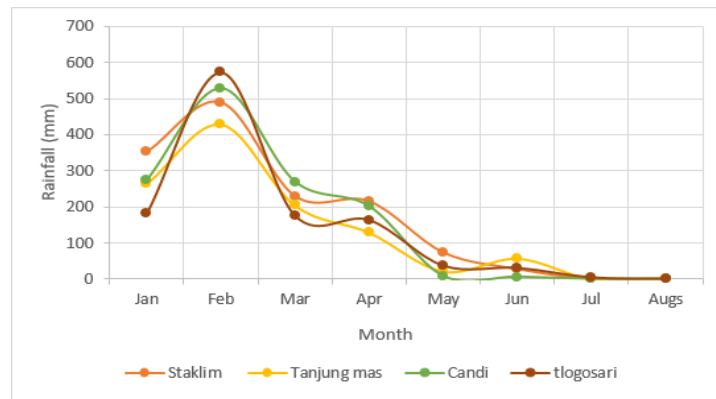
**Figure 5**. Rainfall data on January – August 2018 from station Maritim (Staklim), Tanjung Mas, Candi and Tlogosari

Based on rainfall data (Figure 5) that measurements start in February (1) to August (8) in 2018 at the rainfall recording stations around the research area, such as the Maritim Station (Staklim), Tanjung Mas, Candi and Tlogosari. During this time is seen that the maximum rainfall in March. In the following month the rainfall tended to fall in the end of August and September all recording stations reported no rainfall at the research site. This fact shows that in the span of the dry season, there is no rainwater that seeps into the earth's surface. As a result the free aquifer or unconfined aquifer (Unconfined Aquifer) does not get additional but is used for daily needs so that there is a decrease in the groundwater level.

In the study of TLMVG anomalies are stated [9] which are then summarized as in Table 1, it can be explained that when measuring gravity on the earth's surface and at a certain height, the measurement results on the earth's surface will be more scattered than at a certain height. In reality it is not so, it could be the results of measurements at a certain height greater than on the surface of the earth. This is due to the addition of subsurface mass in the form of rainfall. TLMVG measurement results for the March period (Figure 6a) and September period (Figure 6b)
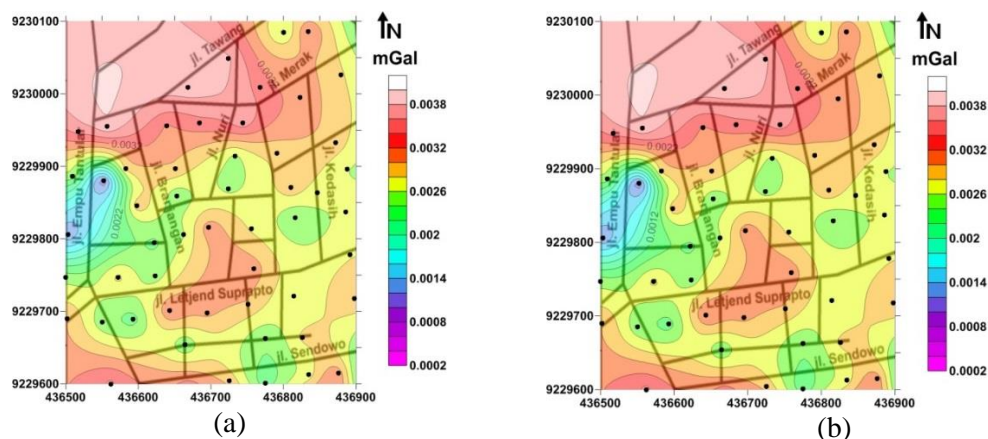


**Figure 6**. Contour map of MVG on (a) March, and (b) September 2018

Based on Figure 6 the results of the MVG measurement show that the measurements in the March and September 2018 periods are relatively the same and as long as the range is small. This is because there is no additional mass of rainfall as the rainfall data in the study area is as shown in Figure 5 which shows a tendency to decline from March to August and no rainfall in September. This condition causes a decrease in the water table even though it is small. This decrease in groundwater is associated with the TLMVG anomaly which is difference between MGV for the September period and March is

of negative value whose conditions in the study area are in the formulation in Table 1. As a justification that in the study location changes in values or gravity anomalies from March to September 2018 do not caused by subsidence but by decreasing the groundwater level using equation (1) and equation (2).

Modeling equation (1) Assuming rock porosity (groundwater reservoir) of 30%, any change in groundwater level of 1 meter causes a change in gravity of 12,579 µGal. This modeling ignores the surface curvature of the earth, topography and altitude. If the TLMVG anomaly measurement results is 18,230 µGal substituted in equation (1) the meal will get a decrease in groundwater level 1,449 m. Furthermore, if the TLM anomaly measurement results is 0.0279 it is substituted in equation (2), it will obtain a subsidence 0.0091 cm.

## 4. Conclusion

TLMVG modeling results show there are three possibilities, namely positive (+), negative (-), and zero. Consecutive means are as follows: a rise in groundwater, a decrease in ground water level and no change. The results showed that during the measurement of TLMVG in the period of March and September, there had been a decrease in groundwater in the Kota Lama. It is shown that during this time period the TLMVG anomaly value is 0.01823 mGal or 18.230 µGal which is related to a decrease in groundwater level of 1.449 m. This condition is reinforced by rainfall data during the January to August range which tends to fall and not rain in September. As a justification by using TLM anomaly data from March to September amounting to 0.0279 mGal, it will be obtained an increment of 0.0091 cm which can be improved. It was concluded that in the Kota Lama during the range of March to September there was no subsidence, but there was a decrease in groundwater level of 1.449 m.

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