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APPLICATION OF VERTICAL GRADIENT METHODS OF MICROGRAVITY TIME FUNCTION TO DETERMINE GROUND WATER REDUCTION IN SEMARANG PERIOD OF 2013

APLIKASI METODE GRADIEN VERTIKAL GAYA BERAT MIKRO ANTAR WAKTU UNTUK MENENTUKAN ZONA PENURUNAN MUKA AIR TANAH DI KOTA SEMARANG PERIODE 2013

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ABSTRAK

Perkembangan kota Semarang yang menuntut ketersediaan air untuk keperluan sehari-hari dan industri seiring dengan pertambahan jumlah penduduk. Pemanfaatan air yang tidak terkendali akan menyebabkan sistem air tanah rusak. Tujuan penelitian ini adalah menentukan zona penurunan muka air tanah untuk memperoleh informasi daerah yang memanfaatkan air secara berlebihan. Metode yang digunakan adalah gradien vertikal gaya berat mikro antar waktu. Pengukuran gaya berat di lakukan di 124 titik yang tersebar merata pada periode Mei dan Oktober 2013. Hasil peneltian menunjukkan telah terjadi penurunan muka air tanah di lingkungan Industri Kecil Kaligawe, perumahan Tanah Mas, Perumahan Tlogosori yang ditandai dengan anomali gradien vertikal gaya berat mikro antar waktu Mei-Oktober 2013. Wilayah yang memiliki perubahan muka air tanah negative tinggi (1,2-1,4 m/tahun), berada di sekitar sumur pantau Madukoro 2, LIK Kaligawe dan PT Aquaria dimana tutupan lahan di sekitar sumur pantau tersebut merupakan kawasan industri. Eksploitasi air tanah pada kawasan industri relatif tinggi jika dibandingkan dengan kawasan lainnya.

ABSTRACT

The development of Semarang city requires the availability of water for daily use and industry in line with population growth. Uncontrolled use of water will damage the groundwater system. The purpose of this study was to determine the zone of the decrease of water level to obtain information about area that utilizes excess water. The method used is a micro-gravity vertical gradient between times. Gravity measurements were done at 124 points spread evenly between May and October 2013. The results showed that there was a decrease in ground water level in the Industries area Kaligawe, Tanah Mas, and Tlogosori which was identified with the vertical gradient anomaly of micro gravity between the times from May to October 2013. The regions which have high negative changes in ground water level (1.2-1.4 m / year) were the monitoring wells Madukoro 2, LIK Kaligawe and PT Aquaria which are the industrial areas. Exploitation of ground water in industrial areas is relatively high compared to the other regions.

Keywords: ground water level, vertical gradient, time lapse microgravity.

INTRODUCTION

Utilization of stressed soil water in the region Semarang according to existing records was begun in the 19th century, i.e since the first drilling done in 1842 during the reign of the Dutch East Indies in Fort Wilhelm I Semarang (Sihwanto and Sukrisno, 2001). After the first successful drilling, the use of groundwater for water supply has increased significantly. The beginning of the utilization of ground water was

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started in 1900. At that time, the groundwater was drilled for ± 1,170 m^3 / day from 16 wells.

In 1910, the utilization of ground water increased to 1,310 m^3 / day from 18 wells drilled, and became 1,400 m^3 / day in 1920. Whereas, in 1932, the groundwater exploration has reached 1,610 m3 / day extracted from 28 wells drilled (Sihwanto and Susilo, 2000). In 1982, the groundwater exploration has reached 37 460 m^3 / day taken from 127 boreholes. Since then, the groundwater exploration was highly increased.

Results of a survey conducted by the soil water DGTL (Directorate of Environmental Geology), until 1990 officially recorded number of wells drilled (licensed) was 260 wells drilled by the amount of groundwater exploration as much as 61 570 m3 / day resulting in increased nearly twice over the 8-year when compared to 1982. Meanwhile, the survey in 1995 showed that the total number of wells drilled was 316 boreholes with the amount of groundwater exploration as much as 74 130 m^3 / day.

Based on the data, the growth of groundwater exploration in Semarang each year tends to increase. In 2002, the amount of groundwater exploration reached 39.2 million m^3 / year (Sihwanto and Susilo, 2000). The increased was occurred due to the high growth of the number of industrial, trading activity, port facility, educational facility, and tourism activity. Currently, the groundwater exploration in Semarang has exceeds the groundwater supply which causes an environmental problems. This condition leads to the decline in groundwater levels and quality which is indicated by the formation of a cone of the decrease of water level of up to 10 m below sea level and the occurrence of the flow of sea water into the aquifer that have ground water level is lower than sea level (Sihwanto and Susilo, 2000). In some areas, the high groundwater exploration causes a negative impact on the environment, such as land subsidence (subsidence).

Micro gravity method over time is the development of method of gravity which has time as the fourth dimension. The micro-gravity method over time was characterized by the measurement of repeated micro-gravity in the order of mGall and the careful measurement of height in the order of mm. Micro gravity anomaly over time indicates the changes that occur at an interval of measurement such as: subsidence and the decrease of water level.

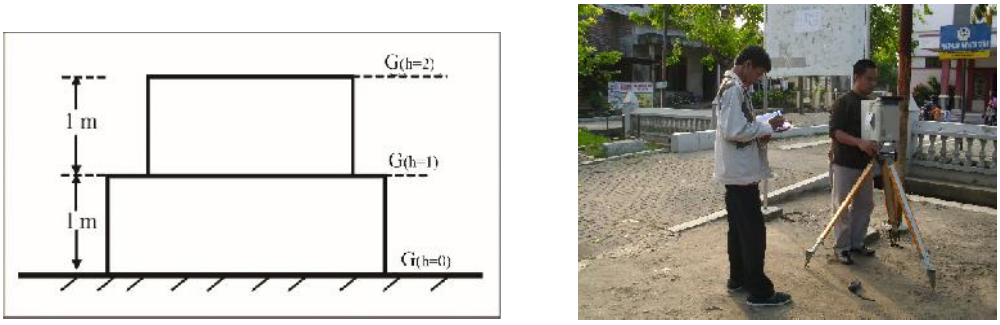
Micro-gravity vertical gradient represents the difference between the values of gravity on two different points divided by distance between the two points. To obtain the gradient, the gravity value was measured at each station at two different heights by using boxes specifically designed to measure the gravity gradient. Meanwhile, the vertical gradient of microgravity anomaly is the difference of the vertical gradient of two consecutive periods.

Application of micro gravity methods for environment has also been done by Branston and Style (2003) that monitors the land subsidence in the mining area. Meanwhile, in 1977, research of micro gravity in hydrology application has been carried out by Lambert and Beamoont (1977). The results showed that the gravity changes in the order of 10 μGal at Cap Pele. Goodkind (1986) showed a good correlation between the changes of gravity with rainfall data. Akasaka and Nakanishi (2000) measured the precipitation, the changes in ground water level and gravity at Oguni geothermal area of Japan, which was used to correct the results of the gravity monitoring at this geothermal area. Galderen et al. (2001) observed gravity changes obtained during four surveys, spanning an 18-year period which were compared to the gravity effect due to natural gas extraction. The random error in the gravity values is small enough to detect the effect of gas extraction after a few years (up to 2 μGal/year), but the trends obtained from the observed and calculated gravity changes in well agreement with their expected error margins after statistical data snooping. Pringle et al. (2012) showed the occurrence of sea water intrusion by observing the major anomaly gravity.

This research used the application of the micro-gravity vertical gradient method of over time to determine the zone that experiences the decrease of the groundwater surface. In this zone, the anomaly of micro gravity from over time is negative. The negative value occurs due to the reduction of the mass of the fluid or water under the surface. Model of relation between the decreases of water level to the respond of micro-gravity anomaly over time was made before applying the micro gravity method. The model was made to simplify the analysis of the measured data of the gravity.

METHODS

The research method consists of: modeling the anomaly response of micro gravity over time due to the decrease of the groundwater surface, designing the surveys of micro-gravity



(a) (b)

Figure 1. (a) Schematic model of gravity measurements to determine the vertical gradient and (b) measurement of the vertical gradient of gravity

Table 1. Data measurement and calculation of gravity observations

No	Stasion	Time	Alliod	Tide (mGal)	Grav Terkoreksi Tide	Drift (mGal)	Grav obs (mGal)
1	Base						
n	Base						

over time for zoning the subsidence surface in Semarang, and interpreting the results with the initial model. The stages of the measurement of gravity data are explained as follow:

1. Determined the measurement point and set the space according to the target which is the shallow aquifer in Semarang. The position of measurement point was expressed by latitude and longitude that scattered around the area of interest. The total number of the measurement point is 120 points. The coordinate of the measurement point was determined by using GPS Garmin.
2. Measured the gravity at a predetermined point by using Gravimeter Scinterc Autograv CG -5 twice which were in May and October 2013, respectively. Measurements were made by making multiple loops in which each loop containing several measurement points started at base point and ended at the base of each loop. At each measurement, the vertical gravity gradient was applied as shown in Figure 1.

For measurement in three difference height, h (i), h (i + 1), and h (i + 2), the vertical gradient of gravity can be calculated by using the following equation:

$$\frac{\partial g(x,y,z)}{\partial z} = \left(\frac{g_{(h=0)} - g_{(h=1)}}{h_{(0)} - h_{(1)}} \right) \quad \text{mGal/m} \qquad 1$$

$$\frac{\partial g(x,y,z,\Delta t)}{\partial z} = \left(\frac{\partial g(x,y,z,t_2)}{\partial z} \right) - \left(\frac{\partial g(x,y,z,t_1)}{\partial z} \right) \qquad 2$$

Where:

$\frac{\partial g(x,y,z)}{\partial z}$: Vertical gradient of gravity,

g (h = 0) : gravity measured in the observation point,

g (h = 1) : gravity measured at a 1 m above the observation point,

h = 0 : the height of the observation point

h = 1 : the height of the observation point plus 1 m,

$\frac{\partial g(x,y,z,\Delta t)}{\partial z}$: micro-gravity vertical gradient as function of time

$\frac{\partial g(x,y,z,t_1)}{\partial z}$: Micro-gravity vertical gradient at t = 1

$\frac{\partial g(x,y,z,t_2)}{\partial z}$: Micro-gravity vertical gradient at t = 2

The above modeling shows the response characteristics of gravity (g), a vertical gradient of gravity and vertical gradient micro-gravity over time caused by the reduction of ground-water and the recharge of groundwater.

3. Corrected the measurement data by using Tide Correction to reduce the influence of tidal and drift correction to reduce the effects of tool fatigue during one loop measurement. Then, calculation was made to obtain gravity observations that have been tied to a reference point (base). The tables of the measurement and calculation

results is shown in Table 1.

4. Processed the data using software surfer ver 9.0. The results of data processing were micro-gravity contour map of May 2013 and October 2013, a contour map of gravity vertical gradient of May 2013 and October 2013, and the anomalies of vertical gradient map of micro gravity across time from May to October 2013. The anomalies was obtained by calculating the difference between the gravity in October and that in May for each measuring point. The time range was selected since the season at this time period is dry season, so that the ground water level is not affected by the rain water.
5. Interpreted the results by analyzing the gravity contour maps using the early models that have been made and the supporting data, which are data of rainfall and tides in the study site for a period corresponding to the measurement activity. Both data were obtained from Geophysics Climatology and Meteorology station and Maritime Station, Semarang.

RESULTS AND DISCUSSION

The results of the study are described below started from modeling and then continued by the gravity measurement results.

The simulation of anomalies response of micro-gravity vertical gradient over time due to the reduction of ground water

Synthetic data simulation was done to determine the characteristics of the vertical gradient of gravity anomalies over time due to reduction or decrease of the ground water level. The parameters of the physical model used were in the three-layer earth model form extended in the horizontal direction as follows (Marsudi, 2000; Arifin and Wahyudin, 2000):

1. The first layer is clay layer with a thickness of 10 m and r = 1.9 g / cm^3
2. The second layer is sand layer (aquifer) with a thickness of 40 m and r = 2.0 g / cm^3. Aquifer porosity is 30%, the density changes due to the groundwater exploration is Δr = -0.3 g / cm^3
3. The third layer is clay layer with r = 2.1 g / cm^3

The decrease of ground water level occurred at coordinates of 4000 - 6000 m with magnitude of: t_1 = 0 m, t_2 = 5 m, t_3 = 10 m, and t_4 = 15 m. Gravity measurements was made at 0 and 1 m above ground level, so that the vertical gravity gradient value is the difference between the value of gravity at the specified measurement points. The object model, the gravity response, the vertical gradient and vertical gradient of gravity over times are shown in Figure 2.

The simulation results show that the decrease of the ground water level reduces the value of vertical gradient of gravity. The decrease also gives a negative value of the vertical gravity over time.

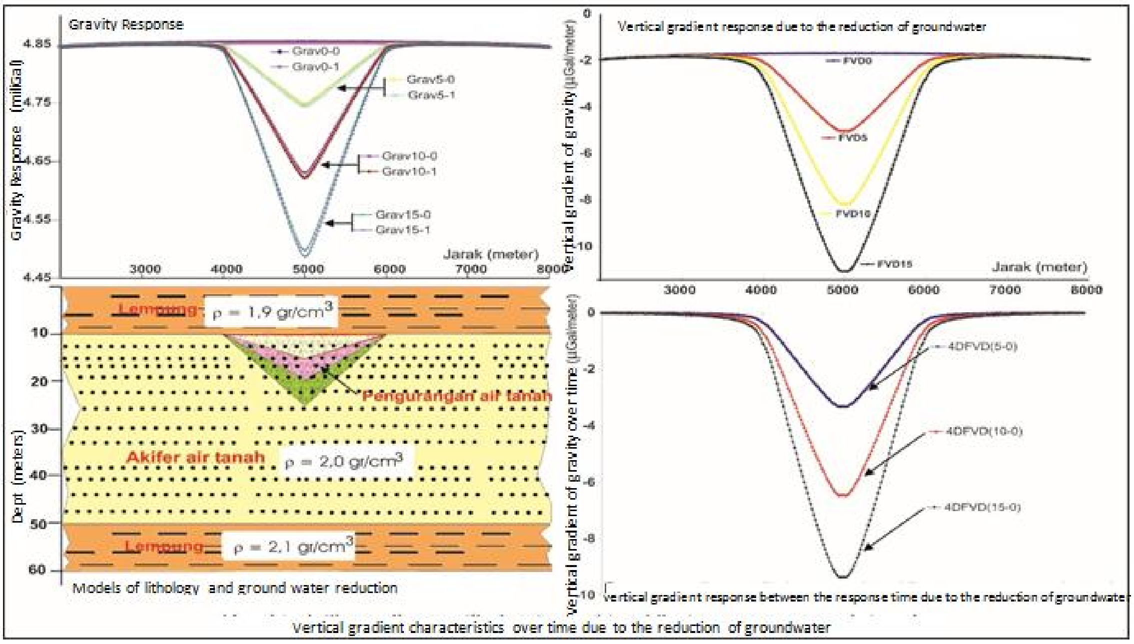


Figure 2. Characteristics of the vertical gradient of the micro-gravity over time due to groundwater reduction (the decrease depth of the groundwater level)

Vertical gradient anomalies response simulation of micro gravity over time as a result of groundwater replenishment

Replenishment of groundwater in the aquifer causes the increase in aquifer density which the magnitude depends on the porosity and saturation of the ground water aquifer. The physical model used was the same as a physical models for groundwater reduction with different initial condition. For the initial conditions (t_1), due to excessive groundwater exploration, the decrease of groundwater forming a cone with a depth of 20 m at coordinates 4000-6000 m. At t_2 the exploration is stopped and then recharged at t3 to 5 and 10 m.

The physical model of the response to the anomalous gravity and vertical micro gravity over time due to groundwater recharging is shown in Figure 3. The simulations result show that the groundwater recharging cause a rise in the value of vertical gradient of gravity. Additional water will give a positive vertical gravity gradient function.

Gravity between May and October 2013

The values of gravity data obtained in May 2013 and in October 2103 are shown in Figure 4a and 4b. The gravity data each month was plotted using Surfer 9. The maximum value of gravity in May 2013 is 978,119.2 mGal and the minimum value is 978,117.4 mGal. The areas that has gravity values between 978,118.6 to 978,119.2 mGal are Kemijen, the Port of Tanjung Mas, Kebonharjo, Widoharjo, Jalan Cipto, SPBE Bandarharjo, Pond Mas, Brass, Indraprasta, Bulu Lor, Poncol, Tugumuda, Simpang Lima, SMK Nusa Putera 1 and Jalan Barito. The areas has a relatively high gravity value compared to that of the area around Marina, Castle Anjasmoro, Kenconowungu, Puspowarno, Tanah Mas and Krobokan which has gravity value between 978,117.4 to 978,118.4.

Gravity data observed in October 2013 showed that the results are not much different from gravity data observed in May 2013. The maximum value of the gravity in October 2013 is 978,119.2 mGal and the minimum value is 978,117.4 mGal. The maximum value spread in the north area to the east area, meanwhile the minimum value spread in the western area likes the result obtained in May 2013.

The gravity data obtained from the observation could not explain the observed gravity changes due to land subsidence, groundwater recharge or intrusion of sea water and reduction of the ground water. To determine the change in gravity due to above mentioned factors, the gravity data observations in May 2013 and October 2013 was used as micro gravity data over time (Figure 4c). Micro gravity data over time obtained by subtracting the gravity data observed in October 2013 with the gravity data observed in May 2013. On the micro gravity over time map, there were positive anoma-

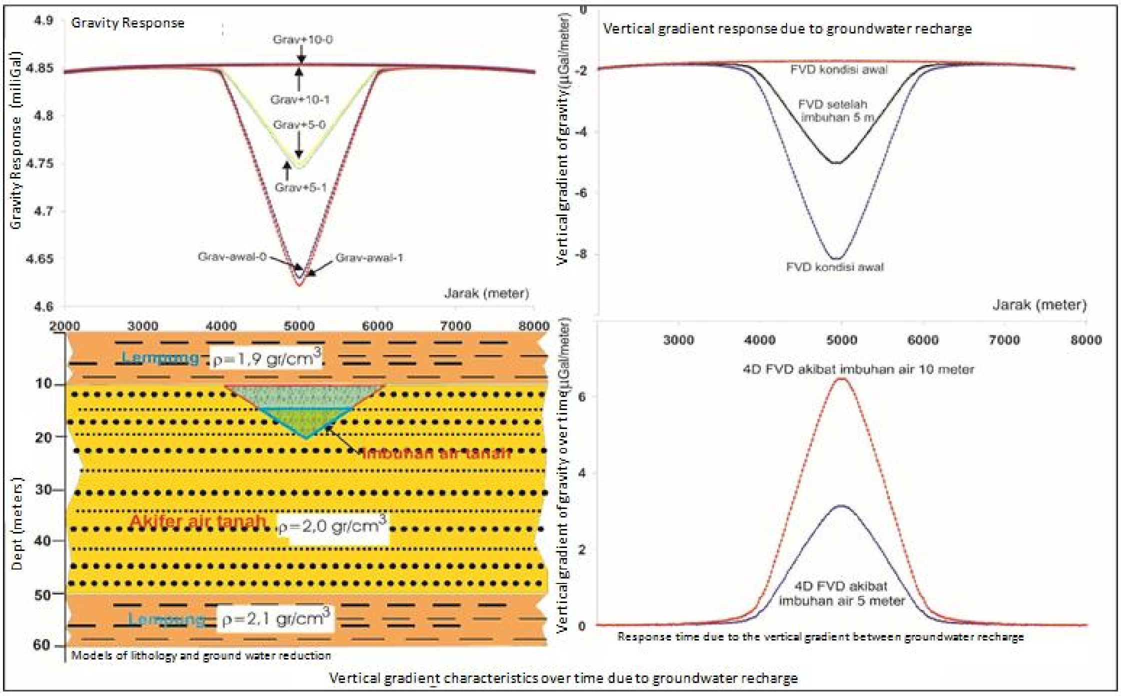


Figure 3. Characteristics of micro-gravity vertical gradient over time due to the replenishment of groundwater

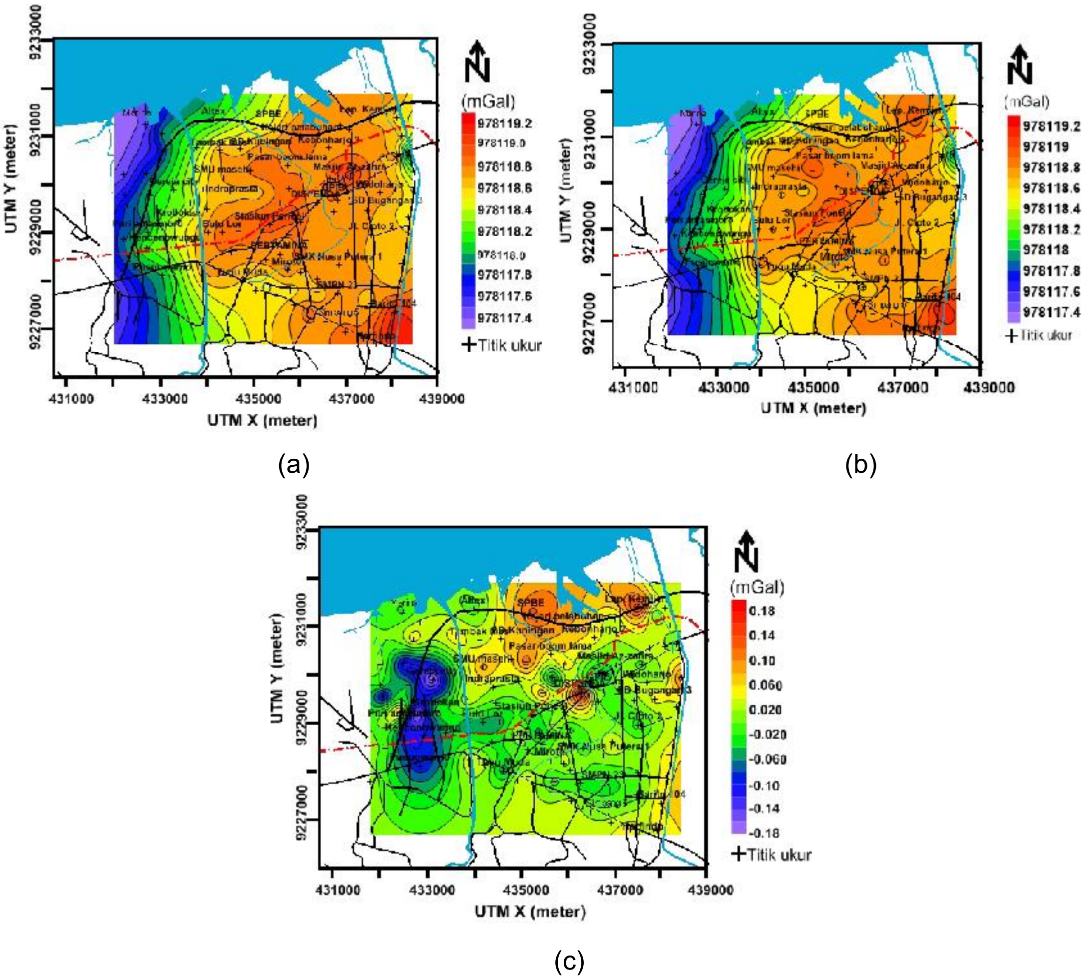


Figure 4. Contour map of the gravity value (a) the period of May 2013, (b) the period of October 2013 and (c) micro-gravity anomaly over time from May to October 2013

ly and negative anomaly. The positive anomaly was occurred due to the subsidence and salt water intrusion while negative anomaly indicates the decrease of groundwater level.

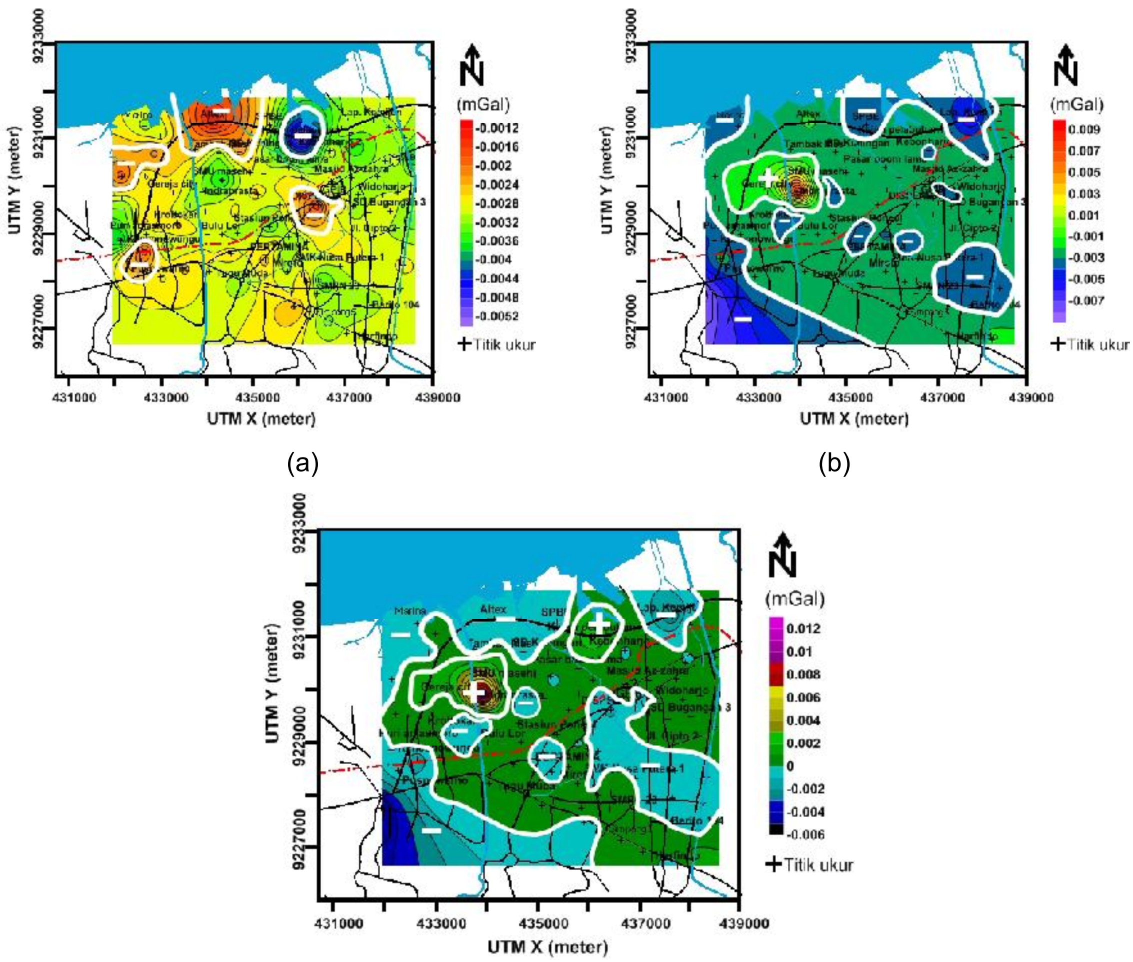
Vertical gradient of gravity between May and October 2013

Vertical gravity gradient data for the period of May and October 2013 are shown in Figure 5a and 5b, respectively. The vertical gravity gradient in May is negative, which the maximum is -0.0052 mGal, the medium is -0.0032 mGal and the minimum - 0.0012 mGal. For October 2013, not all vertical gravity gradient is negative. At certain areas, the vertical gravity gradient values are positive which the maximum and the minimum are 0.009 mGal and 0.001 mGal, respectively. Micro gravity anomaly value over time for May to October 2013 period is negative at some areas. Based on the value of vertical gradient anomalies over time indicates that the negative value is caused by the exploration of water for various purposes, such as for household and industrial. Meanwhile, the positive value was caused by water infiltration in the river flood canals to the wells in the residential area of Tanah Mas.

Rainfall

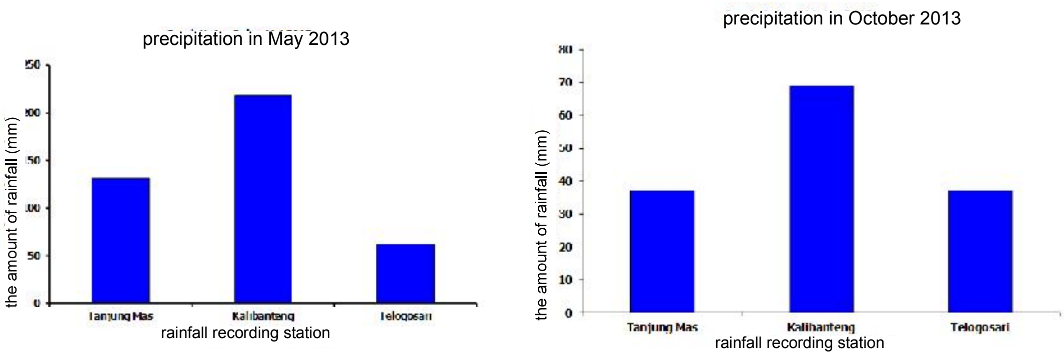
Gravity anomaly value that has been obtained were affected by rainfall that occurred during the period of measurement. Rainfall data obtained from rainfall recording stations, BMKG, Central Java during this period are shown in Figure 6a and Figure 6b.

Location of rainfall recording stations are the western area (Kali Bull), Tanjung Mas (North), and Telogosari (east). Based on the location of the station, it is shown that all regions were represented to a radius of 5 km2. Based on Figure 6 (a) and Figure 6 (b), it is observed that the rainfall in October 2013 lower than in May 2013. It indicates that May 2013 was the rainy season, while October was the dry sea-



(c)

Figure 5. Map of micro-gravity vertical gradient over time (a) the period of May, (b) the period of October 2013, and (c) anomaly of micro vertical gravity gradient over time.



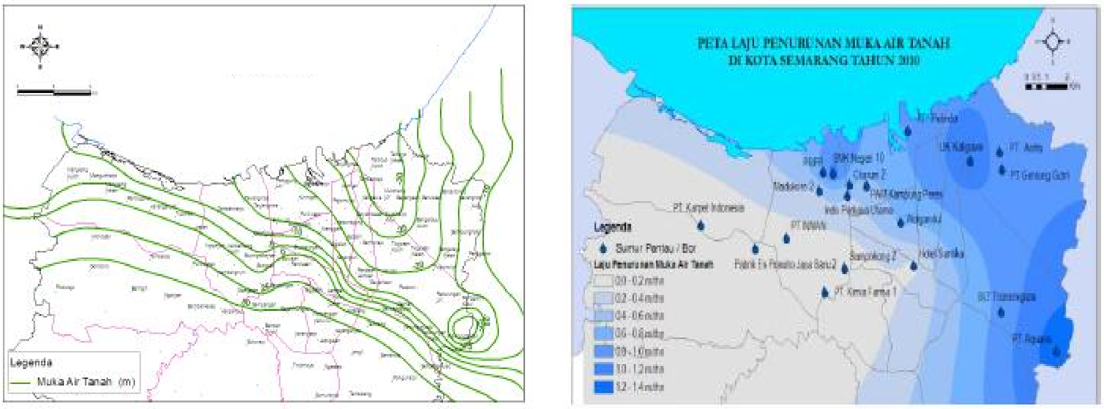
(a) (b)

Figure 6. Rainfall data (a) May 2013, and (b) October 2013

son.

Referring to the gravity measurement results above, the rainfall data supports the value of observed gravity and micro-gravity vertical gradient which the values in May are greater than those in October. If the values are deducted to the values between October and May, then most of the anomaly is negative. This value indicates the decrease in ground water level due to exploration of the groundwater for various purposes while no groundwater refilling occurred.

Research in the same area by using a hydrogeological (Taufiq, 2010) showed that the



(a) (b)

Figure 7 (a). The contour of the ground water level in Semarang in 2010 and (b) Contours of ground water level decreasing rate in Semarang in 2010 (Taufiq, 2010).

cone of decreased water level leads to the east in the area of Kaligawe and Muktiharjo (Figure 7a). Based on the change in ground water level, the areas that have high ground water decrease rate ranges from 1.2-1.4 m / year are Madukoro 2, LIK Kaligawe and PT Aquaria where land cover around the wells is the industrial estate (Figure 7b). The use of ground water in industrial areas is relatively high when compared with other regions. Thus, it can be concluded that the groundwater level decreases in the industrial area Kaligawe LIK, residential area of Tanah Mas, residential area of Tlogosari which are indicated by the negative value of anomaly of vertical gradient of micro gravity over time.

CONCLUSION

Based on the results, it is concluded that there are decreases in ground water surface in Semarang, especially in the residential areas (Tanah Mas and Tlogosari) and in the Industrial area (Kaligawe). This decrease is indicated by a negative value of anomaly of micro gravity gradient over time which is also supported by the results obtained from hydrogeological study in the same location. The decrease of water surface was caused by exploitation of water for domestic and industrial purposes excessively. Therefore, real efforts are required to prevent further decrease of water surface by providing absorption wells in the region. The existence of absorption wells is expected to recharge the groundwater in the rainy season.

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