Relationship between Time Lapse Microgravity Anomaly with Na and Cl Content for prediction of Sea Water Intrusion in Tourism Area Kota Lama Semarang Indonesia

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Abstract. This research is motivated by changes in infrastructure that occur in the old city, the changes in question are the frequent occurrence of flooding in this region. The flooding that occurred was estimated to be caused by subsidence. In addition, subsidence that has other effects, for example seawater intrusion in the Old City, which is located close to the north coast of Java, is also relatively close to about 3 km. The purpose of this study was to find a relationship between seawater intrusion and micro-gravity anomalies between times. The methods carried out are as follows: (1) choose Gravimeter with micro precision. For this study using the Autograv CG5 type, (2) determining the location of the measurement point, which is not expected to experience physical damage due to natural or human behavior for a certain interval, (3) measuring gravity for two different periods in September 2017 and March 2018 at the same point, (4) processing data with initial corrections, namely tidal correction to reduce tidal effects, float correction, and correction of the dynamics of groundwater levels associated with rainfall, and (5) conduct chemical tests of water samples taken from residents' wells at the Research site. The results showed that the negative time-weight gravity anomaly correlated with an average groundwater level decrease of 15,468 cm. This is in accordance with the fact that during this range rainfall trends tend to decline from September 2017 to March 2018. This decrease in ground water causes maximum subsidence and occurs in the south-southwest 2.3 cm. This zone experiences sea water intrusion which is characterized by the content of Na (60-100%) and Cl (100-160%).

1. Introduction
Kota Lama Semarang is a visual image that presents the grandeur of European architecture in the past. Many stand ancient buildings and exotic magnificent Dutch colonial heritage, as if storing a myriad of stories that will never be told. Around Kota Lama water canals were built whose existence can still be witnessed today, even though they are not maintained. This is what caused Kota Lama to be nicknamed Little Netherlands. Its separate location with a city-like landscape in Europe and the canals that surround it make Kota Lama like a miniature Dutch in Semarang.

One of the most popular buildings and must be visited when visiting Kota Lama Semarang, Blenduk Church (Fig. 1a), which is more than two and a half centuries old. The church, which has the original name Nederlandsch Indische Kerk and is still used as a place of worship, is now a landmark in Semarang city.

No less interesting are the colonial heritage buildings in the area, such as the Asurasi Jiwasraya Building (Fig. 1b), Marba Building (Fig. 1c), and the PELNI Building (Fig. 1d).
The history of Kota Lama begins with the signing of the agreement between the Kingdom of Mataram and the VOC on January 15, 1678. At that time Amangkurat II handed Semarang to the VOC as a payment because the VOC had succeeded in helping Mataram quell the Trunojoyo rebellion. After Semarang was under the full control of the VOC, the city began to be built. A fort called Vijfhoek which was used as a residence for Dutch citizens and a military center began to be built. Over time the fort was insufficient, so residents began to build houses outside the east of the fort. Not only residents' houses, government buildings and offices were also established.

In 1740-1743 there was a commotion of Pacinan, the biggest resistance in the period of VOC rule in Java. After the resistance ended, fortification was built around Kota Lama area of Semarang. Afterwards because it was deemed incompatible with the increasingly rapid development of the city, this fortification was demolished in 1824. To commemorate the existence of a bull surrounding the old city, the existing roads were named as Noorderwalstraat, Oosterwalstraat, Zuiderwalstraat and Westerwaalstraat (Fig. 1).

Kota Lama Semarang in 2016 has entered as one of the nominations for the World Heritage Site and is currently proceeding to submit requirements for becoming a World Heritage Site. One important thing that needs to be done in the process is to identify and inventory problems so they can be addressed immediately. The main problem currently in Kota Lama’s problem of subsidence and sea intrusion that is occurring in this region. This will certainly be very detrimental to the development of Kota Lama as a tourist area and preparation for the nomination of the world heritage site.

The effort taken is to conduct a micro gravity survey between times to determine the distribution of sea water intrusion that occurred in Kota Lama area. The method of intermittent gravity is used in this study, considering that it has been used successfully for several purposes, such as observation at archeological sites [1], hydrometerological and Geodetic in La Plata surveys [2], geothermal monitoring [3], the structure of Sumatran subduction (Lange et al, 2018), changes in mass of magma with changes in gravity, monitoring changes in groundwater level using gravimeter [4]. The same is done [5]. Monitoring of subsidence in Jakarta and Bandung [6]. Conducted an airborne gravimeter survey in the Taiwan archipelago [7]. In addition, this method is also applied to hydrocarbon exploration [8] [9].
2.Method

The microgravity method between times is the development of gravity methods with the fourth dimension is time [10]. The principle of this method is repetitive gravity measurement both daily, weekly, monthly and yearly using a careful gravimeter in the µGal order and careful elevation measurements. The existence of changes or differences in gravity results of observations in the first period with the next period is called the microgravity anomaly. The gravity change of observation can be caused by the dynamics around a very high point, such as changes in the depth of the ground water table and soil subsidence.

Before measurements in the field, create a model of the subsidence relationship with groundwater level change using the advanced method. Micro gravity anomaly between two different periods of mathematics are expressed by equation (1).

\[
(G_{\text{obs}(2)} - G_{\text{obs}(1)}) = \left\{ \int_{0}^{\infty} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \Delta \rho(\alpha, \beta, \gamma, \Delta \gamma)(z - \gamma) \left[ (x - \alpha)^2 + (y - \beta)^2 + (z - \gamma)^2 \right]^{-2/3} d\alpha d\beta d\gamma \right\} + c_1 (h_2 - h_1) \tag{1}
\]

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).

\[
H(t) = H_i + \alpha \Sigma n R_n \exp[-c(t - t_n)] \tag{2}
\]

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)

$$\Delta g_w = 2\pi G \rho_w \phi \Delta H$$  \hspace{1cm} (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). For to subsidence correction using equation (4) is called Free air Correction.

$$FAC = \left( \frac{2GM}{R^2} \right) h = 0.3085h$$  \hspace{1cm} (4)

The research location is in the old city as shown in Fig. 3. This location is precisely located in the city of Semarang, Central Java, Indonesia. Gravity data collection is carried out twice a year with different season conditions, namely the rainy and dry seasons.

Figure 3. Research location and distribution gravity point

3. Results and Discussion

The results of synthetic modeling the relationship between time lapse microgravity anomaly with seawater intrusion are explained as follows. The input cell size for the study area is modeled in a 10,000 cells (20 x 20 x 25) mesh. The maximum depth is 100 m. Initial model shown in Figure 4.a and the intrusion model in Fig. 4.b. The initial model assumes no seawater intrusion. Gravity contour map of the early model had a minimum value of 1.8 mGal and a maximum value of 3.4 mGal. The intrusion model has the same value of 1.8 mGal but its maximum is 3.5 mGal. This difference of 0.1 mGal is caused by seawater intrusion. If this model is implemented to a microgravity anomaly data, a gravity anomaly due to seawater intrusion is then obtained. Therefore interpretation of field data will be easier. Gravity anomaly values before and after seawater intrusion is the difference in gravity values at the same point.
The results of gravity measurements in the September 2017 dan Maret 2018 periods at the study location KOTA LAMA were expressed qualitatively with contour maps (Fig. 5a and Fig. 5b). In general the maximum gravity values are in the middle and south which are 978118.79 mGal in the March period, and 978118.77 mGal in the September period.

Figure 5. Gravity values measured for (a) September 2017 dan (b) March 2018

Time lapse microgravity anomaly is obtained by calculating the difference in microgravity values in the period September with the period March for each measuring point. Furthermore, the anomaly values obtained are expressed qualitatively as in Fig. 6. There are two values, positive in the middle, west and south. Negative values are in the north. Base on equation (1), the condition is caused by two sources of anomaly, namely, subsidence, groundwater level change and seawater intrusion.
Based on Table 1 it can be seen that there is a gravity response to the groundwater level. In the period September 2017 – March 2018 the intermittent micro-gravity anomaly is −91.19 alGal in front of PELNI (Jl. Empu Tantular 27) with a change in the groundwater level of -7.24m. The highest microgravity anomaly between times is -313.13 alGal in Tawang Station with a change in groundwater level of −24.83 m. Thus in the Old City area there has been a decrease in ground water levels during the intervals of September 2017 - March 2018. This is supported by the fact that there is a change (anomaly) of micro gravity between the time at the research location with maximum values in the south and southwest as big as -70 mGal.

Table 1. Gravity anomaly against groundwater level changes september 2017–march 2018

| Location                  | Gravity Response (µGal) | Groundwater Level Change (m) |
|----------------------------|-------------------------|------------------------------|
| Jl.Empu Tantular 27       | -91,19                  | -7,24                        |
| Jl.Letjen Suprapto 45     | -123,80                 | -9,84                        |
| Jl. Tawang                | -221,95                 | -17,64                       |
| Jl. Nuri Semarang Utara   | -313,13                 | -24,83                       |
| Jl. Cendrawasih 1         | -223,80                 | -17,79                       |

Based on equation (1), the amount of subsidence can be calculated based on the gravity anomaly data between times by considering the groundwater drop factor (MAT) that has been calculated previously. In full, the amount of subsidence in the Old City is qualitatively as shown in Fig. 7 below. Maximum emission occurs south-southwest of 2.3 cm.

The results of this study are supported by previous studies in various cities in Indonesia that groundwater level reduction has resulted in further impacts including subsidence and seawater intrusion [11]. Sea water intrusion occurs due to two factors, namely internal factors and external factors. Internal factors are intrinsic characteristics of geological and hydrogeological conditions of the research area that are relatively static and beyond human control, such as lithology, types of aquifers. External factors are dynamic characters that can disrupt the hydrostatic balance between groundwater and seawater, such as discharge and the amount of groundwater pumping and sea level rise [12]. Amblesides that occur in Kota Lama area indicate the occurrence of sea water intrusion given the distance from the north coast of the island of Java about 3 km. Seawater intrusion is indicated by the entry of seawater into the pores of the rock and contaminates the groundwater contained in it. The dominant chemical elements in sea water intrusion are Na and Cl. Based on water sample data obtained from population wells in the Old City area. The distribution of Na and Cl is qualitatively as shown in Fig. 8a and Fig. 8b.
Figure 8. Distribution contour maps (a) na and (b) cl in the Kota Lama

Based on Figure 8a and Figure 8b, it can be seen that there is a relationship between the decrease in groundwater level, erosion, and sea water intrusion in Kota Lama area. The zone that experiences sea water intrusion is indicated by the content of Na (60-100%) and Cl (100-160%). The zone in question is a zone that has a decrease in ground water level and subsidence. This is supported by the theory of sea water intrusion [13].

4. Conclusion

Case studies in Kota Lama by using micro gravity anomaly data and groundwater level data can be proven that in this area sea water intrusion occurs. This sea water intrusion is caused by the Semarang river that passes through this area and towards the sea. Seawater intrusion is characterized by the content of the chemical elements Na and Cl which is reinforced by the geological conditions of the decrease in groundwater level and subsidence which are the factors causing sea water intrusion.

5. References

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