Application of Vertical Gravity Gradient to Delineate Groundwater Damage at Bandung Basin

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Abstract. Bandung basin is the center of the population at West Java, and several Industrial areasis. In supporting its sustainability, water needs is one of the factors that must be fulfilled. The water needs are obtained by taking water directly from groundwater. Excessive extraction of groundwater can cause damage, the impact of which is the more difficult it is to obtain groundwater and cause environmental disaster in the form of land subsidence. Using the vertical gravity gradient technique in the Bandung basin area is expected to map the critical groundwater damage zone. The results from the vertical gravity gradient area of the Bandung basin map, the region of groundwater with critical status are found in almost all cities, except in the Baleendah area to Ciparay and Soreang to the south of Cimahi.

1. Introduction
Bandung basin has an altitude between 650 MSL and 2300 MSL with a low elevation in the center and has a high elevation around it. Bandung Basin is Tangkubanprahu Mt., Bukittunggul Mt., Manglayang Mt., Patuha Mt., Malabar Mt located around.

In Bandung basin, it lies in several large cities such as Bandung city, Bandung regencies, the Cimahi city, and West Bandung regencies. Bandung basin has a population around 7.6 million people, with around 40% of the people in the Bandung regency area. There are about 30 thousand industries in the Bandung basin.
2. Method

2.1. Geological Map

There are several vital formations in the Bandung Basin, such as Kosambi Fm., Cibeureum Fm., Cikapundung Fm. And Beser Fm. In the research area, Cibeureum Fm. is the primary aquifer, while Kosambi Fm. is aquitard, and bedrock is Cikapundung Fm.

Cibeureum Fm. Consisting of a low level of consolidation of breccias and tuffs and several basal lava inserts, it has age around Late Pleistocene – Holocene. Breccia, in this formation, is a volcanic breccia compiled by scoring fragments of basalt andesite igneous rocks and pumice. Kosambi Fm. Consists of claystone, siltstone, and sandstones that have not been compact with the age of the Holocene. This formation has interfinger relation with top Cibeureum Fm.. Cikapundung Fm. Consists of conglomerates and breccia compact, tuff, and andesite lava. The age of this formation belong to Early Pleistocene. The compactness of the lithology constituent of this formation can be used as a differentiator to Cibeureum Fm., and the basis for determining the role of this formation as a hydrogeological bedrock in the study area. Besar Fm. In this area is the oldest formation and occupies a basement.
2.2. *Groundwater Conservation Map (2000)*

The following is a groundwater conservation map in the Bandung basin area published by the Directorate of Geology and Environmental Management (Figure 3). It shows that the groundwater level in the Bandung basin area has an altitude between 600 above MSL and 1200 above MSL. Polygon area shows status zones, red for critical areas, yellow for prone zones, blue, orange, and green zones for safe spaces.

**Figure 2.** The geological map of the study area, modification results from [2].

**Figure 3.** Groundwater conservation map in Bandung basin modified from the Directorate of Geology and Environmental Management in 2000 [3].
From the map of groundwater conservation, we can see that general condition of groundwater in the Bandung basin area is good enough, but in some areas, it has critical situations, such as Cimahi, Margahayu-Kopo, Dayeuhkolot, Majalaya, and Rancaekek. If we look at Google Earth (Figure 4), it turns out that the critical groundwater zone in the Bandung basin area is very carefully related to the existence of the industry. In order to this fact, known that the industry exploits groundwater for their needs and it makes groundwater become the critical zone.

2.3. Subsidence rate map (14 January 2007–12 March 2011) generated with ENVISAT ASAR data
Using the remote sensing method come from Envisat Ansar data to determine subsidence rate per year [1]. It can be seen in Figure 5 that almost all areas of the Bandung basin have subsidence, especially in the middle area. The subsidence can be 250 mm/year. The most significant land subsidence is in Cimahi, Dayeuhkolot, Majalaya, and Rancaekek areas.
Figure 5. The rate of land subsidence in Bandung basin come from ENVISAT ASAR data [1].

Figure 6. (left) map of extending groundwater, and (right) map of land subsidence.

Figure 6 shows the comparison of groundwater (left), and land subsidence (right). It shows that there is a positive correlation between the critical zone of the groundwater (red in the left image) and the magnitude of subsidence (red in the right). So we can conclude that a decrease in groundwater at Bandung basin makes decrease pores pressure at aquifer, it makes rock has imbalances stress in it. The reduction in pore pressure makes compression (decrease in volume). Compression of the rock continues from the aquifer zone to the surface which results in subsidence.
2.4. Vertical Gravity Gradient (VGG)

Gravity acquisition techniques by measuring at the same point with varying heights (at least two different levels) are called a vertical gravity gradient technique. The purpose of this measurement is to find out the gravitational gradient value vertically at the measurement point. The formula for calculating vertical gravity gradient written in equation (1). $g_1$, and $g_2$ for gravity value at the lower elevation and the high elevation, and $z_1$, and $z_2$ for the low elevation and the high elevation.

$$VGG = \frac{g_2 - g_1}{z_2 - z_1}$$

Measuring the gravity value is using a gravimeter Scintrex Cg-5, and measuring the elevation value is using a geodetic tripod shown in Figure 7. In general, the vertical gravity gradient value in Indonesia is -0.3085 mGal/m, so anomaly gravity vertical gradient is defined as a different vertical gravity value with this value.

![Figure 7. Vertical gravity gradient measurements using a gravimeter Scintrex CG-5 (a), and a geodetic tripod (b).](image)

To find out the phenomenon of groundwater damage, the author tries to measure the vertical gravity gradient with 63 scattered stations, shown in Figure 8. The distribution of vertical gravity gradient stations concentrated in the central-western area of the Bandung basin.
Figure 8. A symbol plus indicates the distribution of the gravity station.

Figure 9 is results vertical gravity gradient measurement in the Bandung basin. In Figure 9, the red color shows high values of vertical gravity gradient (> -0.3085 mGal/m), and blue indicates a low vertical gravity gradient (<-0.3085 mGal/m). In Figure 9, it can be seen that in the Cimahi area to Bandung, it has a high vertical gravity value. The area of Bandung city to the city of Cimahi, as explained above, shows a critical zone of groundwater. From this, we can conclude that a high vertical gravity gradient shows the critical zone of groundwater.

Figure 9. Vertical gravity gradient at Bandung Basin.
Based on the correlation between critical groundwater zones and large values of vertical gravity
gradients, we can apply to other areas in the Bandung basin. Based on vertical gravity gradient maps in
general Bandung basin suffered groundwater damage at a critical stage except in the Baleendah area to
Ciparay and Soreang to the south of Cimahi.

3. Conclusions
By obtaining a positive correlation between the zone of groundwater damage and the value of the vertical
gravity gradient, this method can delineate the critical area of groundwater in the Bandung basin. The
value of the critical area on the map of the vertical gravity gradient is higher than $-0.3086 \text{ mGal/m}$. Based on vertical gravity gradient maps in general Bandung basin suffered groundwater damage at a
critical stage except in the Baleendah area to Ciparay and Soreang to the south of Cimahi.

References
[1] Ge L, Ng A H, Li X, Abidin H Z and Gumilar I 2014 Land subsidence characteristics of Bandung
Basin as revealed by ENVISAT ASAR and ALOS PALSAR interferometry Remote Sensing of
Environment 154 46–60
[2] Hutasoit L M 2009 Kondisi Muka Airtanah Dengan dan Tanpa Peresapan Buatan Daerah Bandung:
Hasil Simulasi Numerik Jurnal Geologi Indonesia 4 177-188
[3] Taufiq A and Iskandar N 2000 Peta Pengendalian Pengambilan Airtanah Directorate of Geology
and Environmental Management