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Detecting Land Subsidence Using Gravity Method in Jakarta and Bandung Area, Indonesia

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Abstract

Since the declining of groundwater level often causes the land subsidence, it is important to monitor both height changes and gravity changes. The rate of gravity changes versus height changes depends on the density of the material. Thus it gives important information about the mechanism of the land subsidence. The objective of research is to monitoring the land subsidence by gravity observations. Establishing a new method to monitor the environmental issues such as groundwater variation, land subsidence, by means of absolute gravity measurements, a field type absolute gravity meter, Micro-G LaCoste Inc. A10 have been conducted in Jakarta and Bandung area, not only to confirm the accuracy of the instrument but also to investigate the practical and efficient measurement methods for the field surveys. The results present that the gravity value increases in the coastal in Jakarta. Otherwise the biggest gravity change was detected around Lembang fault in Bandung area.

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Keywords: Absolute gravity, density, land subsidence, Jakarta, Bandung, Indonesia

1. Introduction

Jakarta and Bandung are example of urbanized cities in Indonesia that have problem of land subsidence. Land subsidence occurs when large amounts of ground water have been excessively withdrawn from an aquifer. The clay layers within the aquifer compact and settle, resulting in lowering the ground surface in the area from which the ground water is being pumped. Over time, as more water is removed from the area, the ground drops and creates a cone. Once the water has been removed from the sediment, it cannot be replaced. Based on several studies [1, 2, 3, 4, 5, 6], there are four different types of land subsidence that can be expected to occur in the Jakarta and Bandung, namely: subsidence due to groundwater extraction, subsidence induced by the load of constructions (i.e. settlement

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of high compressibility soil), subsidence caused by natural consolidation of alluvium soil, and geotectonic subsidence. The first three are thought to be the dominant types of land subsidence in Jakarta basin.

The impact of land subsidence could be seen in several forms, such as cracking of permanent constructions and roads, changes in river canal and drain flow systems, wider expansion of flooding areas, malfunction of drainage system, increased inland sea water intrusion and increased tidal flooding coverage. Geodesy in the 21st Century is evolving into a crossdisciplinary science and engineering discipline. The strength of blending accurate instruments on space as well as on land enables us to address contemporary problems such as monitoring of environmental variations. The land movements can be measured by present-day space geodetic techniques, such as GPS and InSAR In addition, precise gravity measurements can provide useful information to understand the mechanism of the movements, because they reflect the underground density changes or mass movements. Otherwhile observing changes in gravity is one most powerful methods for detecting mass redistributions associated with solid-earth tectonics, such as those resulting in earthquakes and volcanism [7, 8].

We are, thus, motivated to observed the land subsidence using gravity method in Jakarta (2008-2010) and Bandung (2009-2011) with aim to understand the phenomenon of landsubsidence reproducing hydrogeological gravity change accuratly by monitoring measurement from 2008 to 2010 using absolute gravity meter (A-10). As for the absolute gravity measurements, FG-5 of MGL is well known, A10 has been recently come into practical use and only few studies have been reported so far. A10, which is optimized for outdoor field surveys, is smaller than FG-5 and can be operated with 12VDC power [9]. Consequently it is much suitable for the studies of several environmental issues. One of powerfull methods to detectting mass redistributions associated with groundwater is gravity

2. **Field and equipment**

2.1 Field characteristics of Jakarta

Jakarta is centered at the coordinates of about-6^{o}15' (latitude) and +106^{o}50' (longitude) and, located on the lowland of the northern coast of the West Java province, as shown in Figure 1. The area is relatively flat, with the topographical slopes ranging between 0^o and 2^o in the Northern and central parts, and between 0^o and 5^o in the Southern part. The southernmost area of Jakarta has an altitude of about 50 m above mean sea level [10].

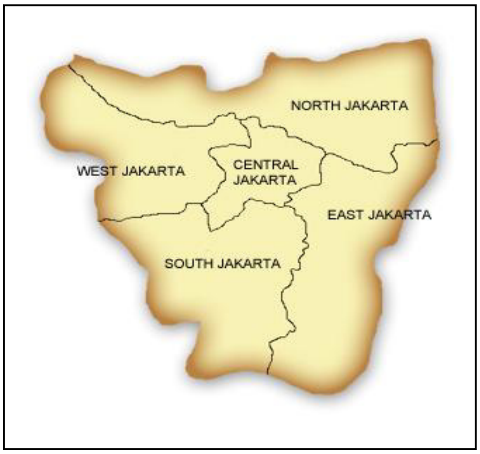


Fig. 1.Jakarta and its souronding area (Abidin et al., 2009).

Jakarta is a lowland area which has five main landforms, namely [11, 12]: (a) Volcanic alluvial fan landforms, which are located in the southern part; (b) Landforms of marine-origin, which are found in the northern part adjacent to the coastline; (c) Beach ridge landforms, which are located in the northwest and northeast parts; (d) Swamp and mangrove swamp landforms, which are encountered in the coastal fringe; and (e) Former channels, which run perpendicular to the coastline. There also 13 natural and artificial rivers flowing through Jakarta, namely Cisadane, Citarum, Ciliung, Angke, Krukut, Sunter, Bekasi, Cakung, Karawang, Cikarang, Ciranjang, Cimancuri and Cidurian.

In terms of geological and hydrological settings, the Jakarta basin consists of a 200 to 300 m thick sequence of Quaternary deposits which overlies Tertiary sediments [13]. The top sequence is thought to be the base of the groundwater basin. The Quaternary sequence can be further subdivided into three major units, which, in ascending order are: a sequence of Pleistocene marine and non-marine sediments, a late Pleistocene volcanic fan deposit, and Holocene marine and floodplain deposits. Three aquifers are recognized inside a 250 m thick sequence of quaternary sediment of the Jakarta basin, namely [14, 15]: the Upper Aquifer, an unconfined aquifer, occurs at a depth of less than 40 m; the Middle Aquifer, a confined aquifer, occurs at a depth between 40 and 140 m; and the Lower Aquifer, a confined aquifer, occurs at a depth between 140 and 250 m. Inside those aquifers, the groundwater generally flows from south to the north [16]. Below a depth of 250 m, an aquifer in the tertiary sediment was also found. But according to [17] it is less productive and its water quality is relatively poor.

Land subsidence is not a new phenomenon for Jakarta, the capital city of Indonesia. It has been reported for many years that several places in Jakarta are subsiding at different rates [17, 18, 19]. The impact of land subsidence in Jakarta could be seen in several forms, such as cracking of permanent constructions and roads, changes in river canal and drain flow systems, wider expansion of flooding areas, malfunction of drainage system, increased inland sea water intrusion and increased tidal flooding coverage.

2.2 Field characteristics of Bandung

Bandung is the capital of West Java province, Indonesia. The city is surrounded by several medium sized towns and all together formed the Greater Bandung; a highland plateu lies in the catchment's area of the upper Citarum river. It is surrounded by range of hills and volcanoes, some of which are still active and formed the intra-montane basin called Bandung basin (Figure 2). More detail information [20] mention that the central part on basin has altitude of about 665 m and surrounded by up to 2400 m Late Tertiary and Quartenary volcanic terrain. The catchment's area of basin and surrounding mountains cover 2300 km^2 and the Citarum River with its tributaries forms the main drainage system of the basin catchment. Deposits in the basin comprise of coarse volcanoclastics, fluvial sediments and notably a thick series of lacustrine deposits.

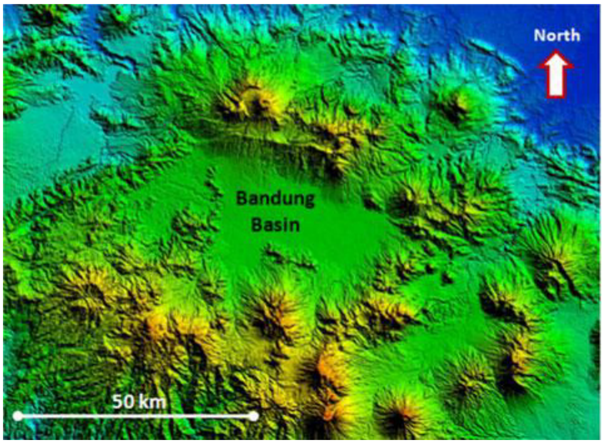


Fig. 2. Bandung basin and its surrounding (Abidin et.al, 2006).

Bandung basin encompasses three administrative units, e.g. Bandung municipality, an urban area 81 km in size perched against the Northern mountain range, the surrounding Bandung regency, plus part of Sumedang regency [21]. Population of Bandung municipality increased from less than 40,000 in 1906 to nearly one million in 1961 and had expanded to two and half million in 1995. In addition, with expansion of manufacturing and textile industries in Bandung basin, urbanization was increased and in 1995 more than 5 million peoples inhabited the basin. This increases in population and industrial activities in turn increase the groundwater withdrawal from the aquifers in Bandung basin, as illustrated in Figure 3.

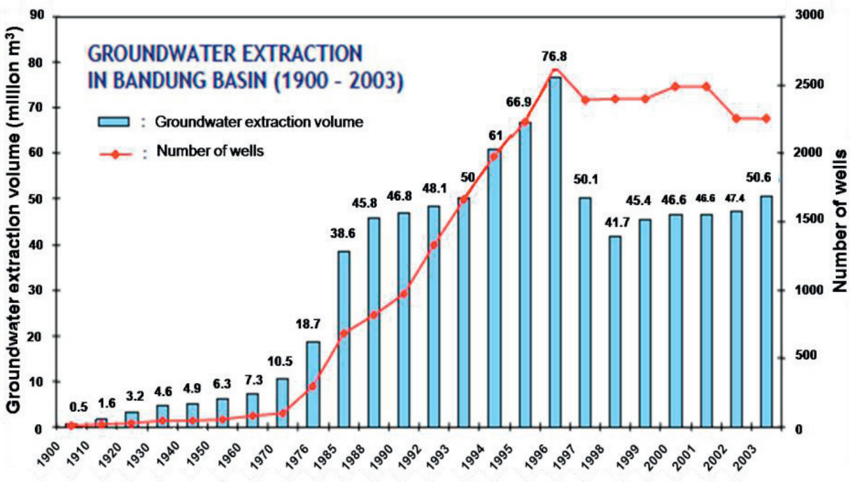


Fig. 3 Registered Groundwater Extraction in Greater Bandung (1900 - 2003),adapted from (Ruchijat, 2006).

On the basis of its hydraulic characteristic and its depth, the multi layer aquifers configuration of the Bandung basin may be simplified into two systems [22]: shallow aquifers (a few meters to around 40 m below the surface) and deep aquifers (more than 40 m to 250 m below surface). These aquifers are composed of *volcanic products* from the volcanic complexes that bordered this basin, and *lake sediments* that were deposited when the central part of the basin was a lake. Increased groundwater abstraction led to a rapid sinking of water tables on the plain and in turn can cause land subsidence, as shown in Table1. During the 1980s, the average annual drop in water tables in the basin was one meter, and in the most heavily abstracted areas annual drops of up to 2.5 meters were recorded [22]. From 1980 to 2004, e.g. in about 24 years, the groundwater level in Bandung basin drop in about 20 to 100 m as shown in Table 1. This groundwater level decreases have both spatial and temporal variations. Increased groundwater abstraction will also decrease the well productivity and also led to drastic changes in the time and direction of travel of water underground [21].

Table. 1. Groundwater level decreases in several location in Bandung basin (Wirakusumah, 2006)

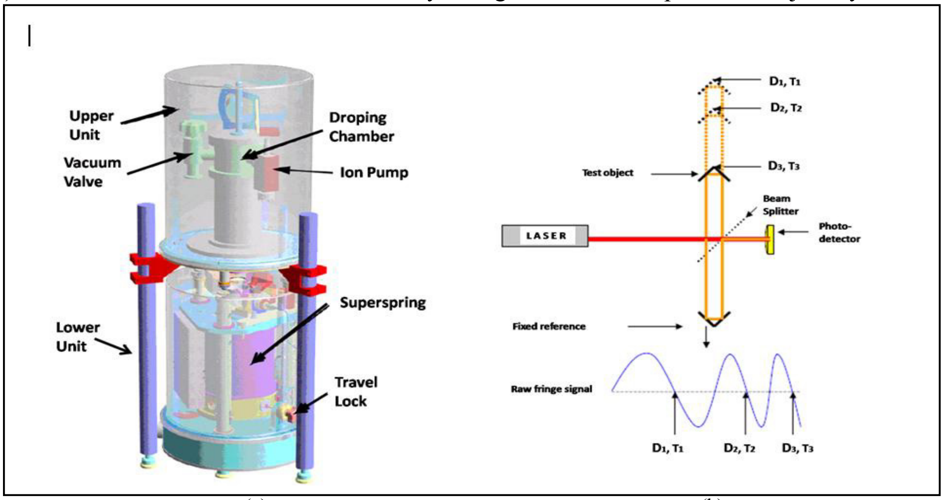
No	Location	1980	2004
1	Cimahi	+ 15 m	-86 m
2	Kebun Kawang	+ 22 m	- 36 m
3	Rancaekek	+ 1 m	- 39 m
4	Lanud Sullaeman	+ 7 m	- 14 m
5	Dayeuh Kolot	+ 2 m	- 55 m
6	Banjaran	+ 2 m	- 20 m
7	Majalaya	+ 3 m	- 41 m

2.3 Absolute gravity measurements using the A10 gravimeter

We employed a portable absolute gravimeter A10 for the absolute gravity measurements in Jakarta and Bandung Cities. The A10's main body is composed of two pieces: a dropping chamber and an interferometer base (IB) unit [9]. The IB unit (lower part of the A10 in Figure 4b) contains a laser which can emit laser beams at two different wavelengths. Although the two wavelengths vary over time, the A10 estimates a true and stable absolute gravity value with a minimum accuracy of 10 μgal by averaging the gravity values obtained with the two laser beams [23]. The main body is connected to the A10 controller and a laptop. The laptop uses 'g' Absolute Gravity Processing Software (g-soft, version 8.09.01.13; [24]) to estimate the gravity value for each drop of the corner-cube reflector, using both the falling distance measured by laser interferometry and the falling time measured by a 10-MHz rubidium clock in the A10 controller. During the gravity estimations, g-soft automatically corrects for gravity changes associated with air pressure changes, polar motions, solid-earth tides, and ocean tide loadings. The important setting parameters for g-soft are presented in Table 1, and other configurations are as follows: polar coordinates given by the International Earth Rotation and Reference Systems Service (IERS) Bulletin A and a delta factor of 1.164 for polar motion corrections; and a delta factor of 1.0 for permanent tide corrections.

The land movements can be measured by present-day space geodetic techniques, such as GPS and InSAR. In addition, precise gravity measurements can provide useful information to understand the mechanism of the movements, because they reflect the underground density changes or mass movements. From this point of view, we have been conducting the precise gravity measurements by using a portable absolute gravimeter, Micro-G LaCoste Inc. (MGL) A10. As for the absolute gravity measurements, FG-5 of MGL is well known. A10 has been recently come into practical use and only few studies have been reported so far. The A-10 absolute gravimeter is a high precision, high accuracy, transportable, field ready instrument that measures the vertical acceleration of gravity (g). While the A-10 will operate as a reliable and accurate laboratory instrument, it is designed primarily with field operation in mind: it operates on a 12V DC (i.e. vehicle battery) power supply, and is optimized to facilitate fast field operation: depending on site conditions [9]. Consequently it is much suitable for the studies of several environmental issues.

As shown in Figure 4, A10 is a ballistic absolute gravimeter which measures the gravity as the vertical acceleration of a dropping test object (corner cube). The test object is freely falling in a vacuum chamber and its dropping distances and times are measured with a laser interferometer and a rubidium atomic clock, respectively. The interferometer basically consists of a beam splitter (a half mirror) and two corner cube retro-reflectors; one is the dropping test object and the other is the fixed reference. The laser beam is split by the beam splitter into the test and reference beams. The test beam is reflected by the test object and the fixed reference and finally recombined with the reference beam. The distance change of the test object causes interference fringes which are detected by the photo detector. The fringes counted and timed with the atomic clock provide the data of distance and precise time pairs (Di, Ti). The vertical acceleration is calculated by fitting these data to a parabolic trajectory.



(a) (b)

Fig. 4 (a) Schematic illustration of A-10 absolute gravimeter. (b) Direct measurement of Absolute gravitymeter

The A10 can automatically lift up and drop the test object every 1 second. We usually combined 100 drops of measurements into a ‘set’, and conducted 10 sets of measurements to obtain an absolute gravity value. According to the MGL web site, the precision of the A10 at a quiet site is 50 μgal /sqrt (Hz). Therefore the 10 sets of measurements (1000 drops) can attain almost 1 μgal precision. On the other hand, MGL announced the accuracy of A10 is 10 μgal, which is restricted by numerous factors including the tides and other geophysical corrections. [25] investigated and discussed about the precision and the accuracy of A10-008 and they confirmed that it was better performance than the specifications. As described later, we also confirmed that the accuracy of A10-017 usually shows better than 10 μgal in good condition.

3. Result and discussion

3.1 Observation in Jakarta

It is well known that local hydrological variations crucially affect the precise gravity measurements. However not many studies have been conducted to monitor groundwater variations or to investigate hydrologic problems primarily because the expected signals are too small to be detected by a spring-type relative gravimeter, for instance Schintrex or LaCoste & Romberg gravimeters. The officially granted accuracy of A10 is 10 μgal and it is almost comparable to those of relative gravimeters. In spite of the specification, we think the absolute gravity values obtained by A10 are much reliable than those obtained by relative gravimeters because the values are free from instrumental drifts, scale factor and other ambiguities which the relative gravimeters can hardly avoid.

The first experimental measurements in Jakarta have been conducted in August 2008. Figure 5 shows a photo of the A10 which was installed on a GPS point (Bench mark) in Jakarta. Actually these measurements in 2008 were not so satisfactory mainly due to instrumental problems. We have obtained only limited number of absolute gravity values. However it was the first filed survey in Indonesia and we learned a lot in both technical and logistical viewpoints.

Fig. 5 A10 at a gravity point in Jakarta

Fig. 6 Land subsidence and gravity changes in Jakarta 2008-2009.

It was a rather tough work to conduct the measurements in high temperature and humid noisy urban circumstances. In particular the measurements in high temperature caused a problem in vacuum. In order to keep the inside of the dropping chamber in high vacuum, the A10 installs an ion vacuum pump. However the efficiency of the ion pump decreases in high temperature (about 40°C). It occurred that the ion pump could not keep the vacuum enough in the 2008 surveys. Mainly due to the vacuum problem, we could not get enough good absolute gravity data in 2008. After the 2008 survey, the gravimeter was returned to the manufactory for overhaul, and then the 2nd ion pump was installed for upgrading the vacuum capability. In the 2009 survey, the vacuum problem has been settled.

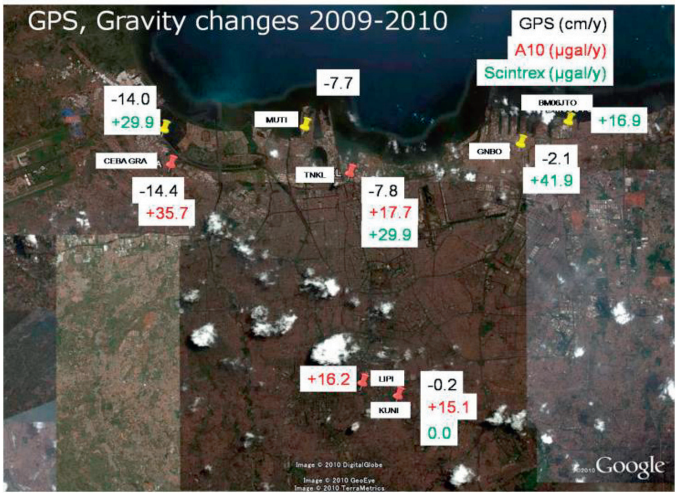


Fig. 7 GPS and gravity changes in Jakarta 2009-2010

However we found another problem that the laser and other controls were unstable in high temp circumstances. Fortunately these problems were withstood by cooling down the instrument and we obtained rather good absolute gravity data of about 10 μgal accuracy. Due to the luck of the absolute gravity data in 2008, we have not obtained the data of enough reliable gravity changes yet. Nevertheless the result of relative gravity measurements presented in Figure 6. Based on the results of research on 2010, we have a good data and detect gravity change with related postif with elevation changed. A few locations have the gravity change rates up to about 15 – 45 μgal. It is suggested the gravity increases in the coastal area where the large subsidence was observed by GPS (Figure 7 and Figure 8)

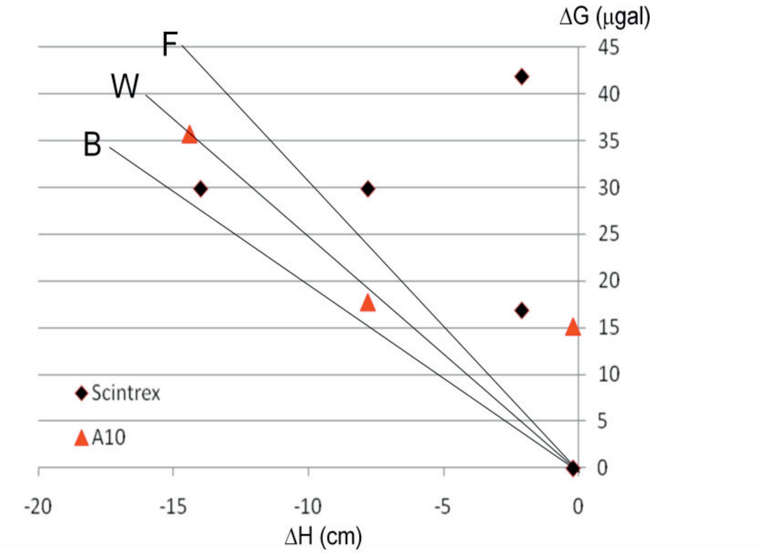


Fig. 8. Relation between gravity changes and heigt in Jakarta on 2009-2010. Red triangle has present of absolute gravimeter A-10 and black square is a value scintrex CG-5 relative gravimeter.

Moreover to understand relation between gravity change associated with water distribution effects in the original gravity data must be corrected by precise elevation and local hydrology data. the following three deficiencies when estimating the effect on gravity due to land-water distributions. First, the majority of models, including the tank model, assume a linear gravity response to precipitation. Since water flow is governed by nonlinear equations, there are limitations in applying linear theory to gravity responses. Second, empirical methods can over- or under-estimate gravity amplitudes resulting from land-water distribution, because empirical methods only fit simple regression curves to observed gravity data. To reproduce gravity response to water distribution, the distribution should be estimated by applying hydrological modeling, independently of observed gravity data. Third, regional and global water storages have often been reproduced rather than local water storage. Unfortunately to get for local hydrology data in jakarta is not so easy, but we still try to develope the hydrologycal model in the future research.

3.2 Observation in Bandung

The absolute gravity observation using A10-017 in Bandung area were taken from 2008 to 2011 which consits of 11 stations.The main target of absolute gravity measurements in Bandung is to detect the ground subsidence due to groundwater pumping. After the gravity data was collected, we estimated the hydrological gravity change in Bandung during 4 years (2008 to 2012). The first absolute gravity measurement in August, 2008 were not so satisfactory mainly due to instrumental problems. We have obtained only limited number of absolute gravity values. However, we experienced lots of both technical and logistical viewpoints. It was a rather tough work to conduct the measurements in high temperature and humid noisy urban circumstances. In particular the measurements in high temperature caused a problem in vacuum. In order to keep the inside of the dropping chamber in high vacuum, the A10 installs an ion vacuum pump. However the efficiency of the ion pump decreases in high temperature (about 40°C). It occurred that the ion pump could not keep the vacuum enough in the 2008 surveys. Mainly due to the vacuum problem, we could not get enough good absolute gravity data in 2008. After the 2008 survey, the gravimeter was returned to the manufactory for upgrading the vacuum capability. In the 2009 survey, the vacuum problem has been settled. However we found another problem that the laser and other controls were unstable in high temp circumstances. Fortunately these problems were withstood by cooling down the instrument and we obtained rather good absolute gravity data of about 10 μgal accuracy. Due to the luck of the absolute gravity data in 2008, we have not obtained the data of enough reliable gravity changes yet. From 2009 to 2010 we have a good result which presented in Figure 9 that shows gravity value changes. Generally the value of gravity change has variate from -0.8 μgal to +22.8 μgal except two stations are CPRY and BNG. The big value change in CPRY caused by the lateral posisition change when measured in 2010 and the BNG points caused from not stabilised land caused near to agriculture land and many traffics, so we dicided to eliminate both of the measuring point.

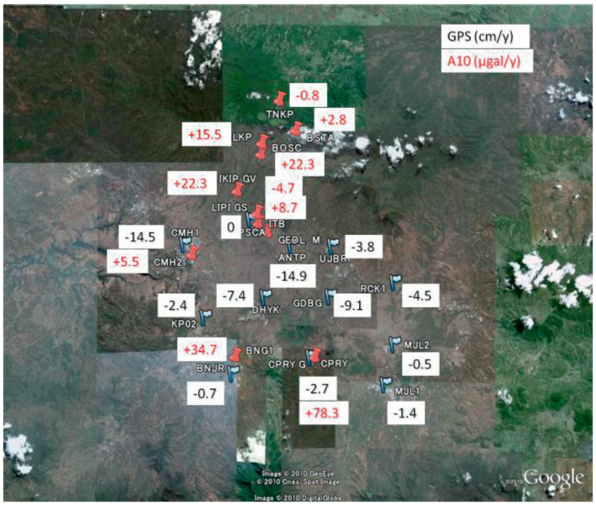


Fig. 9. The banch mark of absolute gravity meter and GPS measurements on 2009-2010.

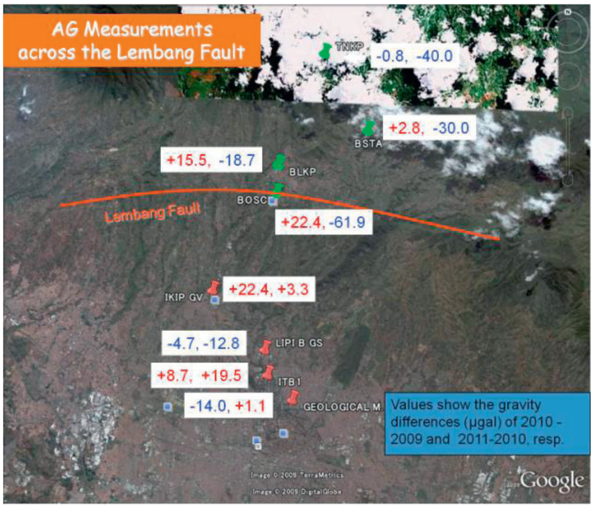


Fig. 10. The absolute gravity value changes related with Lembang fault on 2009-2010 and 2010-2011

Furthermore on 2011 we were focus with high topogrpahy that located at the Southern part on Bandung area which ocurring Lembang fault (Figure 10). During two years interval time the fourth stations are TNKP, BSTA, BLKP and BOSC shows gravity value change variates from 32 µgal to 81 µgal. There two possibilty interepreations: related with activity of Lembang Fault and local hydrology. According from the results of gravity change at BSTA stations indicates that the local hydrology much more bigest than another stations, it's mean that the area have wet seasons, respevtively. Otherwise we can not neglecte the possibility of activity Lembang Fault caused many reference explain that Lembang fault still active yet and seismic data are neded to clarify. We can not neglecte the possibility of activity Lembang Fault caused many reference explain that Lembang fault still active yet and seismic data are neded to clarify.

4. Conclusion

Based on the results obtained from land subsidence monitoring in Jakarta and Bandung, it can be concluded that a portable absolute gravimeter A10 is a powerful tool which can be used for field surveys for studying and monitoring land subsidence phenomenon. The results present that in Jakarta a few locations have the gravity change rates up to about 15 – 45 µgal. It is suggested the gravity increases in the coastal area where the large subsidence. Otherwise the gravity change in Bandung area has variate from -0.8 µgal to +81 µgal and more higher value at surrounding Lembang fault which caused by local hydrology and activity of Lembang Fault. Finnally, the sustainable use of groundwater is a key issue for Jakarta and Bandung area, and the gravity techniques, which are new and still challenging, should contribute to monitor the groundwater variations and related land subsidence as described repeatedly, only gravity measurements can detect the mass variations directly

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