Establishing a new gravity reference station for geophysical investigation and educational purposes: comparison with satellite gravity data in Banda Aceh city, Indonesia

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Abstract Determining the gravity reference point in the form of the absolute gravity acceleration value is necessary for education and research purposes. Department of Physics, Universitas Syiah Kuala (USK), has had the Scintrex CG-5 gravimeter since 2013 and should have had one absolute gravity point around the campus. A new gravity reference point was made at the Tugu Field (Lapangan Tugu) USK, which was derived from the gravity reference point BMKG Mata Ie with an absolute gravity value of 978102.87 mGal. First, we measured the relative difference in gravity's value between the two points using the Scintrex CG-5 gravimeter. The difference of gravity value at the Tugu Field with BMKG Mata Ie is 23.8356 mGal smaller so that the absolute gravity value is 978079.01 mGal. The result is consistent with the geological data where the rocks around BMKG Mata Ie are metamorphic rocks that began to form in the late Jurassic, while the strata at the Tugu Field consist of young alluvium in the Holocene epoch which has a lower rock density. To verify the absolute gravity value, it is compared with the gravity value obtained from the satellite TOPEX. Data from these satellites is around 978140.15 mGal with a difference of 61.14 mGal.

1. Introduction

Absolute gravity data is required for barometer correction, spring scales, force dan physics experiment based on gravity, such as educational experiment of spring mass oscillation [1]. The geophysical application of gravity measurements is subsurface density modeling which is used for exploration and sophisticated study of seismic hazard [2]. For that purpose, the base point of gravity is needed as a reference point for measurement or a reference point for gravity surveys. In general, gravity measurements are carried out in short time intervals (short time closure). Therefore, it is necessary to have dense distribution of the gravity reference point network more evenly in Indonesia which is carried out by BMKG as a government agency. Aceh has 7 points of gravity observation and two points at Banda Aceh namely at BMKG Blang Bintang and BMKG Mata Ie [3][4].

The Geology Directorate has made several gravity reference points, but some points do not exist anymore. Most reference points are placed at airport terminals for easy accessibility after landing in an area. However, due to the expansion of the Sultan Iskandar Muda airport building, the base point has
been destroyed. Therefore, it is necessary to create a reference point at the USK Tugu Field which will become a backup if at any time the reference point at Mata Ie's BMKG is damaged and can no longer be used. In addition, the BMKG reference point is very close to the building so that this will affect the absolute gravity value because of increasing mass of the building. Moreover, the possible reconstruction of the BMKG’s building will add the continuous leverage of mass effect. In consequence, the absolute gravity value that was previously determined for the gravity reference point will be in consistent. At the end, it greatly affects the accuracy of the measurement (Figure 1a, 1b).

From many previous experiences, researchers and surveyors had difficulty accessing the base point as a reference, because they had to go to the Mata Ie BMKG where the distance makes a time consuming which is more than one hour. The reference point at the USK Tugu Field will make community researchers more effectively and efficiently performing their technical activities, such as installing and removing of the equipment within a reachable vicinity. The similar condition occurred as the reference point at the BMKG mentioned above, a reference point was made in 2013 at the volley ball field in the FMIPA since the gravity Scientrex CG-5 survey equipment has been purchased in 2012. However, due to the building expansion project, the point has been vanished. Therefore, the installation of a reference point at the USK Tugu Field (Figure 1c) is very essential and can be used as a place for time series gravity studies from time to time and even be used for the 4D model of gravity study.

Figure 1. (a) Mata Ie's gravity reference point near the BMKG building (b) Gravity Benchmark Reference Point of Mata Ie (c) The established reference point for the gravity of the USK, Tugu Field along with the Scientrex CG-5 tool views a far from the surrounding buildings
2. Methods
The determination of the new gravitational point located at the USK Tugu Field has the coordinates at longitude 95.3692E; latitude 5.5733N dan altitude 2.50 m from mean sea level (msl). To obtain the absolute value at the reference point, it is derived from the gravity reference point at BMKG Mata Ie with the coordinates of longitude 95.296287E, latitude 5.4962964N dan altitude of 14.86m from msl. The two points have a distance of 11.7 km and an altitude difference of 12.36 m (Figure 2a).
The installation of the gravity reference point in the USK Tugu Field has obtained permission from the Vice-Rector II with the letter-number B/4596/UN11/PT.01.04/2019 as shown in Figure 2b. Most of the reference points are made about a half meter high, but this gravity reference point was made as same as the ground level so that it will not interfere other activities in the field.

In general, the method used in this study is based on i) ground-based gravity data and satellite data. Activities began with making a gravity reference point starting on September 4, 2019, as shown in Figures 3a and 3b. Then, it is covered with thick granite that has been given a small hole which corresponds to the CG-5 triangular mini tripod holder so that every time of the measurement is always in the same position as shown in Figure 3c.
Figure 3. (a) The process of making a gravity reference point (b) The cement mix is put into the hole (c) physical finishing covered with thick granite and smooth frame as well as website writing information.

The first trial of measuring the value of gravity on September 6, 2019 dan attended by representatives of University officials as shown in Figure 4a. However, the measurement was delayed, it must be studied again accurately on how to retrieve the correct data. After the data collection was well understood, the measurement was continued at the new reference point of gravity at the Tugu Field on September 9, 2019 (Figure 4b). After completing the monument field, measurements were taken at the gravity reference point at BMKG Mata Ie as shown in Figure 4c.

Figure 4. (a) The inauguration of the benchmark was attended by representatives of University officials (b) the initial measurement in the monument field (c) the measurement at BMKG Mata Ie.

Due to the preparation of the instrument and other non-technical issues, the gravity measurement started at 02:00 PM. The measurement continued at Mata Ie BMKG at 03.00 PM and returned to the measurement at the Tugu Field at 04:30 PM. Measurements should be made back to BMKG and again back to Tugu Field several times so that a careful comparison was obtained. However, due to time constraints, the measurement only took one loop.

The data stored on the CG-5 device was downloaded, see Figure 5b, using a serial communication cable. Processing used Ubuntu as the system operation to run miniterm.py, a program to receive text data sent by CG-5 when the dump process was executed. The results of the received text are shown in Figure 5c.

The relative gravitational acceleration value measured by the CG-5 tool is not only influenced by the mass of surface rock, but it is also influenced by the spring fatigue factor, the gravity of the celestial
body, the position of latitude, altitude, topographic shape dan other influences. Correction of the gravity method is divided into several types, namely: drift correction; tide correction; latitude correction; free air correction; Bouguer correction; and terrain correction [5].

![Figure 5. (a) Re-measurement at the Tugu Field in the afternoon (b) Download data from CG-5 to a computer via serial to USB cable (c) Download data using Linux OS.](image)

In determining the new gravity reference point at Tugu Field, we only focus on the difference in the magnitude of gravity at the BMKG Mata Ie point. Furthermore, we only consider the tide correction factor and instrumental drift. The difference in gravity values was obtained after tidal and drift correction. From this relative value difference, we can determine the absolute gravity value of the new point that will be compared with the old point whose absolute gravity value is known [6].

![Figure 5.](image)

\[ \Delta g = \Delta g_{obs} - \Delta g_{drift} - \Delta g_{tide} + (\Delta g_{lat} + \Delta g_{FAC} + \Delta g_{Bouger} + \Delta g_{terrain}) \]  

(1)

The absolute gravity value of measurements with the CG-5 should be compared with other methods with different data. One of the available global data is satellite gravity data, but it does have a limited resolution. In this study, satellite data were obtained from TOPEX POSEIDON, it was provided by Scripps Institution's Oceanography, University of California San Diego (UCSD).

The data are in the form of coordinate points and gravity values which have been corrected for free-air and latitude correction [7]. Topographic data can also be downloaded on the website for free-air corrections. The data resolution is a spatial resolution of 1 minute/grid with an error rate of about 0.1 mGal and 1 meter for elevation data [8][9]. Absolute gravity data \(g_s\) from satellite data can be calculated using the following equation,

\[ g_s = g_{lat} + \Delta g_{FAC} + \Delta g_{FAC} \]

(2)

Where, \(g_{lat}\) = latitude correction, \(\Delta g_{FAC}\) = free air correction dan \(\Delta g_{FAC}\) = gravity anomaly that has been corrected for latitude and free-air correction. The absolute gravity data, especially at two locations (USK Tugu Field and BMKG Mata Ie), were compared with the gravity data measured by the Scintrex CG-5 tool.

3. Results and Discussion
The first correction is the tide correction which sets in the CG-5 instrument according to the GMT time difference and coordinates with the accuracy of one decimal point. To make sure the correction is accurate, the tide correction obtained is compared with Longman (1959) [10] based on the Tidal Formula as shown in Figure 6a.
Longman, 1959 has performed tide correction calculations that depend on (M in kg) of the mass of the moon, the distance between the earth's weight (r in meters), the distance between the center of the earth and the center of the moon (d), the mass of the sun (S), the distance between the earth and the sun (D), the zenith angle of the moon (θ), the zenith angle of the sun (φ), and the general constant of the force of gravity (G) which values of 6.67·10^{-11} Nm^2 kg^{-2} [6].

\[ g_T = -\frac{GMr}{d^2}\cos^2 \theta + \frac{3GMr^2}{d^4}(5 \cos^3 \theta - 3 \cos \theta) + \frac{CSr}{d^3}(3 \cos^2 \phi - 1) \]  

(3)

The next correction is drift correction, also known as instrumental drift. This is necessary because the CG-5’s gravity equipment is very meticulous. Thus, it becomes very sensitive to spring fatigue, temperature, and shock. This correction value can be obtained by measuring the value of gravity at the same place (the tie point) at different times. The difference in the value of gravitational acceleration as measured by different times is plotted over time to see the pattern of changes in gravity correction. The pattern can be a linear or polynomial function, the process is carried out after tide correction. Moreover, we can assume how the pattern of changes in the instrumental drift and then can be subtracted from the measurement data so that the gravity value at the tie point will be the same. From the regression results, the correction of the instrumental drive as a function of time (in second) during the measurement is

\[ g_{drift}(t) = a + bt = 5014.7136 + 0.015600t \]  

[mgal]  

(4)

The measurement results as shown in Figure 6b are approximated by a linear function because at the binding point there are only two measurements. The correction of instrumental drift over this time interval is assumed to be linear. When applied to the gravity data (after tide correction), the gravity data at Tugu Field will always be the same (blue dots) (Figure 6c). Furthermore, in the picture, we can see the red dots which are the gravity data of Mata Ie BMKG which has 23.8356 mGal bigger than the Tugu Field.

Figure 6a. Tide correction from CG5 equipment (blue dot) compare with Longman Tidal Formula (continuous line)
Figure 6b. Plotting data at points on Benchmark at the Tugu Field and linear regression line.

Figure 6c. Data corrected for instrumental drift.
After correcting the instrumental drift, it can be seen that the relative measurements at the reference point of the Tugu Field have the same value. Meanwhile, at Mata Ie reference point, the results have a relatively higher value than the Tugu Field of 23.8 mGal (Figure 6c). This means that the Tugu Field has a gravity value that is 23.8 mGal lower than the BMKG Mata Ie reference point. The gravity reference point at Mata Ie BMKG has a gravity absolute value equal to 978102.87 mGal. So the absolute gravity value for the Tugu Field can be reduced by a value of

\[
g_{\text{Tugu}} = g_{\text{BMKG}} - 23.8356 \text{ mGal} = 978079.01 \text{ mGal} = 978.07901 \text{ Gal} = 9.7807901 \text{ m/s}^2
\] (5)

If it is related to the standard gravity \( g_0 = 9.80665 \text{ m/s}^2 \), the gravity value at the Tugu Field is 0.99736 g or 0.26% smaller than the standard gravity.

Furthermore, we compare the absolute gravity data with the gravity satellite. The absolute gravity satellite data calculated based on equation (1) is plotted on a map as can be seen in Figure 7. In general, low anomalies are located in the northeast and southwest of the study area. Meanwhile, the rest are associated with high anomalies. High gravity anomaly values correspond to low elevations, on the other hand, low gravity anomalies are located at low elevations. In theory, the value of gravity will be lower at high elevations. The higher the elevation, the distance to the center of the earth (center of gravity) will be farther away so that the gravity value will be lower. The data measured in the field do not refer to the theory mentioned above. Because there are local anomalous factors that affect gravity anomalies, such as heterogeneous geological structures and rock layers. However, satellite data can still be used for regional interpretation of geological structures. For further interpretation, the gravity data needs to go through a process of data correction and filtering.

The satellite gravity values in the study area ranged from 977960 mGal to 978240 mGal. The comparison between the gravity value measured in the field and the satellite gravity value can be seen in Table 1. For the location at BMKG Mata Ie, the gravity value measured in the field is 978102.87 mGal and the satellite gravity value is 978.088.9 mGal, with a difference of 13.97 mGal. For the location at the Tugu Field, the gravity value measured in the field is obtained 978079.01 mGal and the satellite gravity value is 978140.15 mGal, with a difference of -61.14 mGal.

| Station          | Ground (CG-5) (mGal) | Satellite (mGal) | Different Ground-Satellite |
|------------------|----------------------|------------------|---------------------------|
| BMKG Mata Ie     | 978102.87            | 978088.9         | 13.97                     |
| USK Tugu Field   | 978079.01            | 978140.15        | -61.14                    |
| Difference BMKG-Tugu | 23.859            | -51.25           |                           |

It can be concluded that for absolute gravity determination, gravity satellite data is not suitable because it is regional scale. However, regional interpretation can still be used. As shown in Figure 7a, the fault plane boundaries in the study area are visible. The results obtained from the two methods provide opposite directions of difference, which one is more consistent. Based on the difference in the height of the area, the FAC (Free Air Correction) calculation shows that a point in BMKG which is 12.36 m (\( h_{\text{BMKG}} - h_{\text{TUGU}} = 14.86 \text{ m} - 2.50 \text{ m} = 12.36 \text{m} \)) higher than the Tugu Field whose gravity value lower for 3.8 mGal (FAC=0.3086 \( \Delta h = 0.3086 \times 12.36 \text{ m} = 3.8143 \text{ mGal} \)).
Figure 7 (a) Gravity anomaly map based on Topex gravity satellite data [12] (b) Geological map for the Banda Aceh basin [13,14,15].

However, if we look at the geological map in Figure 7b with the different types of rocks, we can understand why gravity at BMKG Mata Ie is greater than at Tugu Field. Geological data where the rocks around BMKG Mata Ie are metamorphic rocks that began to form in the late Jurassic, while the Tugu Field is in young alluvium in the Epoch Holocene, which has a lower rock density. Due to the dense metamorphic rock, the gravity value at Mata Ie BMKG is higher than Tugu Field, which is composed of relatively less compact young alluvium.

4. Conclusion
The absolute gravity value at USK Tugu Field is 978079.01 mGal or 9.7807901 m/s². Gravity satellite data cannot be used for gravity local surveys that have low resolution and no direct observation. The gravity survey is consistent with the geological data. BMKG provides higher gravity than Tugu Field which is above a lower rock density as young alluvium strata. Please visit http://STEM.id/g or http://NPSHA.org/g. The gravity reference point can be used by the public for various purposes. If there is a survey that ties in with other gravity reference points, please inform the author to re-correct the absolute gravity value from the reference point at the USK Tugu field.
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