Bouguer anomaly comparison using elevation data measured with hand-held device and geodetic GPS in Blora and Pandan Mountain

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Abstract. Land gravity measurements for subsurface studies require good accuracy for three-dimensional measurement of station’s coordinate (X, Y, Z). These coordinate data will contribute to calculation of Bouguer anomaly correction in the research area. In this study, we compared the coordinate data measured using hand-held devices and geodetic GPS devices. A more accurate tool is a Trimble R4 geodetic GPS and then we select the acquired data as a reference (Ground Control Points). The hand-held devices that we used are consist of the SUUNTO Escape 203 altimeter and the Garmin GPSMAP 60CSx. The research areas of this study are in Blora and Pandan Mountain. At that location, we conducted acquisition of elevation data and also gravity. The relative gravimeter used to observe variations of gravity in this study is Scintrex CG5. Gravitational data processing is performed until we obtain Complete Bouguer Anomaly (CBA). The results of this study, we get statistical comparison of the accuracy of elevation data as well as differences in CBA values from the study area. Accuracy of elevation data with hand-held devices based on field measurements in Blora and Mount Pandan reaches 6-53 and 54-95 times lower than a geodetic GPS device. The Bouguer anomaly comparison of the 50 point measurements at the two sites gave the difference range of 1.03 to 2.93 mGal.

1. Introduction
Gravitational measurements on the surface of the earth for the purposes of the subsurface study require good accuracy in three-dimensional coordinate (X, Y, Z). In land topographic survey with high data accuracy, we can use geodetic GPS measurements in the field. The survey using geodetic GPS with very high accuracy in the field may costs more budget and requires longer time than the primary survey (gravity). The effectiveness of data control for onsite processing in gravity survey can be helped by the availability of hand-held devices (navigation tools). For geophysical student’s learning needs, hand-held navigation tools offer convenience on every observation in gravity stations despite their accuracy under the geodetic GPS accuracy.

In this study we will show the comparison between hand-held device data and the GPS geodetic data that measured elevation in the field. The research areas are located in Blora and Mount Pandan (shown in Figure 1). The elevation data obtained from the site is then used for gravity data processing to provide Complete Bouguer Anomaly (CBA) values. The gravimeter used in this study is relative gravimeter Scintrex CG5. The hand-held device used in this study are the SUUNTO Escape 203 altimeter and the Garmin GPSMAP 60CSx. A more accurate tool for obtaining good data accuracy as Ground Control Points in this study is used Trimble R4 geodetic GPS.
Figure 1 Location (red dot plot) of study area in Blora and Pandan Mountain with elevation from Jarvis et al. [1].

2. Data from Geodetic GPS

Geodetic GPS (Trimble R4) observation uses a short static method and radial mode. Positioning is done by differential or relative to another point that it’s coordinates has been known. With this differential observation it takes at least two geodetic GPS receivers. The first receiver is placed at the reference point known to its coordinates (base) and the second connective point is placed at the binding point to be determined its coordinate (rover). The observation time in this study ranged from 20 - 280 minutes depending on the distance between the two points (base and rover), weather, and observation area cover.

The reference point used in this study is owned by the Badan Informasi Geospasial (BIG) which has the order-1. The reference point of the research area in Blora and Pandan Mountain respectively used point N1.0317 and point N1.0313. The point N1.0313 is on the left side of the Blora highway to Cepu (about 7.3 km from Blora), while the point N1.0317 is located at SDN Klitik which is located on the left side of the road from Nganjuk towards Madiun. Measurement of position and elevation of JPN point (in Blora) with reference point N1.0313 done for one hour and 40 minutes. Measurement of position and elevation point A01 (on Mount Pandan) with reference point N1.0317 done for four hours and 40 minutes. After the coordinate points of JPN and A01 observed, then those two points are used as local reference points (base points) to measure 48 other points in study area. Figure 2 shows some documentation of geodetic GPS measurements in the research area.
Geodetic GPS data processing using Trimble Total Control software. The resulting coordinates can be geographic coordinates (latitude, longitude and altitude) or cartesian coordinates (X, Y, Z). A raw data processing can be accepted if the baseline between points is fixed. Baseline is a line connected between the base (base) with the point to be determined coordinates (rover). After the baseline processing is completed then the next process is network flattening. Network alignment aims to obtain the final coordinate value of the points.

The data obtained from positioning using geodetic GPS refers to the ellipsoid. Ellipsoid is an elliptical mathematical model of the earth. While the altitude used for practical purposes on earth refers to a geoid or so-called orthometric height. Geoid is the earth's equipotential field that is considered to coincide with the mean sea level (MSL). To obtain the orthometric height from the ellipsoid height, geoid data is needed. The elevation data conversion in this study refers to Earth Gravitational Model 2008 (EGM 2008).

The survey that conducted in August 2017 at Blora using geodetic GPS observed 25 coordinates with X, Y, and Z accuracy respectively are shown as the standard deviation range (σ) 5.3 to 33.7 mm, 4.6 to 24.9 mm, and 7.4 to 83.5 mm. Second study area (Pandan Mountain) also surveyed using geodetic GPS in August 2017 and we observed 25 coordinates with X, Y, and Z accuracy respectively are shown as the standard deviation range (σ) 16.0 to 122.8 mm, 13.7 to 70.4 mm, and 17.9 to 161.2 mm.

3. Data from Hand-held Device

We use use at least 2 altimeters to observe with hand-held altimeter (SUUNTO Escape 203). One altimeter was observed continuously with time intervals of 5 or 10 minutes at base location (representing changes in pressure and temperature in the study area) whereas the second altimeter was used to observe elevation in gravity station coordinates the study area (as rover). The variation of altimeter value as a function of time observed in the base is assumed to be the same for each gravity stations in the study area because the location of gravity stations are relatively close to the base. Thus the variation of the altimeter value at time (t) in the base is used as a correction to the altimeter reading in the field at time (t).

Measurements by hand-held altimeter are generally performed simultaneously with relative gravimeter measurements, so we can get repeat samples to see the altimeter repeatability at reference point. If we compare the beginning and the end of the survey, the rover altimeter value after corrected with altimeter variation in the base will generally show some difference value. The difference in corrected altimeter values is similar to drift in the loop scheme of relative gravimeter survey. The difference of corrected altimeter values at the same location of this observation we refer to as Δ. Based on altimeter observations in the Blora area in 2016, we get a histogram of 42 samples of corrected altimeter difference (shown in Figure 3).
The difference of corrected altimeter values as shown in Figure 3 was observed at some elapsed time between 1 to 9.5 hours (average 6.5 hours). If we apply the correction linearly from the difference of the corrected altimeter value, then the accuracy of the repeat sample at the observation location is assumed to be better. Using the processing step, we get illustrations from 40 samples on the 2016 observation of BM1 Blora station (shown in Figure 4). Based on the scatter-plots in Figure 4, then we can know the average value of 40 samples is 151.07 meters. The smaller deviation of the scatter-plot from the average value (or on the y-axis of Figure 4 is 151.07 meters + 0) then we get good data. Statistically, we can calculate the standard deviation (σ or standard deviation) of the average altimeter values processed to the final stage at several observation stations in Blora. Based on the data collected at several observation stations in Blora, we get a histogram of 26 stations consisting of 118 total samples (shown in Figure 5). Based on the histogram, the standard deviation of altimeter from 26 observation stations range in 44.7 to 2105.6 mm. The accuracy of those altimeter data is 6 to 53 times lower than the accuracy of geodetic GPS data.

In the same way, we can also get 27 total samples from 25 stations in Gunung Pandan. Based on the data, the standard deviation of altimeter from 4 observation stations in Gunung Pandan has a standard deviation in the range of 1696.3 to 8834.1 mm. The accuracy of altimeter data with standard deviations can be 54 to 95 times lower than the accuracy of geodetic GPS data.

4. Coordinate Data Comparison
Observations with hand-held GPS devices (Garmin GPSMAP 60CSx) are generally performed simultaneously with relative gravimeter measurements, so we can get repeatable samples to see the hand-held GPS repeatability at the base point. If we compare at the beginning of the survey and the end
of the survey, the hand-held value of GPS in the reference points will also generally show the difference in results.

In this part, we try to show the comparison from a statistical point of view. Some examples of research ([1] and [2]) as reference related to the comparison of elevation data accuracy using statistical analysis. (2008). We provide more detail illustration in Figure 6 and 7 to show two maps of stations location in the study area of Blora and Pandan Mountain. The legend on the maps provide the information of the survey date. We also show Table 1 to show the 25 coordinates data in Blora observed with GPS geodetic and hand-held device. Table 2 is summary of the comparison from 25 samples from Table 1. Same thing for second study area in Pandan Mountain, We show the 25 coordinates data in Pandan Mountain observed with GPS geodetic and hand-held device in Table 3 and in it’s summary of the comparison in Table 4.

**Table 1.** The coordinate data in Blora uses a Geodetic GPS tool and hand-held device.

| ID | GPS Geodetic | Handheld Device |
|----|--------------|-----------------|
|    | X   | Y   | Z   | X   | Y   | Z   |
| 10  | 557822.11 | 9229100.78 | 157.73 | 557819.00 | 9229091.00 | 159.12 |
| 30  | 557824.32 | 9228856.35 | 152.11 | 557824.00 | 9228854.00 | 153.34 |
| 50  | 557845.06 | 9228626.69 | 140.70 | 557837.00 | 9228614.00 | 138.34 |
| 70  | 557794.02 | 9228355.42 | 125.45 | 557796.00 | 9228356.00 | 126.34 |
| 90  | 557826.81 | 9228099.24 | 149.45 | 557824.00 | 9228094.00 | 140.34 |
| 110 | 557843.56 | 9227587.28 | 147.56 | 557836.00 | 9227588.00 | 144.34 |
| 130 | 557795.04 | 9227376.99 | 136.52 | 557800.00 | 9227368.00 | 137.34 |
| 150 | 557819.15 | 9227104.73 | 133.58 | 557828.00 | 9227097.00 | 134.62 |
| 170 | 557818.69 | 9226854.17 | 152.21 | 557820.00 | 9226853.00 | 151.55 |
| 190 | 557759.56 | 9226349.92 | 159.34 | 557756.00 | 9226347.00 | 155.02 |
| 210 | 557831.87 | 9226347.96 | 133.58 | 557828.00 | 9226345.70 | 124.18 |
| 223 | 556070.65 | 9226349.92 | 159.34 | 557756.00 | 9226347.00 | 155.02 |
| 230 | 557831.87 | 9226347.96 | 133.58 | 557828.00 | 9226345.70 | 124.18 |
| 250 | 557842.01 | 9226089.78 | 153.88 | 557850.00 | 9226083.00 | 155.27 |
| 270 | 557822.11 | 9225863.88 | 148.95 | 557800.00 | 9225853.00 | 149.46 |
| 290 | 557830.73 | 9225615.23 | 136.52 | 557836.00 | 9225614.00 | 137.34 |
| 310 | 557867.58 | 9225386.26 | 126.90 | 557830.00 | 9225378.00 | 135.19 |
| 330 | 557814.60 | 9225095.84 | 126.90 | 557830.00 | 9225095.00 | 127.12 |
| 350 | 557978.41 | 9224887.75 | 126.90 | 557986.00 | 9224883.00 | 134.12 |
| 370 | 557830.19 | 9224617.80 | 132.50 | 557828.00 | 9224614.00 | 132.12 |
| 390 | 557843.22 | 9224370.37 | 124.08 | 557848.00 | 9224367.00 | 125.33 |
| BM1 | 557156.38 | 9226613.14 | 150.29 | 557157.00 | 9226610.00 | 151.07 |
| BM2 | 558211.62 | 9226815.21 | 164.16 | 558212.00 | 9226811.00 | 163.62 |
| JPN | 557947.45 | 9226722.60 | 156.95 | 557946.00 | 9226716.00 | 156.95 |

Based on hand-held GPS observations (2016 and 2014) at 245 stations in Blora, the accuracy of X and Y positions shown as the standard deviation range (σ) is 500.0 to 10969.7 mm and 500.0 to 10392.3 mm, respectively. While the results of hand-held GPS measurements (2016 and 2017) on 12 stations in Mount Pandan obtained the accuracy of X and Y positions shown as the standard deviation range (σ) are 1414.2 to 1858.3 mm and 707.1 to 10745.5 mm respectively. Accuracy of hand-held GPS data coordinate in Blora can reach 94 to 418 times lower than the accuracy of geodetic GPS data. While the accuracy of GPS data hand-held in Mount Pandan can reach 51 to 153 times lower than the accuracy of geodetic GPS data.
In Figure 8, we show linear trend of correlation between 25 scatter plots of GPS geodetic data and altimeter data in Blora and Pandan Mountain. As we can see, the gradient from both trends are close to 1 with coefficient correlation (R^2) also close to value 1. With this correlation, we get strong correlation from the results of GPS geodetic data and altimeter data.

**Table 2.** Comparison of vertical position in Blora using Geodetic GPS tool and hand-held device.

| Summary          | GPS Geodetic | Altimeter SUUNTO Escape 203 | Difference from 25 samples |
|------------------|--------------|-------------------------------|---------------------------|
| Date             | Aug-17       | Sep-14                        | May-16                    | Aug-17(a) | Aug-17(b) |
| Observed Sts.    | 25           | 25                            | 25                        | 12        | 12        |
| Mean (m)         | 143.57       | 143.26                        | -0.09                     |           |           |
| Median (m)       | 147.56       | 144.34                        | -0.06                     |           |           |
| Range (m)        | 41.08        | 43.00                         | 12.14                     |           |           |
| Minimum (m)      | 123.07       | 120.62                        | -6.25                     |           |           |
| Maximum (m)      | 164.16       | 163.62                        | 5.89                      |           |           |
| Accuracy (mm)    | 7.4 to 83.5  | 44.7 to 4363.1                | 37.3 to 4279.6            |           |           |

**Table 3.** Coordinate data on Mount Pandan using Geodetic GPS equipment and hand-held tools.

| ID    | X     | Y     | Z     | X     | Y     | Z     |
|-------|-------|-------|-------|-------|-------|-------|
| A01   | 587601.34 | 9172856.40 | 364.78 | 587597.00 | 9172853.00 | 364.78 |
| A48   | 588857.88 | 9177814.59 | 508.86 | 588852.00 | 9177809.00 | 506.78 |
| A49   | 587314.92 | 9177300.73 | 480.65 | 587322.00 | 9177303.00 | 475.78 |
| A50   | 587000.52 | 9176964.02 | 498.33 | 587002.00 | 9176962.00 | 491.78 |
| A51   | 587314.92 | 9176518.67 | 500.83 | 587322.00 | 9176516.00 | 507.23 |
| C15   | 584072.89 | 9177820.20 | 468.30 | 584080.00 | 9177811.00 | 465.43 |
| C16   | 585025.04 | 9177605.41 | 473.19 | 585030.00 | 9177609.00 | 469.96 |
| C17   | 585939.85 | 9177081.13 | 467.05 | 585936.00 | 9177097.00 | 463.44 |
| C18   | 586230.99 | 9176228.86 | 468.30 | 586235.00 | 9176224.00 | 455.78 |
| D01   | 586907.07 | 9171113.93 | 208.29 | 586911.00 | 9171120.00 | 215.63 |
| D02   | 586833.07 | 9170078.79 | 174.91 | 586837.00 | 9170077.00 | 183.13 |
| D03   | 586543.93 | 9169135.17 | 143.19 | 586553.00 | 9169133.00 | 153.63 |
| D04   | 586212.61 | 9168237.01 | 120.93 | 586210.00 | 9168223.00 | 132.78 |
| D05   | 585552.28 | 9167415.17 | 116.05 | 585563.00 | 9167411.00 | 126.78 |
| T57   | 587968.50 | 9173749.65 | 425.90 | 587953.00 | 9173745.00 | 426.78 |
| T58   | 587670.30 | 9173933.24 | 458.73 | 587665.00 | 9173924.00 | 454.78 |
| T59   | 587499.85 | 9174138.87 | 497.30 | 587490.00 | 9174193.00 | 492.78 |
| T60   | 587353.60 | 9174040.84 | 528.01 | 587366.00 | 9174408.00 | 525.78 |
| T61   | 587353.60 | 9174721.22 | 558.93 | 587339.00 | 9174709.00 | 554.78 |
| T62   | 587292.19 | 9175186.83 | 590.44 | 587285.00 | 9175185.00 | 587.78 |
| T63   | 587127.40 | 9175546.47 | 584.89 | 587121.00 | 9175544.00 | 583.78 |
| T64   | 586881.80 | 9175964.11 | 551.41 | 586863.00 | 9175959.00 | 551.78 |
| T70   | 587353.60 | 9173458.92 | 403.65 | 587381.00 | 9173461.00 | 401.00 |
| T71   | 587733.93 | 9173494.48 | 398.49 | 587737.00 | 9173504.00 | 401.32 |
| T72   | 586363.71 | 9176087.64 | 498.89 | 586359.00 | 9176817.00 | 496.99 |
Table 4. Comparison of vertical position on Mount Pandan using Geodetic GPS and hand-held tool.

| Summary                  | GPS Geodetic | Altimeter SUUNTO Escape 203 | Difference from 25 sample |
|--------------------------|--------------|-----------------------------|--------------------------|
| Date                     | Aug-17       | May-16                      | Dec-16                   | Aug-17       |
| Observed Sts.            | 25           | 11                          | 12                       | 4            |
| Mean (m)                 | 422.18       | 417.23                      | 0.22                     |
| Median (m)               | 473.19       | 445.34                      | -1.90                    |
| Range (m)                | 474.39       | 43.00                       | 18.49                    |
| Minimum (m)              | 116.05       | 131.12                      | -6.64                    |
| Maximum (m)              | 590.44       | 570.24                      | 11.85                    |
| Accuracy (mm)            | 17.9 to 161.2| 1696.3 to 8834.1            | 1678.4 to 8672.9         |

Figure 6 Map of observation points in Blora.

Figure 7 Map of observation points in the area of Mount Pandan.

Figure 8 Correlation between GPS geodetic data and altimeter data: (a) in Blora and (b) on Mount Pandan.
5. Gravity Data

The gravity measurement data in this study is related to studies in Blora [3] and Mount Pandan [4]. Measurements with relative gravimeters in Blora are done in 2014 and 2016, while measurements at Mount Pandan are conducted in 2016 and 2017. The position of gravity observation stations in Blora and Gunung Pandan previously only used hand-held tools, only in August 2017 some gravity observation stations visited again to be measured with a geodetic GPS.

Based on textbooks [5] Complete Bouguer Anomaly (CBA) can be calculated by simplifying the formulation as follows:

\[
\Delta g_{cb} = g_{obs} - g_0 - g_{fa} - g_{sb} - g_t,
\]

where \( g_{obs} \), \( g_0 \), \( g_{fa} \), \( g_{sb} \) dan \( g_t \) are theoretical gravity, free-air correction, Bouguer slab correction, and terrain correction. Calculation of \( g_0 \) in mGal using International Gravity Formula 1980 as follows:

\[
g_0 = 978032.67714 \cdot \frac{1 + 0.00193185138639 \sin^2 \lambda}{\sqrt{1 - 0.00669437999013 \sin^2 \lambda}},
\]

where \( \lambda \) is the latitude of the measurement coordinate position.

Based on the input data in Tables 1 and 3, the value of \( g_0 \) if using \( \lambda \) input from hand-held device and GPS Geodetic can be calculated using equation (2). Using the existing 50 data, the histogram of the different values of \( g_0 \) from two different devices reached -1.2 to 1.1 \( \mu \)Gal (Figure 9). On average, horizontal position differences from GPS observations (in the ± 10 meter range) do not provide significant \( g_0 \) values (in the order of \( \mu \)Gal).

![Figure 9](image)

**Figure 9** Histogram of difference value \( g_0 \) from \( \lambda \) input from handheld device observation to \( \lambda \) input from geodetic GPS observation.

If the horizontal position difference is not very significant in the Bouguer anomaly calculations based on the histogram in Figure 9, then we will see how the influence of the vertical position on the gravity observation station. The height data from the measurement coordinate position is required for \( g_{fa} \) and \( g_{sb} \) calculation inputs. Based on textbooks [5], the calculations of \( g_{fa} \) and \( g_{sb} \) (density 2670 kg/m³) in units of mGal are respectively shown by (3) and (4) as follows:

\[
g_{fa} = -0.3086h,
\]

\[
g_{sb} = +0.1119h.
\]

In equations (3) and (4) use \( h \) height data in meters.
For terrain correction is done using DEM data input or digital elevation model [1]. The calculation of terrain correction in this study was conducted by involving high differences in the gravity observation station with each elevation in the DEM mesh grid. At each observation point gravity is corrected based on the contribution of the near zone and intermediate zone. The near zone consists of 0 to 1 grid intervals from the gravity observation point and the calculations are determined using four sectors of triangular sloping. The contribution of the intermediate zone to terrain correction is approximated by the form of a prism [6]. The total terrain correction calculated in this study is the contribution of near zones and intermediate zones:

\[ g_t = -(g_{t0} + g_{t1}). \]  

(5)

The negative sign indicates that the effect of topographic differences around the gravity observation point gives a reduction in gravity values observed by the gravimeter. Equation (5) uses the negative value of the sloped triangle \( g_{t0} \) and prism \( g_{t1} \) calculation formulations as shown in the geosoft software manual [7] as follows:

\[ g_{t0} = \gamma \rho \phi \left( R - \sqrt{R^2 + \Delta h^2} + \frac{\Delta h^2}{\sqrt{R^2 + \Delta h^2}} \right), \]  

(6)

\[ g_{t1} = -\gamma \rho \left( x \ln(y + r) + y \ln(x + r) + z \tan^{-1}\left( \frac{y}{x} \right) \right) \]  

(7)

where \( \gamma, \rho, \phi, R, r, \) and \( \Delta h \) are, respectively, the universal constant of gravity, the Bouguer slab density, the triangle prism angle (as illustrated in FIG. 10), the distance of the observation point with the outer sloped triangle, the distance between the points observations with the center of the prism, and the high difference between observation points and DEM data.

![Terrain Correction Design](image)

**Figure 10** Illustration of terrain correction design using DEM data grid (map view) is divided into near zone and intermediate zone.

Based on input data in Tables 1 and 3, the CBA value can be calculated using equation (1). Using the existing 50 data, the histogram of the different CBA values of two different devices reached -0.46 s / d 0.37 mGal on the Blora area and -1.03 s / d 2.93 mGal on the Pandan Mountain area (Figure 9). On average, the difference in vertical position of GPS observations (in the range of ± 10 meters) is quite significant since the difference reaches the mGal order.
6. Summary
The results of this study were a comparison of the accuracy of elevation data as well as differences in CBA values in the study area. Accuracy of altitude data with hand-held tools on field measurements in Blora and at Mount Pandan reaches 6-53 and 54-95 times lower than a geodetic GPS device. The Bouguer anomaly comparison of the 50 point measurements at the two sites gave the difference range -1.03 to 2.93 mGal.

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