Combination of Gravity Disturbances and Gravity Anomalies for Geoid Determination: A Case Study in Semarang City, Central Java, Indonesia

by L.m. Sabri

Combination of gravity disturbances and gravity anomalies for geoid determination: a case study in Semarang city, Central Java, Indonesia

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***Abstract*— Conversion of geodetic height to orthometric height requires geoid to transform geometric elevation above ellipsoid into physical elevation above mean sea level. The need of accurate geoid is increasing as many leveling benchmarks have lost and deformed due to city development and natural activities. This paper presents geoid determination based on combination of gravity disturbances data and gravity anomalies data. Gravity disturbances were computed from 185 terrestrial gravity data. Gravity data were measured on March 2016 using Scintrex CG-5 gravimeter. All gravity stations coordinates were measured using rapid static method of GNSS to achieve sub-meter accuracy. Gravity anomalies data for improving the accuracy of the geoid models were measured by some government and private agencies using analogue gravimeters. It consisted of 10,149 data and covered whole Java island which was not less than 2 arc degree of latitude by 10 arc degree of longitude. Gravity disturbances of the city represented local gravity data, gravity anomalies of Java island represented regional data, while EGM2008 represented global gravity data. Gravity anomalies Java were converted to gravity disturbances data using geoid undulation of EGM2008 by simple free air reduction. The converted data were then shifted to local gravity data system. Gravimetric geoid were computed using Remove-Compute-Restore scheme and integral of Hotine based on combination of local and regional data. Gravimetric geoid was validated on 30 geometric geoid points measured by static method of GNSS and leveling. These validation points were distributed along 51 km of leveling line. Accuracy test showed that average deviation of gravimetric geoid to geometric geoid was -0.773 m while standard deviation of geoid was ±0.042 m. Conclusion of this research was that combination of gravity disturbances data and gravity anomalies data could achieve centimeter level accuracy. For future research, it was recommended to apply stochastic weighting to combine local and regional gravity data.**

Keywords*— *geoid, Hotine, gravity disturbance, gravity anomaly

I. Introduction

Semarang City is the capital of Central Java province of Indonesia that is located on the northern coast of Java Island. Topography increases from several cm below MSL (Mean Sea Level) at northern area to about 300 m above MSL at southern area. Boundary of northern part of the city is Java Sea while southern part is Ungaran volcano. More or less than 40%, area of the city grows on alluvial plains [1], [2]. Massive ground water extraction for industrial, business needs, and natural soil compaction lead to land subsidence phenomenon for the city [3], [4], [5], [6].

Land subsidence phenomenon can be seen from tidal flood disaster that occurs more frequently in many part of the city. It affects many damages of buildings and infrastructures [7]. Furthermore, in point of view of geodesy, land subsidence results significant deformation of vertical reference network. Lack of stable reference points in Semarang city leads to inefficient and inaccurate height measurement. Height measurements must refer to vertical reference points that are located outside the land subsidence area. Applying leveling method, height measurement must be referred to first order references namely TTG 447 and TTG 449 that are located about 10 km to 20 km from the coastline. Considering performance of measurement is 1 km per day, precise leveling measurement need not less than 10 days to obtain height of points referred to national vertical datum of Java island.

As described above, leveling measurement in land subsidence region can be costly and time-consuming. These problems encourage modernization in height measurement from leveling-based to geoid-based [8]. Geoid is equipotential surface that fit to global mean sea level. Geoid-based height measurement combines GNSS (Global Navigation Satellite System) and geoid to obtain normal/orthometric height as leveling does. GNSS delivers geodetic height referred to ellipsoid, while leveling produces orthometric height referred to MSL. Conversion of geodetic height to orthometric height and vice versa requires precise geoid.

The problem with the application of geoid in Indonesia especially in Semarang is lack of precise geoid. According to previous researches, low precision geoids were contributed by coarse distribution of terrestrial gravity data and intrinsic error of gravity data. Geoid in Yogyakarta of Indonesia that was calculated using Molodensky approach gave ± 0.127 m error [9]. The application of Molodensky approach to Indonesian geoid determination gave ± 0.450 m precision as it was tested on 14 first order vertical reference points in Java. Geoid computed from airborne gravity data of Sulawesi Island was still classified as medium precision geoid [11]. Test of Sulawesi geoid in Central Sulawesi, South Sulawesi, and North Sulawesi showed that standard deviation of geoid were 0.521 m, 0.686 m, and 1.061 m respectively.

For terrestrial application, Molodensky approach as described above and Stokes approach require neither normal height or orthometric height above mean sea level [12], [13]. Elevation of gravity points were obtained by leveling measurement. As described above, this method was precise but time-consuming and high cost. For airborne application, elevation of gravimeter on airplane was calculated by subtracting geodetic height of GNSS with geoid undulation of EGM2008 (Earth Gravitational Model of 2008). The later approach might reduce height precision and then propagated to geoid precision.

Alternative method to avoid leveling measurement was to calculate the geoid by Hotine approach [14]. Hotine approach aims to solve Boundary Value Problem or BVP based on measurement of gravity data and geodetic coordinates using GNSS or GPS receivers. The problem of defining boundary with gravimeter and GNSS is better known as the BVP GPS or GPS problem.

Hotine approach requires gravity disturbance data which is the difference of actual gravity values to normal gravity values at a certain height above reference ellipsoid. Application of this approach in Western Australian showed that geoid modeled from 60 gravity disturbance data delivered similar form to the geoid modeled from the gravity anomaly data [15]. The Western Australia geoid model calculated by Stokes approach deviates by ± 0.165 m, whereas the standard deviation of the Hotine approach is ± 0.267 m.

Hotine approach had applied for geoid calculations in China [16]. The research was based on GNSS and gravity disturbances data measured at 702 sites. Validation on 52 geometric geoid points resulted ± 0.048 m standard deviation. The fitting process on 29 points produced geoid with precision ± 0.024 m.

Some previous researches showed that precision of geoid were mostly affected by the distribution and quality of gravity data, as well as the geoid validation process. Since area of Semarang city were only 15 arc-minute in latitude by 15 arc-minute in longitude, observed gravity data might be treated as local gravity data. Precision of geoid could be improved by combining local gravity data to regional gravity data that cover larger area. For Semarang city case, the geoid ought to be calculated using locally measured gravity data and regional gravity data of Java island. Unfortunately, regional gravity data of Java were in form of free air gravity anomalies data while the recent local gravity data were in form of gravity disturbances data. Differences in data quality, references, and spatial distribution may lead problems in geoid computation. This study aims to calculate gravimetric geoid from a combination of gravity disturbances data and gravity anomalies data using Hotine integrals in Semarang city.

II. Method of Research

A. Data collection

Hotine geoid calculation required precise gravity data and precise geodetic position data. Terrestrial gravity data were classified into local gravity data and regional gravity data. Local data were measured in 2016 using Gravimeter Scintrex CG-5 with ± 5 µgal accuracy. In SI unit, 1 µgal is equal to 10^{-8} m/s^2 while 1 mgal is equal to 10^{-5} m/s^2 The gravity measurements were carried out at 185 locations in Semarang City at intervals of 2 to 3 km as shown by Fig. 1. The regional gravity data used in this research were the free air gravity anomalies data of Java Island that consisted of 10,149 as shown by Fig. 2. The data were compiled by National Gravity Committee, Pertamina, and Department of Geodetic Engineering of UGM. Local gravity data were observed on March to April 2016. Regional gravity data were measured on various periods.

Fig. 1. Distribution of gravity disturbances data at Semarang city

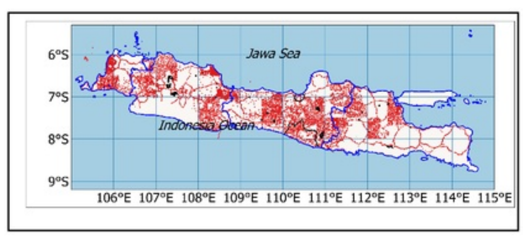

Fig. 2. Distribution of gravity anomalies data at Java island

This research applied R-C-R (Remove-Compute-Restore) technique [17]. Despite terrestrial gravity data, R-C-R technique required spherical harmonic coefficients of EGM2008 with 2190 maximum degree as Global Geopotential Model and SRTM90 Plus as short wavelength data. The accurate geodetic position of the observation points were measured by the rapid static method using TopCon Hiper II and TopCon Hiper SR. Orthometric height for geoid validation were measured using Wild NAK2.

B. Gravity data combination

Due to lack of metadata, gravity anomalies data of Java could not be combined directly to gravity disturbances data. Historical data about equipment, procedures, and references of regional gravity data were unknown. Transformation parameter between both data were obtained by measuring the gravity and geodetic position at a common point. For this research, the chosen common point was regional gravity reference station located at the BPPTKG Office in Yogyakarta. This point was measured on April 6, 2016. Computation of gravity observation of 2016 using least squares adjustment showed that gravity value of common point was 978202,748 mgal with standard deviation of ± 0,008 mgal while the absolute value specified at that point is 978202,980 mgal. It could be seen that all regional data must be subtracted with 0.232 mgal to confirm that local and regional data were at the same system.

Next stage of data processing was converting free air gravity anomalies data to gravity disturbances data using geoid undulation data from EGM2008 n=2190. Upward continuation of regional data were calculate using (1), as follows.

$$\delta g_p = \Delta g_p - 0.3086\,.\,N \tag{1}$$

where Δg_p is gravity anomalies on geoid, δg_p gravity disturbances on earth's surface, N is geoid undulation of EGM2008.

Although local data and regional data were already at same system, both data must be treated differently. In this study, combination of local and transformed regional data was based on buffers with a distance of 0 km, 2.5 km, 5 km, and 10 km. Buffering was applied as deterministic weights that assume the local data was more precise than the regional data. The 0 km buffer scenario was used to occupy all regional data in the geoid determination. Scenario of buffer using 2.5 km and so on were applied to eliminate regional data within a certain radius of the local data.

C. Gravimetric geoid computation

Ellipsoid is a mathematical model to fit the shape of the geoid. Theoretically, gravity potential of geoid is equal to normal gravity potential on ellipsoid. Irregular shapes of the earth and density variation introduce discrepancies between the quantities in normal earth model and actual earth. Potential disturbance can be computed linearly by (2) as follows.

$$T = W - U \tag{2}$$

where W denotes actual gravity potential on the earth's surface, U denotes potential of normal gravity (U) at the earth's surface.

First derivative of potential anomaly is gravity disturbance. Gravity disturbance can be obtained by conducting gravity and GNSS measurement. It can be computed using (3) as follows.

$$\delta g_p = g_p - \gamma_p \tag{3}$$

where g_p denotes actual gravity on the earth's surface and γ_p denotes normal gravity on earth's surface. Gravity disturbances are occupied for geoid determination using Hotine approach.

Other value that is occupied for geoid determination is gravity anomaly. Gravity anomaly is computed by (4) as follows.

$$\Delta g = g_Q - \gamma_0 \tag{4}$$

where g_Q denotes actual gravity on the geoid, and γ_0 denotes normal gravity on the ellipsoid. Gravity on the geoid is computed using free air reduction shown at (5) below

$$g_Q = g_P + 0.3086\,.\,H \tag{5}$$

where g_P denotes actual gravity on surface, and H denotes height above MSL.

Measured gravity data can be classified into three type of wavelength, namely short, medium, and long wavelength. Short wavelength is contributed by topographical effect, while long wavelength is contributed by global gravity of the earth. Medium wavelength itself is gravity data contributed by density contrast below earth surface. Interpolation of terrestrial gravity distortion values directly with Stokes integral or Hotine integral can decrease the precision of geoid determination. Global effects and topography should be eliminated from gravity data. The process of removing the effects on gravity disturbances and returning them in the form of geoid undulations is known as R-C-R.

First step of R-C-R is computation of residual gravity disturbance using (5) as follows.

$$\delta g_{res} = \delta g_p - \delta g_{EGM2008} - \delta g_{topo} \tag{6}$$

where δg_p denotes gravity disturbance on surface, $\delta g_{EGM2008}$ denotes gravity disturbance from EGM2008, δg_{topo} denotes gravity disturbance from topography.

Formula for computing global gravity disturbance can be seen in (7) as follows.

$$\delta g_1(\theta,\lambda) = \frac{GM}{R^2}\sum_{n=2}^{N}(n+1)\sum_{m=0}^{n}P_{n,m}(\cos\varphi)\left[\Delta\bar{C}_{n,m}.\cos m\lambda + \Delta\bar{S}_{n,m}.\sin m\lambda\right] \tag{7}$$

where G denotes Newton gravitational constant, M denotes earth's mass, R denotes earth's radius, $P_{n,m}$ denotes legendre function, while φ and λ denote latitude and longitude of point of interest. The value depends on degree (n) and order (m) of the function.

Residual gravity disturbance are then interpolated using krigging method in specific grid size [18]. Residual geoid undulation (*Nres*) can be calculated using Brun's formula as seen in (8) as follows.

$$N_{res}(\varphi,\lambda) = \frac{R}{4.\pi.\gamma}\int_{\lambda'=0}^{2\pi}\int_{\varphi'=-\pi/2}^{\pi/2}\delta g(\varphi',\lambda').H(\psi).\cos\varphi'.d\varphi'.d\lambda' \tag{8}$$

where $\delta g(\varphi',\lambda')$ denotes residual gravity disturbance of grid point, $d\varphi'$ and $d\lambda'$ denote grid size, $H(\psi)$ denotes function of Hotine at specific distance (ψ).

Hotine function (H) can be found in (9) as follows.

$$H(\psi) = \frac{1}{\sin\frac{\psi}{2}} - \ln\left(1 + \frac{1}{\sin\frac{\psi}{2}}\right) \quad (9)$$

where ψ denotes spherical distance between evaluation point (φ, λ) and contribution point (φ',λ'). Spherical distance can be computed using (10) as follows.

$$\cos\psi = \sin\varphi.\sin\varphi' + \cos\varphi.\cos\varphi'.\cos(\lambda' - \lambda) \quad (10)$$

Restoration of Global Geopotential Model effect on local geoid (N1) to obtain definitive undulation (N) can be found in (11) as follows.

$$N = N_{res} + N_{EGM2008} + N_{topo} \quad (11)$$

where N_{res} denotes residual geoid, $N_{EGM2008}$ denotes geoid undulation from EGM2008, N_{topo} denotes geoid effect from topography. Formula for computing geoid from EGM2008 coefficient can be found in (12) as follows.

$$N_1(\varphi,\lambda) = R.\sum_{n=2}^{N}\sum_{m=0}^{l} \overline{P}_{nm}.(\sin\varphi)\left(\Delta\overline{C}_{nm}.\cos m\lambda + \Delta\overline{S}_{nm}.\sin m\lambda\right) \quad (12)$$

III. Results and discussions

Free air gravity anomalies data of Java were applied to compute geoid by Molodensky approach and Hotine approach. Geoids were computed using Gravsoft programs with some modification to accommodate integral of Hotine and some specific parameters. For Molodensky approach, the regional data were already on geoid and could be used directly for geoid determination. For Hotine approach, regional data were upward continued from geoid to earth's surface. Geoid of Semarang City computed by Molodensky approach ranged from 25.63 m to 26.35 m as shown by Fig. 3. Geoid of Java computed by Hotine approach ranged from 25.64 m to 26.30 m as shown by Fig. 4. Those maps indicated that Hotine and Molodensky approaches could deliver similar result.

Statistic of validation on 30 geometric geoid points in Semarang city was shown at Table I. Mean deviation and standard deviation of Molodensky geoid were -0.701 m and ±0.063 m. Promising result could be found on Hotine approach since it delivered ±0.049 m standard deviation.

TABLE I. DEVIATION OF GEOID OF JAVA BY MOLODENSKY AND HOTINE APPROACHES ON 30 POINTS

Deviation	Molodensky	Hotine
Minimum (m)	-0.830	-0.832
Maximum (m)	-0.587	-0.642
Range (m)	0.243	0.190
Mean (m)	-0.701	-0.717
Standard deviation (m)	±0.063	±0.049

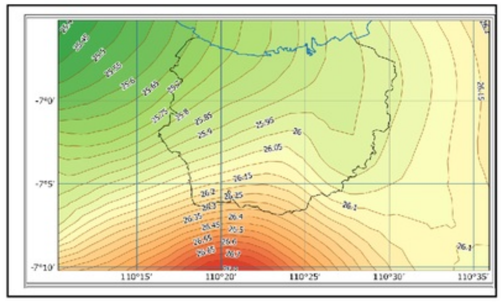

Fig. 3. Geoid computed from regional gravity data using Molodensky approach

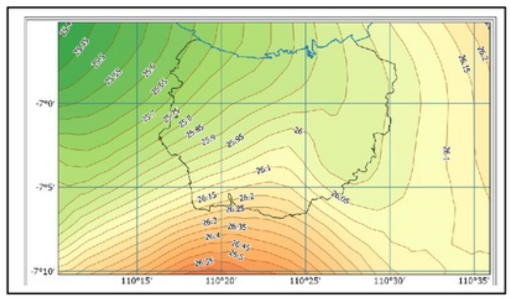

Fig. 4. Geoid computed from regional gravity data using Hotine approach

In general, the data of gravity disturbance in 2016 only covered about 15 arc minute by 15 arc minute. Improvement of geoid precision was obtained by combining local gravity data and regional covering large area. Problems in merging regional gravity data and local gravity data measured in 2016 were lack of information about regional gravity measurement techniques, gravity reference points, geodetic positioning and altitude measurements.

Although the regional gravity data had been transformed to local gravity data system, the qualities of regional data were still questionable. If standard deviation of regional data were available, then data combination could be weighted by stochastic methods. Without standard deviation information, the combination of data were determined by deterministic weighting [19]. The mechanism of weighting was based on buffering. Regional data were selected by a certain buffer distance from the local gravit data measured in 2016. Buffer distances applied in ths research were 0 km, 2.5 km, 5 km and 10 km.

The geoid map calculated from the combined primary data 2016 and the secondary data with a 0 km buffer can be seen in Fig. 5. By applying a 0 km buffer, the Hotine integral calculation involved 10,085 regional gravity disturbances. The form of geoid contour lines generally similar to the geoid that was only contributed by regional data. A significant difference between the regional geoid and the combined geoid could be found in the eastern part of Semarang City.

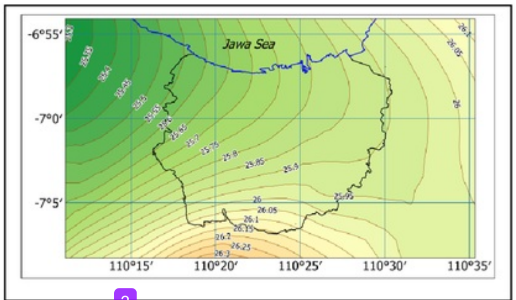

Fig. 5. Geoid of combination of local and regional data with 0 km buffer

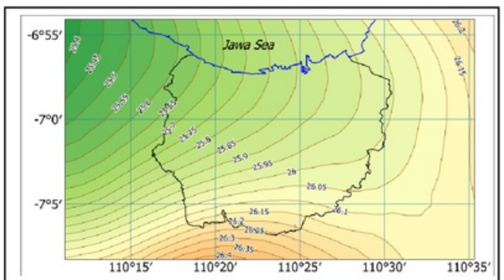

Fig. 6. Geoid of combination of local and regional data with 2.5 km buffer

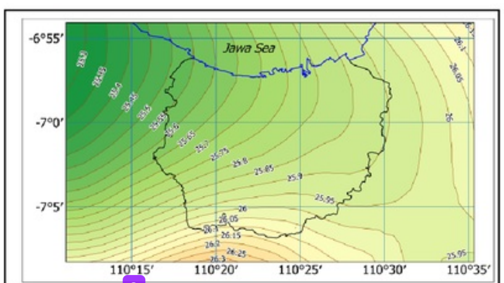

Fig. 7. Geoid of combination of local and regional data with 5 km buffer

The local gravity of 2016 was measured between 2 km to 3 km intervals. The 2.5 km buffer was intended for excluding regional data inside the buffer area to be gridded. The aim of 2.5 km buffer was to minimize the elimination of secondary data. At this stage, geoid undulations were calculated using 9,913 regional gravity disturbances data. Application of 2.5 km buffer only included regional data located at 5 km outside the City of Semarang. Geoid map calculated from the combination of local data of 2016 and regional data with 2.5 km buffer can be seen in Fig. 6.

In the eastern of Semarang, geoids contributed by regional data tend to have different forms with geoid computed from the local gravity data only. Theoretically, the contour shape calculated from both local and regional data should be similar to whose computed from Global Geopotential Model. Anomalous forms of geoid contours indicated some unrecognized errors in regional data. Scenario to minimize the effect of system differences on combined data was to eliminate regional data within 5 km and 10 km from local data of 2016.

The result of R-C-R combined local data of 2016 and 9,730 regional data outside the 5 km buffer can be seen in Fig. 7. The shape of the combined geoid contour line outside the 5km buffer generally similar to the geoid contributed by the local data of 2016. Contour of geoid computed using 5 km buffer were from 25.55 m to 26.18 m. Geoid of 5 km buffer was analog to geoid of 0 km buffers. A significant effect of data elimination within 5 km of primary data 2016 was the loss of contour bulge in the east of Semarang City.

The geoid test results from the combined primary gravity data of 2016 and the secondary data at 30 validation points can be seen in Table II. Directly merging regional data to local data of 2016 generated geoid with standard deviation of ± 0.044 m. Comparing with standard deviations involving only 2016 local gravity data of ± 0.042 m, the combination of regional data directly without buffers was ineffective to improve geoid precision. The improvement of geoid precision to ± 0.041 m achieved after merging of regional data beyond 10 km distance from the local data of 2016 as shown by Fig. 8. This fact indicated that the weighting strategy, both stochastic and deterministic, was required in the process of geoid calculation of primary data combined with regional data. Comparing to the previous researches, combining 185 gravity disturbances in Semarang city and archived free air anomalies data gave satisfactory result. Geoid determination in Western Australia by combining 60 gravity disturbances to 6,266 gravity anomalies data resulted geoid with ±0.066 m accuracy [15].

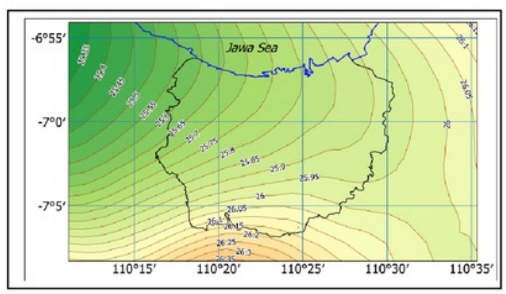

Fig. 8. Geoid of combination of local and regional data with 10 km buffer

TABLE II. DEVIATION OF GEOID OF DATA COMBINATION ON 30 POINTS

Deviation	0 km buffer	2.5 km buffer	5 km buffer	10 km buffer
Minimum (m)	-0.826	-0.838	-0.876	-0.853
Maximum (m)	-0.659	-0.675	-0.728	-0.714
Range (m)	0.167	0.163	0.148	0.139
Mean (m)	-0.736	-0.749	-0.791	-0.773
Standard deviation (m)	0.044	0.043	0.042	0.041

IV. CONCLUSION

Combination of gravity disturbances data of Semarang city and gravity anomalies data of Java Island successfully produced geoid with cm level accuracy. Selecting data by 10 km buffer area gave best precision geoid with ± 0.041 m of standard deviation.

Deterministic weighting by buffering method did not improve geoid precision significantly. The result indicated that local gravity had significant effect to precision of geoid. Recommendation of this research was to apply stochastic weighting for geoid determination based on combination of local dan regional gravity data.

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REFERENCES

[1] M. A. Marfai and L. King, “Monitoring land subsidence in Semarang, Indonesia,” Environmental Geology, 53, pp. 651-659.

[2] Wardhana, D. D., Harjono, H., & Sudaryanto, “Struktur Bawah Permukaan Kota Semarang berdasarkan Data Gayaberat,” Jurnal Riset Geologi dan Pertambangan, 2014, 53-64.

[3] H. Z. Abidin, H. Andreas, I. Gumilar, T. P. Sidiq, M. Gamal, D. Murdohardono, Supriyadi, Y. Fukuda , “Studying Land Subsidence in Semarang (Indonesia) using Geodetic Methods,” FIG Congress 2010 Facing the Challenges – Building the Capacity. 11-16 April 2010.

[4] H. Z. Abidin, H. Andreas, I. Gumilar, T. P. Sidiq, Y. Fukuda , “Land Subsidence in coastal city of Semarang (Indonesia),” Geomatics, Natural hazards and Risk, 2012, DOI:10.1080/19475705.2012.692336.

[5] H. Z. Abidin, H. Andreas, I. Gumilar, T. P. Sidiq, M. Gamal , “Environmental Impact of Land Subsidence in Urban Areas of Indonesia,” FIG Working Week 2015,” From the wisdom of the ages to the challenges of modern world, 17-21 May 2015. Sofia, Bulgari.

[6] Supriyadi and M. Yusuf, “The potential of sea water intrution in the northern city of Semarang based on time lapse micro gravity anomaly,”. Proceeding of the 3rd Applied Science for Technology Innovation ASTECHNOVA 2014, 11-14 August 2014. Yogyakarta, Indonesia.

[7] I. Gumilar, H. Z. Abidin, T. P. Sidiq, H. Andreas, R. Maiyudi, M. Gamal, Y. Fukuda , “Mapping and Evaluating The Impact of Land Subsidence in Semarang (Indonesia),” Indonesian Journal of Geospatial, Vol. 2, 2013, pp. 26-41.

[8] A. Leick.” GPS Satellite Surveiing,”. John Wiley & Sons, 2004.

[9] B. Triarahmadhana, and L. S. Heliani, “Evaluation of GOCE's Global Geopotential Model to The Accuracy of Local Geoid (Case Study: Java Island, Indonesia),”. FIG Congress. 2014.

[10] A. Kasenda, “Height Precision of Geoid for Modernization of Geoid of Indonesia,” University of New South Wales, 2009.

[11] A. Pahlevi, D. Pangastuti, N. Sofia, A. Kasenda, and K. Prijatna, “Determination of Gravimetric Geoid Model in Sulawesi – Indonesia,”. FIG Working Week 2015, 17-21 May 2015. Sofia, Bulgari.

[12] W. E. Feathersone, and J. F. Kirby, “The Reduction of Aliasing in Gravity Anomalies and Geoid Heights using Digital Terrain Data,” *Geophysic Journal International*, Vol. 141, 2000, pp. 204-212.

[13] A. Hernandez-Navarro, “The Submetric Geoid of Mexico,”. FIG Working Week 2004. Mei 22-27 2004. Athena, Greece.

[14] B. Hofmann-Wellenhof and H. Moritz, “Physical Geodesy”. Berlin: Springer,2005

[15] J. F. Kirby, “On the Combination of Gravity Anomalies and Gravity Disturbances for Geoid Determination in Western Australia. Journal of Geodesy , Vol. 77, 2003, pp. 433-439.

[16] F. Li, J. Yue, and L. Zhang, “Determination of Geoid by GPS/Gravity,”. Chinese Journal of Geophysics, Vol. 48, 2005, pp. 326-330.

[17] F. Sanso, and M. Sideris, *Geoid Determination: Theory and Methods*. Springer. 2013.

[18] Amos, M. J., & Featherstone, W. E. (2003). A Comparison of Gridding Techniques for Terrestrial Gravity Observations in New Zealand. *New Zealand Surveyor.*

[19] F. Ning, “Using Surface Fitting and Buffer Analysis to Estimate Regional Geoid Undulation,”. Boletin de Ciencias Geodesicas, 2015. 624-636.

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