ISSN 2354-9114 (online), ISSN 0024-9521 (print)
Indonesian Journal of Geography Vol.53 , No. 2, 2021 (198 –205)
DOI: http://dx.doi.org/10.22146/ijg.55219 website: https://jurnal.ugm.ac.id/ijg

INDONESIAN JOURNAL OF GEOGRAPHY

RESEARCH ARTICLE

Determination of a Local Hybrid Geoid as a Height Reference System for 3D Cadastre

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Received: 2020-05-26
Accepted: 2021-06-11

Keywords:
height reference system;
3D cadaster;
local hybrid geoid

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Abstract *Use and development of vertical building(s) on land parcel(s) have been a common progress to many urban landscapes around the world. 3D cadastre has been a research area that involves legal, technical and institutional assessments to the use and development of vertical buildings. Initial Land Registration of 3D cadastre objects require a representative geometry to determine the legal boundaries of 3D objects. For that purpose, a height reference that is used to define 3D geometries of registered 3D cadastre objects is important. This study focuses in determining a height reference system by developing a local hybrid geoid for the representation of 3D cadastre. The local hybrid geoid was developed by fitting the gravimetric to the geometric geoid. Four strategies were utilized, based on the combination of GGM's SGG-UGM-1 and GO_CONS_GCF_2_SPW_R5, Remove-Compute-Restore method and control point distribution for geoid fitting. Based on comparison with geometric geoid at six independent control points, the local hybrid geoid from strategy 3 produces mean difference of 0.354 m, accuracy of 0.137 m and increased level of closeness of 86%, which is further applied as an alternative reference surface in 3D cadastre.*

1.Introduction

Three-dimensional (3D) cadastre is defined as a cadastre that is related to measurement and registration of rights and restrictions not only for land parcels (which are 2D) but also 3D property units (Stoter & Gorte, 2003). Uses and developments of 3D properties and public facilities are inevitably emerging in major cities and urban areas as the results of urbanization and increased needs for land plots. 3D cadastre that covers legal, spatial and institutional arrangements in order to support the registration and control of 3D property units and public facilities becomes more and more relevant than before (Aien, 2013). Rights, restrictions and responsibilities (3Rs) of 3D units of high-rise buildings and underground facilities are therefore required to be captured and presented accurately in order to better represent the complex relationship between parties, 3Rs and geometries of 3D units as a part of cadastre information (Kaufmann & Steudler, 1998). For this purpose, a current 2D cadastre system that represents of 2D land parcels, could not represent the complex relationship among vertical spaces clearly and accurately referring to the exact vertical reference of the earth surface. As an impact of un-registered 3D cadastre objects there are many disputes and conflicts between above and below the surface (Kim & Heo, 2019). Thus, it is a challenging task in 3D cadastre to register and manage, both regarding properties built on upper and lower the land surface, also both indoors and outdoors (Guo et al., 2014).

One of the important components in the 3D cadastre system is the definition of height components. The height of a cadastre object is defined as the vertical distance to a height reference. The reference that commonly use is surface to model of the earth. Currently most of the height of 3D cadastre objects is determined to refer to the surface of the earth in relative terms with the height difference determined between cadastre objects, call relative height. The other method using the model of the Earth, where the height is determined absolutely to refer to the model of the earth, called absolute height (Karki, 2013). The absolute height of 3D cadastre component must have an accurate height reference, resulting in a 3D cadastre system that fulfill the requirements of e-government, as a digital cadastre maps are typically part of an e-government infrastructure (Kim & Heo, 2019; Navratil & Unger, 2013). The geoid surface can be used to define absolute height, which can represent 3D cadastre objects above and below the surface as in the real world (Cemellini et al., 2018). Compared with the relative height, the absolute height is more ideal because it refers to the national height system, so that it is consistent everywhere (Van Oosterom et al., 2011; Navratil & Unger, 2013).

The geoid is an equipotential surface of the actual gravitational field which is assumed to coincide with an undisturbed Mean Sea Level - MSL (Hofmann-Wellenhof & Moritz, 2005). Geoid as an ideal height reference surface in concept and physical realization on the surface of the earth, currently has not been accurately defined for all regions of Indonesia. Limited availability of terrestrial gravity and un-event gravity distribution in Indonesia are factors that make a geoid as a unified 3D reference surface for 3D cadastre representation is not available (Heliani et al., 2013).

Thus, there is a need for local geoid references in a narrow coverage using the latest global geoid models as a practical solution (Heliani, et al., 2013). The availability of geoid reference and surface height helps to recognize whether 3D cadastre objects are located above or below the surface (Smart & Priebbenow, 2018). Practical height definition for 3D cadastre strongly connected with the realization of local height system, so that the definition of the geoid must be consistent with the local height system. One of the methods that can be used to define such a geoid is hybrid geoid modeling. In the hybrid geoid modeling, a gravimetric geoid model is fitted to the local surface/the local height system (Erol & Çelik, 2004). So that the hybrid geoid modelling produces a geoid model that is fit to the surface, continuous and has a high accuracy value, also consistent with the local height system.

Considering the above conditions, the aim of this research is to determine a height reference system of 3D cadastre using an absolute height system with geoid reference. Specifically, the aims of the research are to developed a hybrid geoid from combination of gravimetric geoid and geometric geoid, to examine the quality of the hybrid geoid using the geometric geoid in an independent control points, and to propose a height reference for representing the 3D Cadastre objects in the case study area of DI Yogyakarta province.

2. Methods

Height is the vertical distance between points on the earth's surface and a reference surface. The common reference surfaces used are ellipsoid and geoid (Hofmann-Wellenhof & Moritz, 2005), which generate geometric height (H) and orthometric height (h), respectively. Figure 1 shows a geometrical relationship between ellipsoid, geoid and topographical surface. The difference between the both heights is known as undulation or geoid height (N). Mathematically, geometrics relationship among ellipsoid, geoid and topography in latitudinal (φ) and longitudinal (λ) positions can be written into the following equation (Featherstone, et. al., 1998) .

$$N_A(\varphi,\lambda) = h_A(\varphi,\lambda) - H_A(\varphi,\lambda) \quad (1)$$

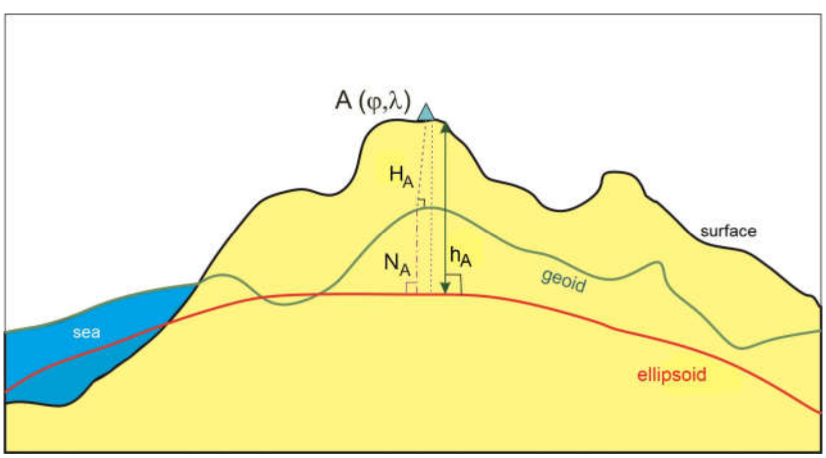


Figure 1. Geometrical relationship between ellipsoid, geoid and topographical surface (modified version from Featherstone *et al.*, 1998)

The concept of the relationship between height in Figure 3 is used as a method to validate or determine the accuracy of the developed geoid model. In this study, the geoid is modeled by calculating the geoid undulation (N) value gravimetrically based on gravity data, called a gravimetric geoid. The result of gravimetric geoid (N) were validated using the geometric geoid obtained from co-site geometric height (h) and orthometric height (H).

Data

Data for local geoid modelling consist of three components including long-wavelength, medium-wavelength, and short-wavelength components (Hofmann-Wellenhof & Moritz, 2005). The long-wavelength component represents the global mass contribution provides from a global geopotential model, while the medium-wavelength shows the distribution and the influence of mass in a particular area are generated from terrestrial gravity data. In addition, the short-wavelength component represents the topographic condition of a particular area based on the Digital Terrain Model (DTM). Among the three components however, the long-wavelength component contributes the most significant value and error (Vanicek & Christou, 1993).

In this study, two Global Geopotential Models (GGMs) from the GOCE gravity satellite (http://icgem.gfz-potsdam.de/tom_longtime), including SGG-UGM-1 and GO_CONS_GCF_2_SPW_R5 were used as long-wavelength component. The SGG-UGM-1 model published in 2018 and reached a maximum degree and order of 2159 (Liang, et. al., 2018; Xu, et al., 2017), meanwhile the GO_CONS_GCF_2_SPW_R5 published in 2017 and reached a maximum degree and order of 330 (Gatti, et. al., 2016).

The medium-wavelength component was obtained from terrestrial gravity data in DI Yogyakarta, while the short-wavelength component was a combination between heights on land and ocean (above and below mean sea level). Finally, a total of 17 GNNS/leveling control points were used for fitting and validating the resulted geoid.

Study area

The research area covers the province of DI Yogyakarta with boundary coordinate 110°5' E to 110°50' E and 7°33' S to 8°15' S. This area was chosen as the research area because of its geological, topographical and administrative conditions. Although this area is relatively small, it has a complete topographic variation and some geologically active structures (Husein & Srijono, 2010). Nevertheless, regarding this research, Yogyakarta as a city of culture and education is currently developing rapidly, where there are many buildings above and below the surface that require a 3D cadastral registration system in near future.

Gravimetric and Hybrid Geoid Modelling

A local geoid had determined using Remove-Compute-Restore (RCR) method as shown in the following equation (Forsberg and Tscherning, 2008):

Remove step: $\Delta g_{res} = \Delta g_{FA} - \Delta g_{GGM} - \Delta g_{RTM}$ (2)

Restore step: $N = N_{\Delta gres} + N_{GGM} + N_{RTM}$ (3)

For the remove step, Δg_{res} is the residual gravity anomaly, Δg_{FA} is the free-air gravity anomaly, Δg_{GGM} is the GGM anomaly and Δg_{RTM} is the terrain correction value. For the restore step, N is the local geoid, N_{gres} is the residual geoid which is calculated from the residual gravity anomaly using the Stokes integral, N_{RTM} is the indirect effect, and N_{GGM} is denotes the long wavelength part of the geoid obtained from a global geopotential model.

Furthermore, based on the resulted gravimetric geoid (3), a local hybrid geoid is developed by fitting a gravimetric geoid to GNSS/levelling data/geometric geoids. It produces an integrated local and global height systems which increase the accuracy of the geoid model results (Arana et al., 2017).

The process of local hybrid geoid modelling is illustrated in Figure 2, where the points A, B, C, D and E are the control points used in the fitting process. N is the undulation (m), h is the orthometric height above the geoid reference (m), and H is the geometric height towards ellipsoid reference (m). The fitting process is carried out by calculating the corrector surface (e), resulting from the reduction between gravimetric and geometric geoids at local GNSS/levelling control points (Nakagawa et al., 2003).

In the process of modelling the local hybrid geoid, four strategies have been utilized from combination of the two obtained gravimetric geoids from different global geopotential model, SGG-UGM-1 and GO_CONS_GCF_2_SPW_R5, with two different patterns of Control Point Distribution (CPD) as shown Figure 3.

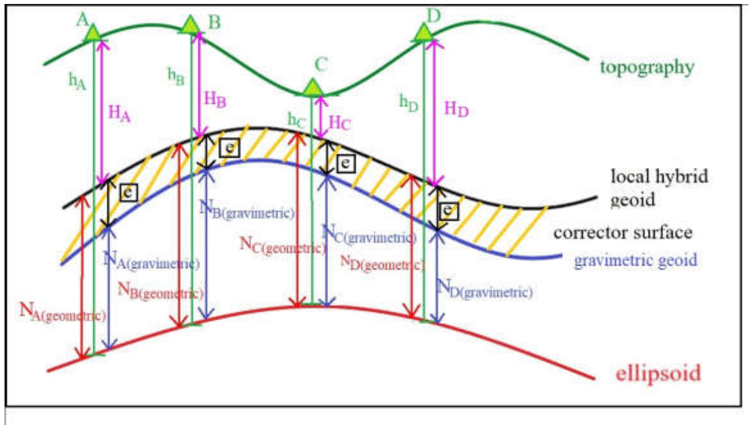


Figure 2. The process of local hybrid geoid modelling with corrector surface calculation (modified version from Nakagawa *et al*., 2003)

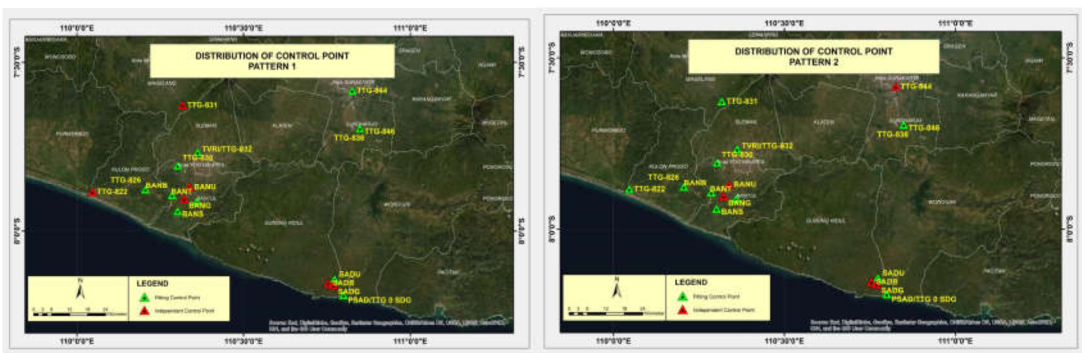


Figure 3. The CPD Pattern 1 and Pattern 2

Table 1. List of fitting geoid and independent control points used for local hybrid geoid determination

Pattern	Control Point	
	Independent	Fitting Geoid
Pattern 1	TTG-822, TTG-831, BANG, BANU, SADG, SADB	TTG-826, TTG-830, TTG-836, TTG-844, TTG-846, TVRI/TTG-832, BANB, BANS, PSAD/TTG 0 SDG, SADU
Pattern 2	TTG-836, TTG-844, BANG, BANU, SADG, SADB	TTG-826, TTG-830, TTG-846, TTG-822, TTG-831, TVRI/TTG-832, BANB, BANS, BANT, PSAD/TTG 0 SDG, SADU

Source: data processing

The list of control points that became the fittings and independent control points are shown in Table 1. Those strategies were Strategy 1 (a combination between SGG-UGM-1 and CPD Pattern 1), Strategy 2 (a combination between SGG-UGM-1 and CPD Pattern 2), Strategy 3 (a combination between GO_CONS_GCF_2_SPW_R5 and CPD Pattern 1), and Strategy 4 (a combination between GO_CONS_GCF_2_SPW_R5 and CPD Pattern 2).

3. Result and Discussion

The local gravimetric geoid obtained in this study derived from combination of the long-wavelength components, namely MGG SGG-UGM-1 and MGG GO_CONS_GCF_2_SPW_R5, medium-wavelength component from terrestrial gravity and short-wavelength component from Shuttle Radar Topographic Mission (SRTM) data. In order to determine the 3D cadastre height reference, the height reference field must be consistent with the applicable local or national height system. Therefore, a gravimetric geoid is fitted to a geometric geoid from co-site GNSS-levelling to produce a hybrid geoid. In this case, the levelling data represent the applicable national height system. Further, the geoid hybrid was validated using independent geoid geometric points to determine its accuracy and use as a 3D cadastre height reference surface.

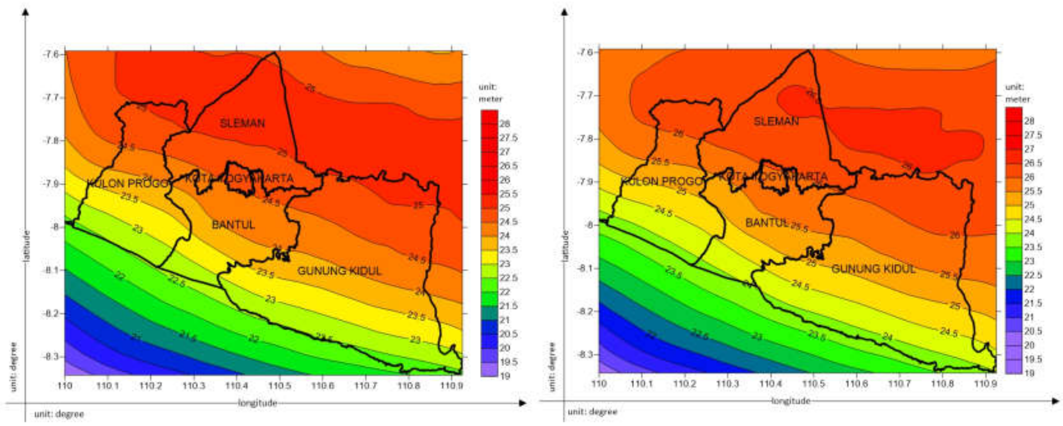


Figure 4. Gravimetric geoid of (a) SGG-UGM-1 and (b). GO_CONS_GCF_2_SPW_R5

Gravimetric Geoid

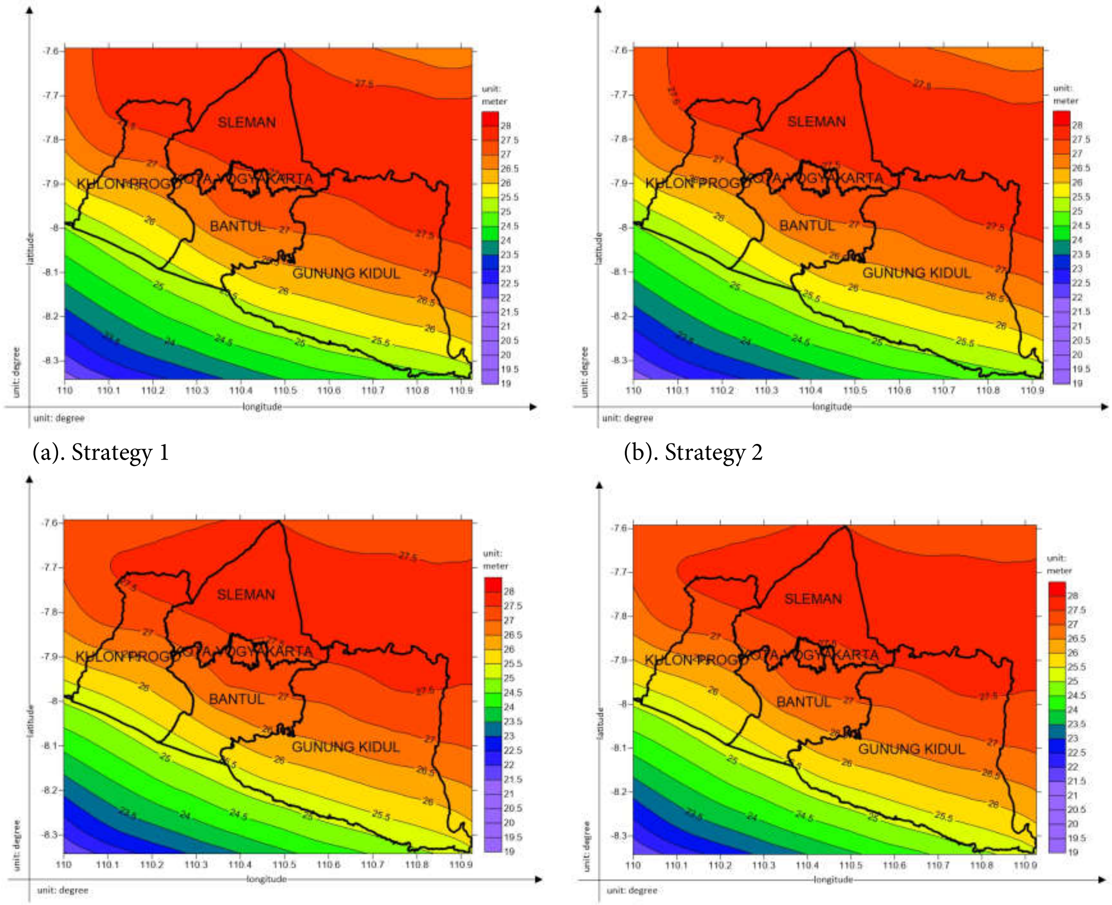
Figure 4 shows the visualization of gravimetric geoid using different GGM data, i.e SGG-UGM-1 and GO_CONS_GCF_2_SPW_R5 in the studied area. The gravimetric geoids from both GGMs in DI Yogyakarta showed similar patterns and increased from the southside (yellow gradation) to the northside (red gradation). However, there is a slight difference in the pattern shown by the derived GO_CONS_GCF_2_SPW_R5 geoid for the area around the Merapi volcano which shows a more detailed geoid pattern. The gravimetric geoid values ranged from 25.3 m (SGG-UGM-1) to 26.6 m (GO_CONS_GCF_2_SPW_R5) with the highest undulation found in Sleman Regency. The mean gravimetric geoid values were 23.80 m for SGG-UGM-1 and 25.02 m for GO_CONS_GCF_2_SPW_R5. The quality of a gravimetric geoid model is depend on the earth mass density, precision and accuracy of the gravity data (Nakagawa et al., 2003). The earth mass density affects the terrain contribution when calculating the topographic effect or short wavelength component in the remove-restore step. Sjöberg stated that the earth mass density in geoid modelling cannot be considered homogeneous (Sjöberg, 2007). However, this study uses a homogeneous earth mass density of 2.67 gr / cm^3, which can affect the accuracy of the obtained gravimetric geoid. Meanwhile, the number of land gravity data used is 784 points and sea gravity data used is 3,721 points, which has a fairly good data distribution, with grid size is about 5 km on land and denser at sea. These data are affected to the contribution of the medium-wavelength component. Thus, increasing the accuracy of the obtained gravimetric geoid. Further, this gravimetric geoid is a fundamental model for developing a hybrid geoid model.

Hybrid Geoid

Figure 6 shows four local hybrid geoids determination used 4 (four) strategies. The visualization of four local hybrid geoids showed a similar pattern, which increased from the southside (yellow gradation) to the northside (red gradation). The highest geoid value is located in the northern region of DI Yogyakarta. Visually, the pattern of the hybrid geoid is not change much from the pattern of the gravimetric geoids.

The Accuracy of Hybrid Geoid

This study used the mean value of differences and the standard deviation (STD) differences to represent the accuracy of hybrid geoid (Wolf & Ghilani, 1997). The accuracy presents the level of closeness between the hybrid geoid with the national datum system. In order to know its accuracy and increasing its accuracy between the geoid models, the calculation and evaluation of accuracy using six independent control points, was done not only for the hybrid geoid, but also for the gravimetric geoid, as shown in Table 2.



(a). Strategy 1 (b). Strategy 2

(c). Strategy 3 (d). Strategy 4

Figure 5. The local hybrid geoid based on four strategic processes

Comparing the mean and standard deviation values between gravimetric and hybrid geoids to geometrics geoids shows that the mean and standard deviation values of the hybrid geoids are much smaller than gravimetric geoids. The change in the mean difference between geoids, the gravimetric and hybrid, with geometrics geoid is significant, which show level of closeness increases and also the bias reference between global and local reference height system decreases. For the geoid using SGG-UGM-1 changed from 2.548 m to 0.396 m and it is closer to 84% (Strategy 1) and from 2.548 m to 0.305 m, it is closer to 88% (Strategy 2). While those for geoid using GO_CONS_GCF_2_SPW_R5 changed from 2.549 m to 0.354 m, it is closer to 86% (Strategy 3) and from 1.234 m to 0.397 m, it is closer to 67% (Strategy 4). It can be seen that the Strategy 2 and 3 had mean difference values which are lower than EGM2008 with minimal mean difference of 0.365 m (Wiranata, 2016). It shows that the local hybrid geoid is able to reduce the bias between local and global height systems resulting from gravimetric geoid models (Nakagawa et al., 2003).

Furthermore, the comparison in the STD values also show significant change from the gravimetric to hybrid geoid model, which is shows increased level of accuracy, i.e for SGG-UGM-1 changed from 0.505 m to 0.171 m, increases of 66% (Strategy 1) and from 0.441 m to 0.202 m, increases of 54% (Strategy 2). While those for GO_CONS_GCF_2_SPW_R5 changed from 0.545 m to 0.137 m, increases of 75% (Strategy 3) and from 0.532 m to 0.178 m, increases of 66% (Strategy 4).

Table 2 showed that based on comparison between the gravimetric and local hybrid to geometric geoids at six independent control points, the local hybrid geoid of Strategy 3 produced highest accuracy. A combination of the GO_CONS_GCF_2_SPW_R5 degree 330 and distribution of GNSS/Levelling data in Strategy 3 generated the best local hybrid geoid, with mean difference to geometric geoid of 0.354 m and a standard deviation of 0.137 m.

Table 2. Statistic comparison between gravimetric and local hybrid to geometric geoid at six independent control points

Strategies	GGM	Deviation between gravimetric and geometric geoid (m)			Deviation between local hybrid and geometric geoid (m)		
		Range	Mean	STD	Range	Mean	STD
1	SGG-UGM-1	2.001-3.167	2.548	0.505	0.136-0.631	0.396	0.171
2	SGG-UGM-1	0.484-2.657	2.548	0.441	0.018-0.574	0.305	0.202
3	GO_CONS_GCF_2_SPW_R5	1.966-3.199	2.549	0.545	0.165-0.572	0.354	0.137
4	GO_CONS_GCF_2_SPW_R5	0.696-1.889	1.234	0.532	0.094-0.592	0.397	0.178

Source: data processing

However, the accuracy of the local hybrid geoid is still in decimeter level, this could be due among others: 1) Five (5) control points used in the fitting process was obtained by linear interpolation, 2) height interpolation process from height topographic map data, 3). topographic variations and 4). error propagation during the depth data conversion process.

Two local hybrid geoid (the Strategy 2 and 3) which had the highest accuracy level were subjected to a significance test to evaluate whether there is a significant difference between both models. The significance test was performed using 95% confidence level with a degree of freedom (df) of 5 because the number of samples was 6 (six) control points. The results indicated that null hypothesis (Ho) was accepted, depicted by a t-test value of 0.9698, which was lower than t-student value of 2.015. The acceptance of Ho implied that the accuracy values between the Strategy 2 and 3 were not significantly different. Accordingly, the Strategy 2 and 3 could be applied for reference of 3D cadastre purposes. However, this study used the Strategy 3 that has a smallest difference value and smallest STD local hybrid.

Implementation of Local Hybrid Geoid for 3D Cadastre

Two types of height commonly used to define an object height on the Earth, namely relative and absolute heights. The relative height is determined by using reference or local surface, such as the topographic surface around the location of 3D cadastre objects, while the absolute height is determined based on national horizontal and vertical reference frame (Kim & Heo, 2019). Due to its connection with the national reference system, it is recommended to use absolute height as a 3D cadastre height (Jaljolie, Oosterom, and Dalyot, 2018). Regulation of Geospatial Information Agency (BIG) Number 5 of 2013 on the Indonesian Geospatial Reference System (SRGI) also state that the Indonesian absolute height system uses geoid as a Vertical Geospatial Reference System (SRGV) in determining the height of the earth's surface on the map of Indonesia. The height value generated by the geoid is different from the one produced by GNSS with WGS-1984 as the ellipsoid reference. On the other hand, Regulation of the Minister of Agrarian Affairs Provisions for Implementing Government Regulation Number 24 Concerning Land Registration 1997 states that land administration uses 3D GPS measurement that refer to WGS 84, both for horizontal and vertical components.

In accordance with the regulation, the 3D cadastre object has a value of geometrics height that refers to the WGS 84 ellipsoid surface. However, as previously stated, the geometric height has no physical realization on the earth's surface, so it must be transformed into an orthometric height which has physical realization on the earth's surface so as to indicate logically the position of cadastral objects above and below the surface. With purposes to study the application of geoid for 3D cadastral height reference, four buildings were selected as sample of 3D cadastre object, those are the Student Park Apartment, Gemawang Flats, Jogjatronic Building and Jogja City Mall. Detail of each cadastral object has been measured using terrestrial methods and tied to 3D GPS control point. In order to bring the height of cadastral objects into the national height system, in the form of orthometric height that refers to the geoid, the geometrics height component of each control point has been transformed into the orthometric height using obtained Strategy 3 hybrid geoid (Figure 7). Table 3 shows the height control points of four (4) cadastral objects measured by GNSS method and its undulation (N) from Strategy 3 and derived orthometric height using equation (1). Meanwhile, distribution of the height control points of four cadastres objects is shown in Figure 8.

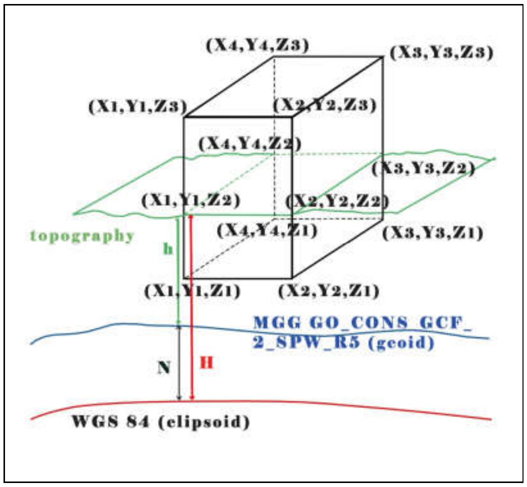


Figure 7. Geometric and orthometric heights in a 3D cadastre using GGM GO_CONS_GCF_2_SPW_R5 hybrid geoid

Table 3. Derived orthometric height of control points based on GNSS and Strategy 3 hybrid geoid data

Control Point	Undulation	Height (m)		Control Point	Undulation	Height (m)	
		Ellipsoid	Orthometric			Ellipsoid	Orthometric
SPA1	27.767	168.984	141.217	RS5	27.763	171.820	144.057
SPA2	27.766	168.583	140.817	RS6	27.764	171.917	144.153
SPA3	27.766	183.459	155.693	JCM1	27.759	185.440	157.681
SPA4	27.766	168.869	141.103	JCM2	27.758	185.309	157.551
SPA5	27.767	168.514	140.747	JCM3	27.758	185.852	158.094
SPA6	27.766	167.632	139.866	JCM4	27.758	182.461	154.703
RS1	27.764	171.735	143.971	JT1	27.629	129.964	102.335
RS2	27.764	173.881	146.117	JT2	27.629	129.787	102.158
RS3	27.763	171.795	144.032	JT3	27.629	129.534	101.905
RS4	27.763	171.755	143.992	JT4	27.629	128.880	101.251

Source: data processing

These control points are then used to transform all coordinate of cadastral object detail that measured using terrestrial methods into a national coordinate system or orthometric height system, call georeferencing (Reshetyuk, 2009), so that the height system used for georeferencing is orthometric height based on the N values obtained from its control points. SPA1 to SPA6 points are used for Student Park Apartment, RS1 to RS6 for Gemawang Flats, JT1 to JT4 for Jogjatronic Building and JCM1 up to JCM4 for Jogja City Mall. The location of four 3D cadastre objects and also the control points were located in South Part of Sleman Regency and Yogyakarta City, which has a relatively small varied topography condition. The condition causes the variation of the geoid undulation is very small, as indicated in Table 3, the highest and the lowest undulation for GO_CONS_GCF_2_SPW_R5 were found to be 27.629 and 27.767 m, respectively, with mean of 27.736 m and a range undulation of 0.138 m. Figure 10 shows comparison of orthometric and geometric height of control points at the four cadastral object location.

As shown in Figure 10, the obtained orthometric and geometric heights had similar pattern, as the geoid variation is low around the location of control points. However, the pattern of height obtained cannot be used as a general representation for DI Yogyakarta, because the location of control points is not evenly distributed and the topographical variation in this region is low.

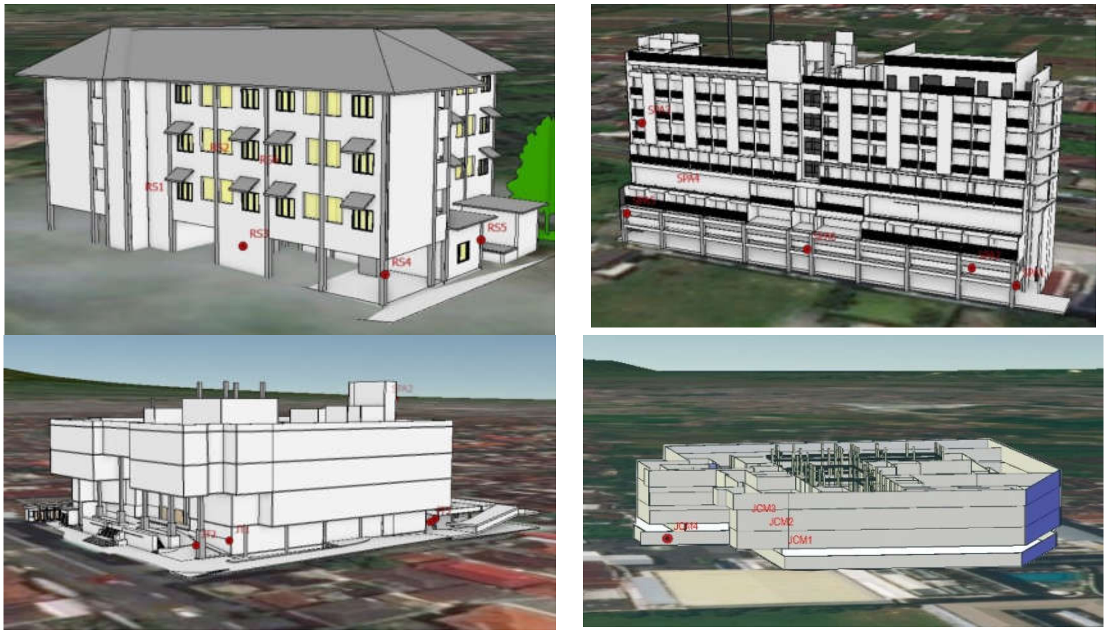


Figure 8. Distribution of height control points (red marker) of 4 objects of 3D cadastre in the study

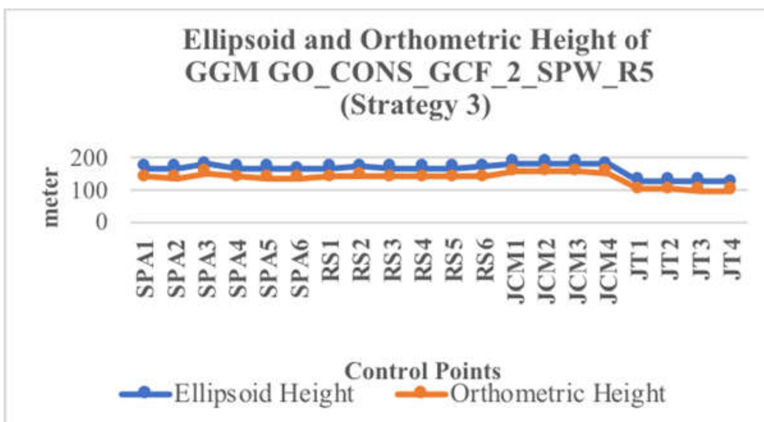


Figure 10. Comparison of ellipsoid and orthometric heights using GGM GO_CONS_GCF_2_SPW_R5

4.Conclusion

This study focuses to define a height reference system for representation of 3D cadastral object by developing a local hybrid geoid. The hybrid geoid was developed by fitting the gravimetric geoid, developed by using Remove-Compute-Restore (RCR), to the geometrics geoid derived from GNSS/levelling data. Four strategies were used to generate local hybrid geoids, from combination of 2 GGM, namely GGM SGG-UGM-1 and GO_CONS_GCF_SPW-R5, and two set pattern of GNSS/levelling control points (CPD). The accuracy and increased accuracy of local hybrid geoid was calculated by comparing the hybrid geoid and gravimetric geoid with the geometric geoid at six independent control points. Based on this arrangement, this study found that Strategy 3 has resulted the best local hybrid geoid, with the smallest mean difference (0.354 m) and smallest standard deviation (0.137 m). Strategy 3 was a combination between GO_CONS_GCF_2_SPW_R5 and CPD Pattern 1. Furthermore, being compare with the STD of gravimetric geoid, the STD of strategy 3 significantly change from 0.545 m to 0.137 m, showing an increase accuracy of 75%. The strategy 3 hybrid geoid can be used to transform geometric height into orthometric height, as well as for 3D cadastre purposes to represent a

3D cadastre object. This geoid is applied as an alternative of the 3D cadastre reference surface.

Acknowledgement

First author would like to thank: PT Pertamina; National Gravity Committee; Ministry of Research, Technology and Higher Education (aerial map data); and BIG (tidal and control point data); Halim Wiranata and Mohamad Bagas Setiawan (data process stage).

References

Aien, A. (2013). *3D Cadastral Data Modelling* (Issue March). The University of Melbourne, Victoria, Autralia.

Arana, D., Camargo, P. O., & Guimarães, G. N. (2017). *Hybrid Geoid Model : Theory and Application in Brazil. 89*, 1943–1959.

Cemellini, B., Thompson, R., Vres, M. De, & Oosterom, P. Van. (2018). Visualization/dissemination of 3D Cadastre. *FIG Congress 2018*, *9591*.

Erol, B., & Çelik, R. N. (2004). Modelling Local GPS/Levelling Geoid With the Assesstment of Inverse Distance Weighting And Geostatistical Kriging Methods. *ISPRS Congress*.

Featherstone, W. E., Dentith, M. C., & Kirby, J. F. (1998). Strategies for the Accurate Determination of Orthometric Heights from GPS. *Survey Review*, *267*(January), 278–296.

Forsberg, R., & Tscherning, C. C. (2008). *An overview manual for the GRAVSOFT Geodetic Gravity Field Modelling Programs* (2nd Edition; Issue August). National Space Institute.

Gatti, A., Reguzzoni, M., Migliaccio, F., & Sanso, F. (2016). Computation and assessment of the fifth release of the GOCE-only space-wise solution. *1st Joint Commission 2 and IGFS Meeting*.

Guo, R., Luo, F., Zhao, Z., He, B., Li, L., Luo, P., & Ying, S. (2014). The Applications and Practices of 3D Cadastre in Shenzhen. *International Workshop on 3D Cadastre, Dubai, Enited Arab Emirates*, *November*, 299–312.

Heliani, L. S., Putraningtyas, M. E., & Widjajanti, N. (2013). Sistem Tinggi Dalam Realisasi Kadaster 3D Di Indonesia : Tantangan, Permasalahan dan Alternatif Solusi. *Jurnal Ilmiah Pertanahan Bhumi, Yogyakarta*.

Husein, S., & Srijono. (2010). Peta Geomorfologi Daerah Istimewa Yogyakarta. *Simposium Geologi Yogyakarta*, *March 2010*. https://doi.org/10.13140/RG.2.2.10627.50726

Jaljolie, R., Oosterom, P. Van, & Dalyot, S. (2018). Spatial Data Structure and Functionalities for 3D Land Management System Implementation : Israel Case Study. *International Journal of Geo-Information*, *1*, 1–17. https://doi.org/10.3390/ijgi7010010

Karki, S. (2013). *3D Cadastre Implementation Issues in Australia* (Issue June). University of Southern Queensland.

Kaufmann, J., & Steudler, D. (1998). *Cadastre 2014 - A Vision for a Future Cadastral System*. 1–8.

Kim, S., & Heo, J. (2019). Registration of 3D Underground Parcel in Korean Cadastral System. *Cities*, *89*(January), 105–119. https://doi.org/10.1016/j.cities.2019.01.027

Liang, W., Xu, X., Li, J., & Zhu, G. (2018). The Determination of an Ultra High Gravity Field Model SGG-UGM-1 by Combining EGM2008 Gravity Anomaly and GOCE Observation Data. *Acta Geodaeticaet Cartographica Sinica*, *47*(, 425–434. https://doi.org/10.11947/j.AGCS.2018.20170269

Nakagawa, H., Wada, K., Kikkawa, T., Shimo, H., Andou, H., Kuroishi, Y., Hatanaka, Y., Shigematsu, H., Tanaka, K., & Fukuda, Y. (2003). Development of a New Japanese Geoid Model , " GSIGEO2000 ." *Bulletin of the Geographical Survey Institute*, *49*, 1–10.

Navratil, G., & Unger, E. M. (2013). Reprint of: Requirements of 3D cadastres for height systems. *Computers, Environment and Urban Systems*, *40*, 14–23. https://doi.org/10.1016/j.compenvurbsys.2013.04.001

Reshetyuk, Y. (2009). *Self-calibration and direct georeferencing in terrestrial laser scanning* (Issue January). Royal Institute of Technology (KTH), Stokholm. Swedia.

Sjöberg, L. E. (2007). The topographic bias by analytical continuation in physical geodesy. *Journal of Geodesy*, *81*, 345–350. https://doi.org/10.1007/s00190-006-0112-2

Smart, M., & Priebbenow, R. (2018). Designing a 3D Cadastral System Demonstrator : A Case Study. *6th International FIG 3D Cadastre Workshop*, *October 2018*, 1–16.

Stoter, J., & Gorte, B. (2003). Height in the Cadastre Integrating Point Heights and Parcel Boundaries. *FIG Working Weeks 2003, Paris, France, 13-17 April 2003*, 1–12.

Stoter, J., Ploeger, H., & Van Oosterom, P. (2013). 3D cadastre in the Netherlands: Developments and international applicability. *Computers, Environment and Urban Systems*, *40*, 56–67. https://doi.org/10.1016/j.compenvurbsys.2012.08.008

Stoter, J., & Van Oosterom, P. (2006). *3D Cadastre in an International Context: Legal, Organizational, and Technological Aspects*. Taylor & Francis.

Vanicek, P., & Christou, N. T. (Eds.). (1993). *Geoid and Its Geophysical Interpretations*. CRC Press.

Wellenhof, & Moritz, H. (2005). *Physical Geodesy* (Second). SpringerWienNewYork.

Wiranata, H. (2016). *Pemodelan Geoid Lokal Teliti Wilayah D.I. Yogyakarta*. Universitas Gadjah Mada.

Wolf, P. R., & Ghilani, C. D. (1997). *Adjustment Computations Statistics and Least Squares in Surveying and GIS*. Jhon Wiley and Son Inc.

Xu, X., Zhao, Y., Reubelt, T., & Tenzer, R. (2017). A GOCE only gravity model GOSG01S and the validation of GOCE related satellite gravity models. *Geodesy and Geodynamics*, *8*(4), 260–272. https://doi.org/10.1016/j.geog.2017.03.013