COMMUNICATIONS IN SCIENCE AND TECHNOLOGY
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Evaluating 3-D positioning infrastructure quality and utilization: The potential improvement with multi-GNSS methods

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Article history:
Received: 1 March 2024 / Received in revised form: 22 June 2024 / Accepted: 23 June 2024

Abstract

This article evaluates the quality of the national 3-D positioning infrastructure using multi-criteria decision making (MCDM) to simulate the potential application of multi-GNSS method. The MCDM evaluation used coverage and availability of Indonesia Continuous Operating Reference System (INACORS) services, distribution of survey pillars, and accuracy of height determination using the Indonesian Geoid Model (INAGEOID). The term multi-GNSS method refers to the utilization of PPP method as a complement to the conventional differential GNSS method for the production of mapping control points. The results of this evaluation were complemented by a questionnaire analysis on the utilization of positioning infrastructure by respondents from various professional backgrounds. The MCDM evaluation results showed that Java had nearly 100% good or excellent 3-D positioning infrastructure quality. Other regions in Indonesia still had significant areas of average, fair, or even poor quality. The questionnaire results showed that many users have faced some problems in areas with fair or poor infrastructure quality. The application of multi-GNSS method can contribute to reduce up to half of the area with fair and poor positioning infrastructure quality.

Keywords: Continuously operating reference system (CORS); survey pillars; geoid model; positioning infrastructure; multi-GNSS methods

1. Introduction

Positioning infrastructure is a set of systems consisting of a Continuously Operating Reference Station (CORS), survey pillars, and services providing accurate and authoritative references for various positioning applications. This term was firstly introduced by the Intergovernmental Committee on Surveying and Mapping (ICSM) of Australia and New Zealand (https://www.icsm.gov.au/). Ideally, positioning infrastructure is evenly distributed and covers all regions. A constant density and evenly distributed positioning infrastructure leads to good coverage [1,2].

In Indonesia, positioning infrastructure consists of INACORS, Geodetic Control Network (JKG) survey pillars, and web-based INAGEOID service [3]. The main function of positioning infrastructure is to implement the Indonesian Geospatial Reference System (SRGI). To refer SRGI, users have to perform differential GNSS measurements using the nearest INACORS or JKG survey pillar. If users require orthometric height, it is also necessary to perform a leveling measurement to the nearest vertical survey pillar. The distribution of the INACORS and JKG survey pillars and the coverage of INAGEOID has been featured on the SRGI website. However, currently there is no detailed information about whether a user is within the coverage of INACORS and JKG survey pillars. This raises some questions such as how is the coverage of INACORS and JKG survey pillars on a national scale and does the infrastructure have an adequate coverage?

INACORS coverage also likely to shrink as stations may not be online all the time. The Geospatial Information Agency (Badan Informasi Geospasial - BIG) has set a service availability standard of 95% [4]. Nevertheless, there has been no publication that informs the current service availability performance at a national level. Another challenge faced is the related to the high cost of procuring and maintaining CORS and the infrequent installation of new survey pillars. Hence, positioning in uncovered areas remains a challenge. The differential GNSS method is conventionally applied for positioning in these uncovered areas, through extensification or densification of survey pillars. The farther the project site is from the positioning infrastructure, the more the control points, time and cost to be required while the accuracy will decrease.

Non-differential positioning such as Precise Point Positioning (PPP) might be an alternative solution since it can generate solutions with centimeter-level precision without a need to refer to nearby positioning infrastructure [5-8]. Rather than using differential corrections, PPP utilizes precise satellite clock and orbit corrections [9,10]. PPP is typically tied directly to the International Terrestrial Reference Frame (ITRF)

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https://doi.org/10.21924/cst.9.1.2024.1403

[11,12]. Hence, theoretically PPP is compatible with SRGI up to the centimeter level since SRGI is tied to ITRF 2008 and ITRF 2014. However, to date, Indonesian regulations require positioning to be directly tied to SRGI.

This article aims to evaluate the quality of existing positioning infrastructure in Indonesia, and to promote a multi-GNSS method that combines differential GNSS and PPP, primarily to replace the conventional process of control point densification and extensification. The article also presents the simulations of improvements to the quality of positioning infrastructure if the multi-GNSS method is implemented. This research also analyzes feedback from users regarding the use of positioning infrastructure in Indonesia to complement the results of positioning infrastructure evaluation carried out in this study.

2. Materials and Methods

In this research, 3-D positioning infrastructure in Indonesia was evaluated using MCDM. Criteria involved in the evaluation consisted of five factors; INACORS coverage, INACORS service availability, distribution of horizontal survey pillars, distribution of vertical survey pillars, and accuracy of INAGEOID height determination. The island/region spatial data used was downloaded from the official BIG website. The evaluation results were complemented by questionnaire analysis on the use of positioning infrastructure in Indonesia. A simulation was also conducted to see the improvements to the quality of positioning infrastructure when the multi-GNSS method was applied.

2.1. INACORS coverage estimation

CORS coverage can be estimated from the user positioning methods. For static GNSS data processing, referring to the national standards in Indonesia, scientific software is mandatory to be used for baseline length of 100 km or longer [13]. Commercial software is commonly used for distances under 50 km. According to Cina et al. [14], RTK single base coverage ranges up to a radius of 20 to 30 km, while NRTK ranges from 40 to 80 km. Hausler & Collier [15] mapped the coverage of NRTK in Australia by delineating the perimeter of CORS network aggregated at a certain distance, and then calculated the area, including when a buffer with a certain radius was applied (e.g. buffer 10 km to the CORS aggregation within 70 km inter-distance).

CORS coverage mapping combined with internet communication service data for Java Island has been carried out by Chiuman et al. [16]. The research was carried out with the assumption that the single base CORS range was 30 km and NRTK was 50 km. In 2021, Geoscience Australia (GA) estimated the CORS coverage of Australia by combining CORS coverage of 50 km and telecommunication services area.

In this study, the estimation of INACORS coverage for GNSS static network processing and single base RTK was carried out by applying buffer of 30 km and 50 km for each INACORS station and by calculating the resulted area. Estimation for NRTK method was carried out by delineating the perimeter of CORS aggregated within 70 km inter-distances. A buffer of 30 km was then applied and the resulted area was calculated. The distribution of 342 site of INACORS used in this research referred to the distribution as of December 2022 as presented in Fig. 1. Average CORS inter-distances and their distribution ratios are presented in Table 1. CORS inter-distances refer to a calculation of the average distance between CORS stations on each island. Distribution ratio shows the ratio of the area of each island to the total number of CORS.

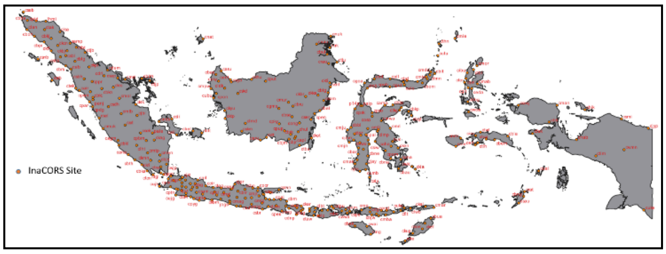

Fig. 1. INACORS distribution per December 2022 (visualized by authors, data source: http://srgi.big.go.id)

Table 1. INACORS inter-distances average and distribution ratio per December 2022 (computed by authors, data source: http://srgi.big.go.id)

Island/region	CORS inter-distance average (km)	Number of CORS sites	Distribution ratio (CORS per 10,000 km^2)
Java	58,341	75	2.8
Sumatra	112,035	74	0.8
Kalimantan	126,828	48	0.4
Bali, NTB, NTT	93,510	44	3.0
Sulawesi	132,924	66	1.7
Maluku	230,887	24	1.9
Papua	371,250	11	0.1

2.2. INACORS service availability estimation

From the user side, service availability can be estimated by web scraping the INACORS server. This technique can be carried out using a web scraper program that is capable of searching, extracting, and storing certain information in a database [17]. In this study, the service availability of the INACORS service was estimated by web scraping the INACORS server for four months with data sampling every 30 minutes. The flowchart of the web scraping process is presented in Fig. 2.

The web scraping process started with logging into the INACORS web according to the registered username and password of the account. Subsequently, the web scraper searched the live status and site status fields from each INACORS station. The data were extracted and recorded with a sampling period of 30 minutes for four months. The web scraper also recorded the account credentials used so that if there were any restrictions on the duration/connection of the web scraper account, it would automatically log back in and ran the web scraping again. The collected data consisted of time tag, site ID, and site status. The INACORS site status was presented in numbers where 3 means online and 0, 1, and 2 were offline.

From the sample data collected, the cumulative value of service availability for each INACORS station was then calculated. To present the results into a map, the availability percentage was divided into ten availability classes. The availability map was presented using the Bertin's color visual variables [18] referring to the illustration compiled by Roth [19] or as implemented by [20].

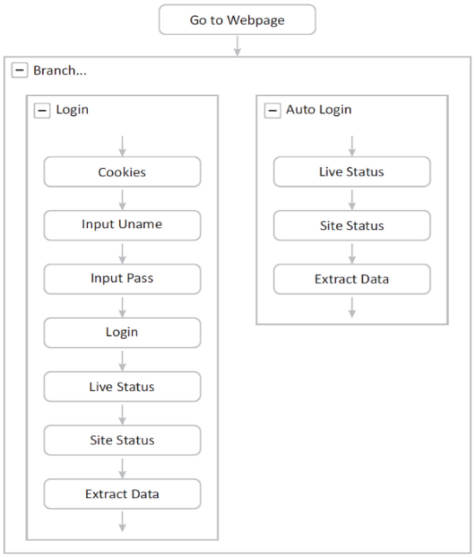

Fig. 2. The web scraping process

2.3. Horizontal and vertical survey pillars distribution analysis

According to the data presented on official BIG website, the JKG survey pillars consist of horizontal control points (JKH), vertical control points (JKV), and gravity control points (JKG). In the last few decades, it consisted of around 1266 JKH, 5747 JKV, and 5434 JKG. However, the number of pillars drastically decreased due to damage, and loss [21], the high cost of conducting geodetic surveys on these pillars, and other problems.

The data used for this analysis were 1416 survey pillars from the latest definition of SRGI coordinates [22]. The distribution of was analyzed by calculating the average distance from each pillar to the five nearest pillars. A density distribution contour line [23,24] was then created by using the data. The results are presented in the form of a survey pillars distribution map using visual variable of value [19]. Visual variables were created by creating color gradations based upon the distribution density of JKH and JKV survey pillars. The darker color in the gradation indicates a tighter distribution.

2.4. INAGEOID accuracy analysis

The data used for this analysis refers to the publication on the official BIG website. INAGEOID was modelled by using gravity data, global geoid model, and elevation data. The gravity data used included primary data from terrestrial and airborne gravity surveys. The global geoid model used was the Earth Gravity Model 2008 (EGM 2008) degree 360. Elevation data used Digital Elevation Model (DEM) data, i.e. Shuttle Radar Topographic Mission (SRTM) 15 meters. The geoid modeling method used the Remove - Restore Technique concept and the Fast Fourier Transformation (FFT) approach.

As presented in Table 2, the accuracy of INAGEOID varies in various regions in Indonesia. Regions where accuracy is marked as unavailable (n/a) means that accuracy verification has not been conducted. The results are displayed in the form of a INAGEOID accuracy map with value visual variable [19].

Table 2. INAGEOID accuracy (modified from: http://srgi.big.go.id)

Island/region	Number of validation points	Deviation standard (cm)
Java	186	5.1
Sumatra	26	17.3
Kalimantan	265	6.6
Bali, NTB, NTT	184, n/a, n/a	10.3, n/a, n/a
Sulawesi	53	22.4
Maluku	n/a	n/a
Papua	n/a	n/a

2.5. MCDM positioning infrastructure quality evaluation

MCDM is a method considering multiple criteria in the decision selection process. It can be defined as follows [25];

$$A = \{Ai \mid i = 1, 2, \dots, m\} \quad (1)$$

$$C = \{Cj \mid j = 1, 2, \dots, n\} \quad (2)$$

$$W = \{Wj \mid j = 1, 2, \dots, n\} \quad (3)$$

where A is a distinct and finite set of criteria, and m represents the number of them. C is a set of certain criteria used to evaluate A, and n is the number of criteria. All criteria can have different units without any inter-relationships and with different conflicting objectives. W refers to a set of normalized weights assigning to each criterion based on their importance.

The criteria used in the MCDM consisted of INACORS coverage and availability, horizontal and vertical survey pillar distribution and INAGEOID accuracy. Classes, rankings, and scores for each criterion were then arranged. The details of the criteria are presented in Table 3 to Table 7.

As these criteria were considered to have an equally important role, the rank score was aggregated using the outranking method [26]. The aggregation results were reclassified into five classes: excellent, good, medium, fair and poor. Classification was done using equal-interval classes in which the poor criteria referred to the class with the lowest score range, while the excellent criteria referred to the class with the highest score range. The 3-D positioning infrastructure map was presented using the Bertin's color visual variables [18] referring to the illustration compiled by Roth [19].

Table 3. Criteria for INACORS coverage

Coverage class	Rank	Score
Within NRTK Coverage	1	4
Outside NRTK, within 30 km CORS buffer	2	3
Outside NRTK within 30-50 km CORS buffer	3	2
Outside NRTK, outside 50 km CORS buffer	4	1

Table 4. Criteria for INACORS service availability

Service availability	Rank	Score
80-100 %	1	5
60-80 %	2	4
40-60 %	3	3
20-40 %	4	2
0-20 %	5	1

Table 5. Criteria for distribution of horizontal survey pillar

Distance to horizontal survey pillar	Rank	Score
Below 30 km	1	3
Between 30 and 50 km	2	2
More than 50 km	3	1

Table 6. Criteria for distribution of vertical survey pillar

Distance to vertical survey pillar	Rank	Score
Below 5 km	1	4
Between 5 and 10 km	2	3
Between 10 and 15 km	3	2
More than 15 km	4	1

Table 7. Criteria for INAGEOID accuracy

INAGEOID accuracy	Rank	Score
Above 10 cm	1	4
10-20 cm	2	3
20-30 cm	3	2
Below 30 cm	4	1

2.6. Positioning infrastructure utilization analysis

Positioning infrastructure utilization was carried out using an online questionnaire filled out by users from various professions and fields of work. Table 8 presents the list of the questionnaire questions that was aimed to figure out the proportion of respondent occupations, fields of work/applications, problems encountered in measurements related to positioning infrastructure, and problems in performing mapping control point densification and extensification.

The questionnaires were also used to assess the urgency of 3-D positioning, the urgency of determining geometric and orthometric height, problems in determining orthometric height, the level of CORS usage, and the information of current CORS coverage. Respondents were asked to answer questions on 5-points Likert Scale [27]. Questionnaire results were then tested for statistical validity using Cronbach alpha analysis [28].

2.7. Analyzing the potential of improvement with multi-GNSS methods

The outcome of this paper is an evaluation of Indonesia's 3-D positioning infrastructure quality. Considering that the quality can vary and discrepancies may occur, the concept of multi-GNSS positioning needs to be considered for implementation in Indonesia. One concept that has the potential to be applied is the use of the PPP as a complement to differential GNSS. For instance, PPP can be implemented in areas not covered by CORS or the horizontal survey pillar, or where the distance is more than 50 km, such as in the regions of Papua, Kalimantan, Sumatra, and Maluku (see Table 1).

Table 8. Positioning infrastructure utilization questionnaire

Questions	Information
User profession	Profession proportion
Field of work	Field of work proportion
Measurement refers to positioning infrastructure and its problem	Problem proportion
Densification and extensification of control points and its problem	Problem proportion
The urgency of 3D positioning	Five points Likert
The urgency of determining geometric and orthometric height	Five points Likert
Orthometric height determination and its problem	Problem proportion
Level of use of INACORS to support work/application	Five points Likert
Information about CORS coverage	Five points Likert
Use of positioning methods other than static and RTK method	Yes/No

Determining the orthometric height from GNSS data using the national geoid model is also an important element of applying the multi-GNSS method. Taking into account the sparse distribution of vertical survey pillars, especially in eastern Indonesia, height determination by converting GNSS geometric height to INAGEOID orthometric height will facilitate height determination in various regions in Indonesia.

It is important to note that the use of this technique will be affected by the quality and accuracy of INAGEOID, which is currently still quite variable in various regions in Indonesia. However, it is expected that the model will become more homogenous in quality and increase in accuracy in the next few years. The concept of multi-GNSS method is presented in Fig. 3.

The multi-GNSS method has been applied in Australia, which faces similar challenges where there are still many areas that have not been covered by positioning infrastructure [29]. PPP is applied as a complement to the differential method to determine the position in areas that has not been covered by infrastructure [30]. It is also advisable to determine the height using the national geoid model for applications requiring an accuracy of 6 cm or lower [31].

In this research, the estimation of improvement from the implementation of multi-GNSS method was done by comparing the existing condition against the condition if PPP was applied. This was done by reprocessing the MCDM using INACORS coverage criteria whose rank has been adjusted. In this study it was assumed that the area with rank 4 turned into rank 3. This was based on the idea by implementing PPP the user do not need to do densification or extensification.

Reprocessing involving INAGEOID accuracy criteria was not performed. This was because verification has not been carried out in NTB, NTT, Maluku, and Papua regions, despite of the significant improvements likely covering these areas.

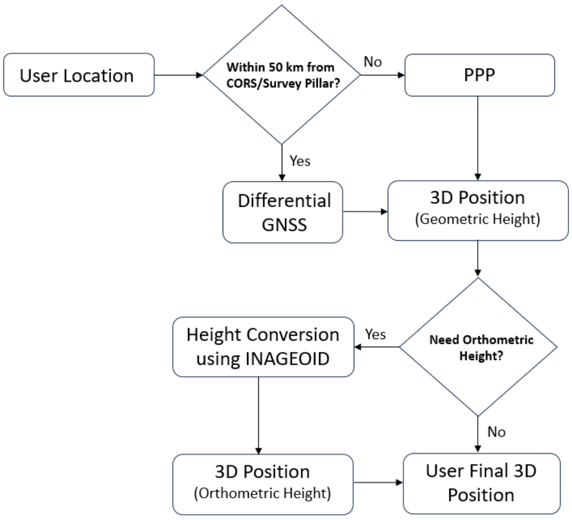

Fig. 3. The multi-GNSS method concept

3. Results and Discussion

3.1. INACORS coverage

The estimation of a 30 km buffer for 342 INACORS stations resulted in a total coverage area of 536,183.45 km^2 or around 30.76% of Indonesia's total land area of 1,890,244.79 km^2. The 50 km buffer of INACORS stations provided a coverage of 988,738.10 km^2 or around 52.72% of Indonesia's land area. Fig. 4, Table 9 and Table 10 show the general INACORS coverage in Indonesia.

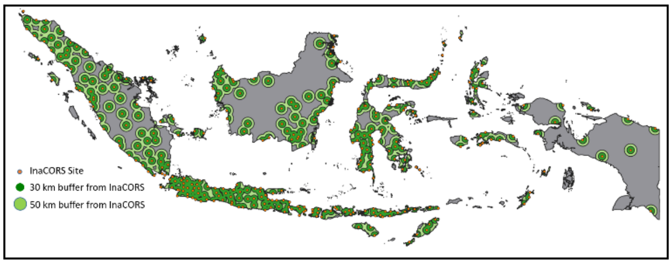

Fig. 4. INACORS general coverage map

Table 9. Estimated INACORS 30 km buffer coverage

Island/region	30 km buffer		
	Coverage (km^2)	Coverage (%)	Indonesia Covered (%)
Java	104,742.99	78.91	5.59
Sumatra	147,372.58	31.00	7.86
Kalimantan	97,677.23	18.29	5.21
Bali, NTB, NTT	50,814.28	70.87	2.71
Sulawesi	88,661.42	47.57	7.03
Maluku	25,290.35	40.22	1.35
Papua	19,181.47	4.65	1.02
Total	536,183.45		30.76

Table 10. Estimated INACORS 50 km buffer coverage

Island/region	50 km buffer		
	Coverage (km^2)	Coverage (%)	Indonesia Covered (%)
Java	131,454.84	99.04	7.01
Sumatra	325,177.81	68.40	17.34
Kalimantan	216,892.01	40.62	11.57
Bali, NTB, NTT	68,427.08	95.43	3.65
Sulawesi	151,716.15	81.41	8.09
Maluku	46,206.30	73.48	2.46
Papua	48,863.91	11.85	2.61
Total	988,738.10		52.72

The NRTK estimation by delineating the aggregation of 342 INACORS stations with maximum inter-distance of 70 km resulted in a total coverage area of 77,226.15 km^2 or around 4.09% of Indonesia's land area. Applying 30 km buffers to the delineation produced a total coverage area of 368,148.76 km^2 (Table 11 and Fig. 5). This was approximately 19.63% of Indonesia's total land area.

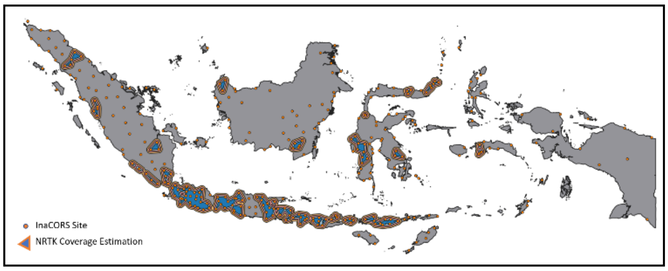

Fig. 5. INACORS NRTK coverage map

Table 11. Estimated INACORS NRTK coverage

Island/region	Inner NRTK coverage (km^2)	30 km buffer		
		Coverage (km^2)	Coverage (%)	Indonesia covered (%)
Java	45,860.99	142,497.25	83.29	7.60
Sumatra	6,986.80	70,132.67	14.75	3.74
Kalimantan	3,571.17	21,315.17	3.99	1.14
Bali, NTB, NTT	12,091.76	69,574.48	97.03	3.71
Sulawesi	8,469.62	56,728.63	30.44	3.02
Maluku	245.81	7,900.56	12.56	0.42
Papua	0	0	0	0
Total	77,246.15	368,148.76		19.63

It is apparent that INACORS generally covers approximately half of Indonesia's total land area but the NRTK method only covers about one-fifth of it. These Figures are based on the assumption that all INACORS have 100% service availability. Technical constraints very likely to be experienced by INACORS stations when operating 24 hours non-stop, will reduce the service availability, which in turn will also decrease the coverage.

3.2. INACORS service availability

Based on the web scraping result it was identified that 228 stations have had service availability above 90%. Hence, two thirds of INACORS stations have almost met 95% availability standards set by BIG. However, there have been 34 stations with 50% availability or less. Fig. 6 presents the INACORS service availability map. Stations with service availability below 50% were denoted in the color range from red to cream. Service availability above 50% was presented with a color range from light green to dark green.

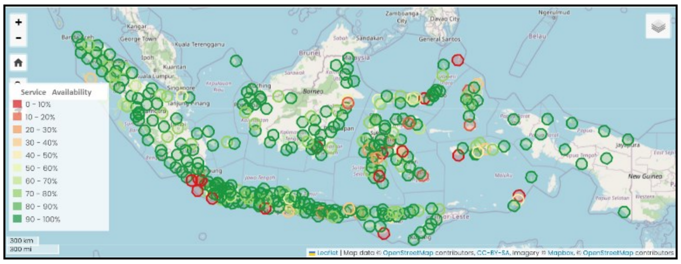

Fig. 6. INACORS NRTK service availability map

As shown in Table 12, Sulawesi and Maluku regions had the lowest average service availability of 69.63% and 78.88% respectively. This was in stark contrast to the Papua region, which had 98.66% availability. However, because some INACORS stations were distributed at relatively close inter-distances, several areas in Sulawesi with low availability were still covered by the nearby INACORS station, which had higher service availability (e.g. site ID CUMB and CSIW stations in South Sulawesi, site ID CLMP, TEST and CKLA in Southeast Sulawesi). Fig. 7 presents the availability map of INACORS services in Sulawesi.

Table 12. INACORS NRTK service availability

Island/region	Number of INACORS for each service availability percentage					Availability average (%)
	0-20	20-40	40-60	60-80	80-100	
Java	3	1	2	4	63	89.02
Sumatra	3	1	1	9	61	88.76
Kalimantan	2	0	1	1	43	90.52
Bali, NTB, NTT	1	3	1	3	36	87.25
Sulawesi	8	2	3	8	45	78.88
Maluku	4	2	2	2	14	69.63
Papua	0	0	0	0	12	98.66
Total	21	9	10	27	274	

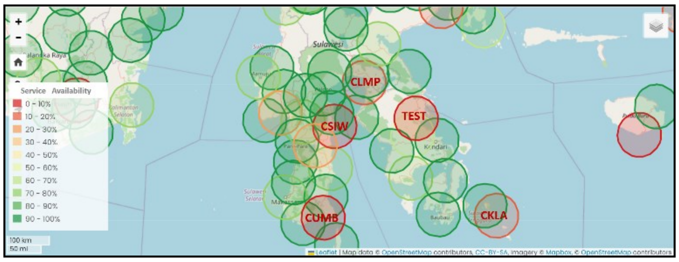

Fig. 7. INACORS service availability map in the region of Sulawesi

3.3. Horizontal and vertical survey pillar distribution

The results of the analysis showed that horizontal survey pillars in Java have been distributed at a distance of 30 km or denser. There is a small part of Java where the distribution is in the range of 30-50 km. Sumatra is the second best where almost half of the region has survey pillars distributed below 30 km and 30-50 km. Papua, Kalimantan and Maluku still have areas with survey pillars spread over 50 km. The horizontal survey pillar distribution map is presented in Fig. 8.

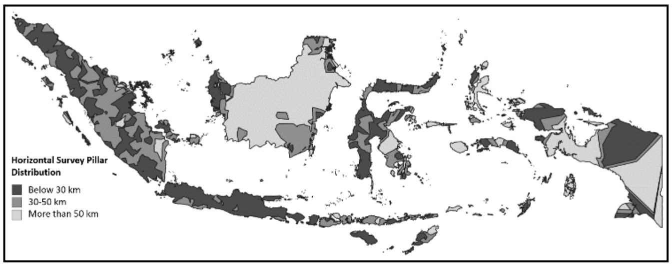

Fig. 8. Horizontal survey pillar distribution map

Most parts of Indonesia have a distribution of vertical survey pillars with a density above 15 km. This condition causes the height determination at these locations to take longer and cost more than areas where the distribution of vertical survey pillars is below 15 km. Fig. 9 illustrates the map of vertical survey pillars distribution.

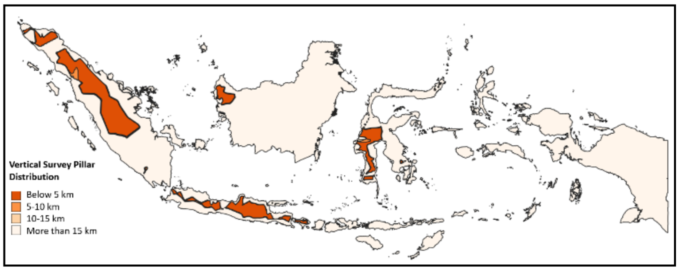

Fig. 9. Vertical survey pillar distribution map

3.4. INAGEOID accuracy

Fig. 10 presents the INAGEOID accuracy map in which the accuracy of INAGEOID in Java and Kalimantan was found as the highest (above 10 cm). Height determination in Sumatra, and Bali had an accuracy of 10-20 cm. INAGEOID accuracy in Sulawesi was in the range of 20-30 cm. Accuracy information is not available yet for the NTB, NTT, Maluku and Papua regions.

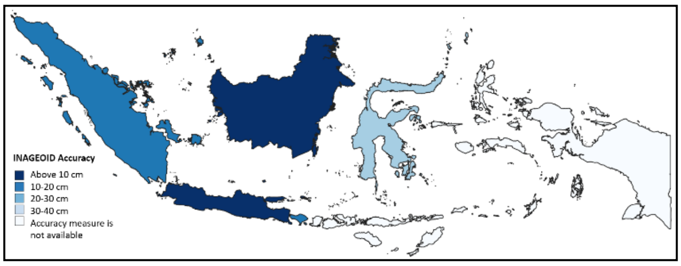

Fig. 10. INAGEOID accuracy map

3.5. Positioning infrastructure quality

Fig. 11 presents the map of Indonesia's 3D positioning infrastructure quality. Visually, the evaluation results showed the discrepancies of the positioning infrastructure quality. Areas with fair quality marked in orange refer to dominant areas that have not yet been covered by positioning infrastructure. Areas with poor quality marked in red are areas that have not been covered by infrastructure and INAGEOID verification has not been carried out.

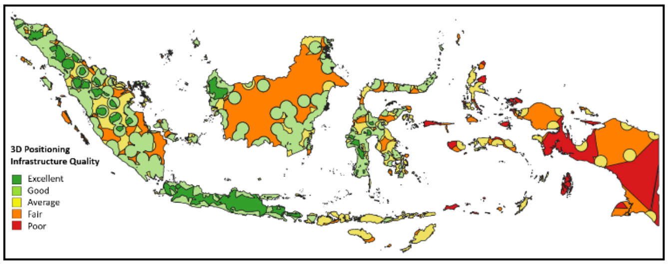

Fig. 11. Indonesia 3D positioning infrastructure quality map

Table 13 and Fig. 12 show the quality of Indonesia's 3D positioning infrastructure. Variations in each island/region are presented as a percentage of area covered by positioning infrastructure from poor to excellent quality.

Table 13. Indonesia 3D positioning infrastructure quality

Island/region	Quality of 3D positioning infrastructure				
	Excellent (%)	Good (%)	Average (%)	Fair (%)	Poor (%)
Java	28.95	69.77	1.28	0	0
Sumatra	5.2	62.53	12.59	19.68	0
Kalimantan	6.46	33.58	22.60	37.36	0
Bali, NTB, NTT	3.74	10.65	74.90	6.13	4.58
Sulawesi	0.15	65.62	15.77	16.22	2.24
Maluku	0	0.32	35.76	17.88	46.04
Papua	0	0	9.92	1.94	88.15

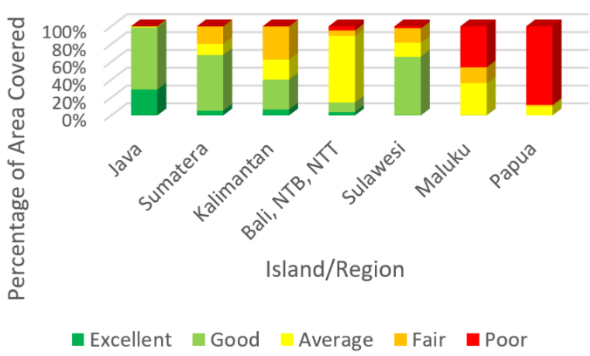

Fig. 12. Indonesia 3D positioning infrastructure quality graph

It can be identified that for Java almost 100% of the region were of excellent or good quality, while Sumatra and Sulawesi had more than 60% that fulfilled these conditions. For Kalimantan, only about 40% of its area was covered by excellent or good quality. Meanwhile for eastern Indonesia, positioning infrastructure needs to be improved significantly because the quality is far adrift from other regions. The results of the analysis showed that for Maluku and Papua regions, positioning infrastructure with poor quality was 46.04% and 88.15% respectively.

3.6. Positioning infrastructure utilization

The questionnaire received feedback from more than 40 respondents from various professional backgrounds and fields of work. As shown in Fig. 13, the proportion of respondents consisted of 25% civil servant surveyors, 20% private surveyors, 15% mapping survey consultant,12.5% academics (lecturers, researchers, and students), and 27.5% other professionals. The field of work of the respondents dominated by cadastral survey (27.5%), mining survey (22.5%) and other mapping survey works (27.5%).

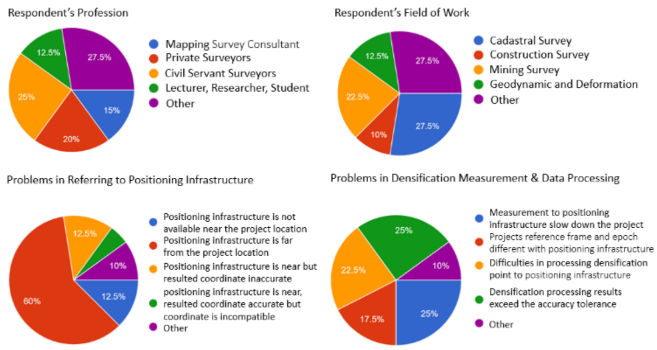

Fig. 13. Proportion of respondent professions, field of work, problem in referring to positioning infrastructure, densification measurement, and data processing

The problems in referring to positioning infrastructure were dominated by positioning infrastructure being far from the project location (60%). Regarding the measurement and processing of control point densification and extensification, the problem often faced by users is that the processing results have poor accuracy (25%), the measurement to positioning infrastructure slow down the project (25%) and difficulties in processing densification point to refer to positioning infrastructure (22.5%).

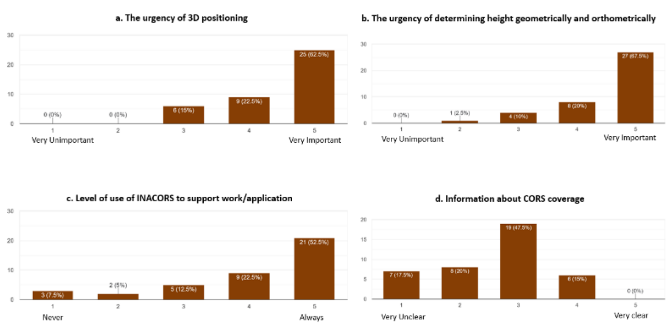

Fig. 14. Positioning infrastructure utilization questionnaire result

As presented in Fig. 14(a), concerning the urgency of 3D positioning, 62.5% of respondents considered it as very important, 22.5% stated it as important, and the remaining 15% neutral. Regarding the urgency of determining height geometrically and orthometrically, 67.5% considered it as very important (Fig. 14(b)). Concerning the use of INACORS to support work/application, 52.5% of respondents stated that they always use it, 22.5% very often and only 7.5% stated they never used it (Fig. 14(c)). For CORS coverage information, 17.5% of respondents stated that it was very unclear and 20% stated it is unclear (Fig. 14(d)).

The questionnaire results also showed that problems in determining orthometric height were dominated by JKV that was unavailable near the project location (36.4%) and JKV being far from the project location (33.3%). It was also identified that 40.5% of respondents have had already used non-differential methods such as PPP and real-time PPP as alternative positioning in supporting the completion of their work. The results of the questionnaire had good validity as indicated by the Cronbach Alpha value of 0.81.

3.7. Improvement with multi-GNSS method

As presented in Fig. 15, the results of the MCDM reprocessing with PPP complementing the differential GNSS method showed that the areas with fair and poor positioning quality were significantly reduced. Regions with poor quality were so few that they were visually almost invisible. Areas with average positioning quality were considerably improved.

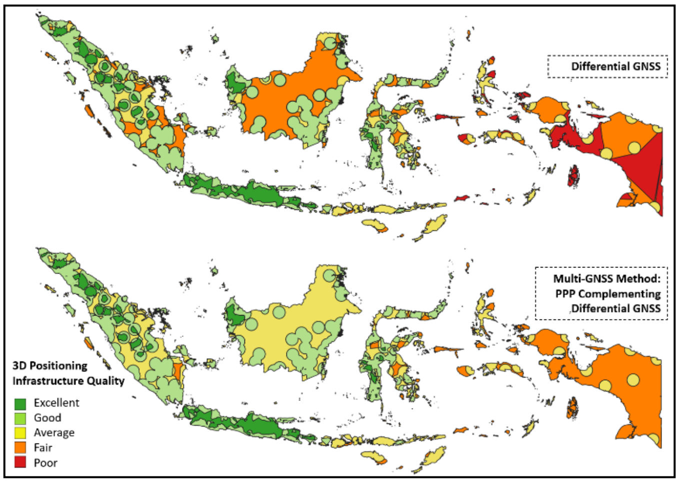

Fig. 15. Improvement of Indonesia 3D positioning infrastructure quality map

Table 14 presents the percentages for each positioning quality category in Indonesia at a national scale. The improvement was marked by the reduction of regions with fair and poor positioning infrastructure quality from a total of 43% to 24%. Areas with fair quality decreased from 31% to 23.9% and poor quality significantly decreased from 12% to 0.1%.

Table 14. Indonesia 3D positioning infrastructure quality improvement

Method	Quality of 3D positioning infrastructure				
	Excellent (%)	Good (%)	Average (%)	Fair (%)	Poor (%)
Differential GNSS only	8	32	17	31	12
Multi-GNSS Method	8	32	36	23.9	0.1

It should be emphasized that the quality improvement presented here is based on simulation the role of PPP to replace the conventional process of control point densification and extensification. This needs to be followed up with future research using real data from various locations in Indonesia to obtain empirical data of the PPP performance.

4. Conclusion

The analysis of Indonesia's positioning infrastructure quality revealed significant regional variations. Java demonstrated almost 100% coverage of excellent or good quality, while Sumatra and Sulawesi exceeded 60%. Only 40% of Kalimantan fulfilling the abovementioned condition. The regions include eastern Indonesia, particularly Maluku and Papua, exhibiting poor quality with poor coverage ranging from 46.04% to 88.15%.

The questionnaire received feedback from various respondents across different professional backgrounds. Challenges identified included the unavailability of positioning infrastructure near project locations and poor accuracy in the processing of densification/extensification. Some respondents resorted to non-differential methods such as PPP and real-time PPP as alternative positioning solutions.

The use multi-GNSS method in MCDM reprocessing resulted in a significant improvement in the quality of the positioning infrastructure. This concept could reduce the area with fair or poor positioning quality from a total of 43% to 24%. Area with poor quality decrease from 12% to 0.1%.

Quality improvement results presented in this paper are limited to the simulations of PPP utilization for control point densification and extensification processes conventionally conducted with differential GNSS. This needs to be followed up with research using real GNSS data from various locations in Indonesia to obtain empirical data on the accuracy of PPP and its compatibility with the Indonesian reference frame (SRGI 2013). Having such empirical evidence will have positive implications as users can use PPP in areas with poor quality positioning infrastructure.

Acknowledgements

This research is fully supported by Universitas Gadjah Mada. The authors fully acknowledged Universitas Gadjah Mada for the approved fund which makes this important research viable and effective.

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