Assessing the Quality of Photo Imageries from UAVs for Cadastral Purposes in Indonesia

Sheilla Ayu RAMADHANI, Rahmat SIDIK, Fitriyani HASIBUAN, Hias Hardika PRABAJATI, Indonesia

Keywords: Unmanned Aerial Vehicle, Cadastral Basemap, Fit-for-Purpose

SUMMARY

The cadastral base map plays a crucial part in cadastral data acquisition, starting as the reference to conduct survey and mapping, the working map, the base layer to plot the surveyed parcel, and also the survey instrument to define parcel boundaries. Unmanned Aerial Vehicle (UAVs) has always been related to the Fit-for-Purpose Land Administration; therefore, the use of UAVs has been developed to adjust the land administration in Indonesia – especially to achieve the goal of the fully-completed-registered parcel throughout Indonesia. Photomapping using UAV was considered to be beneficial in terms of time and cost efficiency for cadastral surveys, including cadastral base mapping. UAV technology also has the privilege of being easily customized to generate the expected quality of imageries – related to both geometric and radiometric accuracy.

Since 2016, the Government of Indonesia has been conducting the utilization of UAVs to address the backlog of base map unavailability for cadastral purpose – and the efforts to realize the implementation has been taken into action ever since. As part of the institutionalization effort, to standardize the product of the cadastral base map, the procedure including the requirements of the instruments and arrangement of the acquisition methods had been stipulated in a government regulation by 2019.

In 2022, twelve areas of a total of 180.000 hectares were captured using non-metric sensors mounted in UAVs and generated as cadastral base maps. The projects were held using the same reference framework document but interestingly the products came out in various qualities. The quality of the imageries from the project was assessed and the findings were elaborated on throughout this paper. The results are presented in the summary section, and some interesting conclusions made from the research are also mentioned and recommended – thus the projects can be a lesson learned for further advancement.

Assessing the Quality of Photo Imageries from UAVs for Cadastral Purposes in Indonesia

Sheilla Ayu RAMADHANI, Rahmat SIDIK, Fitriyani HASIBUAN, Hias Hardika PRABAJATI, Indonesia

1. INTRODUCTION

Cadastral activities contain 2 aspects, a legal aspect, and a spatial aspect. In terms of the spatial aspect, a survey and mapping are the required steps to get the data. The activities of surveying and mapping the land that is related to defining the boundaries of a land parcel are known as cadastral surveying. Measuring points to get the land parcel boundaries can be done using various methodologies. Craig and Wahl (2003) elaborated on the direct and indirect methods of measurement to get the value quantifying the boundaries, where measuring a distance between two points using a measuring tape is categorized as direct measurement, and surveying using the Global Navigation Satellite System (GNSS) is an example of the use of the indirect method.

The modernization of technology has also been impacting the shifting methods of cadastral survey and mapping. In Indonesia, the cadastral survey was first conducted using a direct method, a measuring tape was used and local references were used. It was improving along with the advancement of technology with the use of GNSS, photomap, and also surveying applications and software to support data processing and management.

Since 2016, Indonesia has targeted the achievement of a fully registered parcel by 2025 and the cadastral survey and mapping methods have been developing intensely ever since. Following the fit-for-purpose recommendation to make use of the photo map for the cadastral survey was one of the actions chosen. Ramadhani et al (2022) explained the efforts of institutionalization of Unmanned Aerial Vehicles (UAV) to produce a photo map that aimed to increase the speed of the land registration process. It was also mentioned by Ramadhani et al (2022) that UAV can be the solution for the needs of the base map in land affairs and spatial planning – acknowledging its promising capacity to provide data with better quality.

Considering that a photo map has a wide range of functional use – thus a different standard in terms of quality existed, an evaluation of the existing base map photo was conducted. The assessment aimed to give a review of the imageries' quality produced using a sensor embedded in a UAV after the efforts of institutionalization – especially whether the output suffices the requirement of spatial data in land affairs and spatial planning – specifically for the cadastral purpose.

2. CADASTRAL SURVEY AND MAPPING IN INDONESIA

Methodology for cadastral survey and mapping in Indonesia has been developing along with the need for improvement and is supported by the available technology. The land registration procedure was formalized in Indonesia through the enactment of the Basic Agrarian Law in 1960. Back then, the cadastral survey was conducted using analog tools and mapped using a local reference. A timeline describing the development of cadastral survey technology in Indonesia below illustrates how the cadastral survey and mapping have been conducted (see Table 1).

Table 1. The development of the cadastral survey method in Indonesia

1960	Formalization of Land Registration in Indonesia (Basic Agrarian Law)
1995/1996	Establishment of National Cadastral Framework using GNSS, starting to use photo maps for land registration base map
1997	Issuance of Government Regulation Number 24 on Land Registration, defined the technical base point (reference point) and land registration map
	Issuance of Ministerial Regulation number 3 on the provision of government regulation number 24 on land registration, defines the cadastral surveying methods in Indonesia along with the principles and standards
2000	Issuance of the standardization for land registration map
2003/2004	Pilot project on the use of High-Resolution Satellite Imageries
2008	Procurement of High-Resolution Satellite Imageries throughout Indonesia
2009	Establishment of a Continuously Operating Reference System for Cadastral Purposes (namely Reference Network System for Land Affairs or JRSP)
2014	Technical book for cadastral survey and mapping: updated the elaborations on the standards, requirements, and procedures for cadastral survey and mapping
2016	Implementation of digital photogrammetry for cadastral survey and mapping
2017	Issuance of Technical Guidance for the use of UAV in making work map for cadastral survey
2021	Issuance of Ministerial Regulation number 16 (revision for the Ministerial regulation number 3/1997: elaborated the methods used for cadastral survey, including the photogrammetric method, mentioned the cadastral survey activities for 3D aspect
2022	Pilot project for integrated cadastral survey and mapping: the cadastral survey and mapping is conducted with a perquisite of photo map for participatory mapping and the collection of the use and utilization of the parcel/plot

Since the emergence of digital photogrammetry and the intense implementation of the technology for cadastral surveys in 2016, cadastral practitioners in Indonesia have been arguing whether photogrammetry can function well as other methods (namely measuring tape or using GNSS). Projects and research related to the utilization of UAVs have been carried out to find out the proper setup and to see the extent of how the method should be employed in the system. In 2017, to rule out the use of UAVs for cadastral surveys, technical guidance was issued. The sequence of mandatory activities was mentioned and both equipment and output were also standardized in the guidance. Acknowledging the possible development of cadastral 3D, in 2021 the government of Indonesia regulated the 3D aspect which can also utilize the data generated from photo maps (using UAV). Also in 2021, a regulation regarding the standardization and specification for non-metric sensors (in UAV) was stipulated for the general utilization of UAVs (the Republic of Indonesia, 2020c).

For cadastral needs, the spatial data needed has been regulated in terms of data types on a scale of 1000, 2500, and 10.000. In 2022, a technique for boundary definition was initiated where objects as land parcel boundaries are directly pricked/marked in photo maps produced by UAVs. With the requirement of the ability to detect boundaries of the parcels – so it is determined that the data that can be used for this method is limited to a photo map with a minimum scale of 1:1000. Referring to the Republic of Indonesia (2021) provisions, the data specifications that must at least meet include the following:

Table 2. Output specification

Spatial resolution	:	0,15 meter
Color	:	Red Green Blue
Forward Overlap	:	80%
Side Overlap	:	60%
Horizontal Accuracy (CE90)	:	0,375 meter
Vertical Accuracy (LE90)	:	0,2 meter

3. CAPTURING PHOTO IMAGERIES FROM UAV

In 2022, the Ministry of Agrarian Affairs and Spatial Planning (ATR/BPN) carried out 12 projects for making photo maps using an unmanned aerial vehicle (UAV), where the activity locations are spread across 11 provinces in Indonesia with a total area of around 180,000 Hectares (see Figure 1).

Figure 1. Location of the 12 Projects in 11 Provinces

For the whole 12 projects, the requirements were arranged to meet the requirements of Ground Sampling Distance (GSD) ≤ 5 cm, horizontal accuracy of (CE 90) ≤ 75 cm, and vertical accuracy of (LE90) ≤ 50 cm. Along with the specific requirements of output, the platform of UAV was also defined to have a Vertical Take-off and Landing (VTOL) capability and it is equipped with Post Processing Kinematic/Real Time Kinematic capability with dual-frequency GNSS type, meanwhile for the camera sensor was stated to have a minimum specification of 24 MP and a fixed lens feature. The projects were all carried out during the second semester of 2022 (between July to November), and the overall character and specifications of each project are delivered in Table 3.

Table 3. Description of general specifications from the 12 projects

Loc	Province	Area (Ha)	Type		Avg Flying Altitude	Total		
			Drone	Camera		Flights	GCP	ICP
1	Central Sulawesi	15000	Quantum System Trinity F90	Sony RX 1r Mark II 42 MP	330 m	39 Flights	21	20
2	South Sumatera	15000	VTOL SKYDR ONE160	Sony Alpha 6000 lens 20 mm 24MP	240 m	90 Flights	8	22
3	Papua	13000	Foxtech Long, Skywalke r VTOL	Sony Alpha 6000 lens	±350 m	N/A	20	21

Loc	Province	Area (Ha)	Type		Avg Flying Altitude	Total		
			Drone	Camera		Flights	GCP	ICP
				25 mm 24MP				
4	East Kalimantan	16000	Quantum System Trinity F90	Sony RX 1r Mark II 42 MP	±350 m	30 Flights	10	25
5	South Sulawesi	16000	VTOL-Inovamap (Nimbus)	Sony Alpha 6000 lens 25 mm 24MP	±320-520 m	108 Flights	11	46
6	Central Kalimantan	16000	JOUAV CW 15	Sony Alpha 7R IV 61 MP	±350 m	20 Flights	5	22
7	Riau	14000	VTOL-Cendrawasih (assembled)	Sony Alpha 6000 lens 35 mm 24MP	230 - 250 m	70 Flights	34	20
8	North Sumatera	15000	VTOL P330 PRO	Sony Alpha 7 RII 42 MP	±350-400m	24 Flights	34	21
9	Jambi	15000	VTOL P330 PRO	Sony Alpha 7 RII 42 MP	±350-400m	16 Flights	6	22
10	West Kalimantan	15000	VTOL P330 PRO	Sony Alpha 7 RII 42 MP	±350-400m	20 Flights	6	21
11	West Java	15000	VTOL RAKITAN NIMBUS DAN SKYWALKER	Sony Alpha 6000 lens 35 mm 24MP	±300-350m	124 Flights	6	20
12	North Sumatera	15000	JOUAV CW 007	Sony Alpha 7R IV 61 MP	±370-450m	18 Flights	5	21

Regarding the types of unmanned aerial vehicles (UAV)-VTOL from the 12 projects, 7 projects used industrial manufacturing (commercially manufactured) UAVs, and 5 projects used local-custom (assembled) UAVs. The Flying altitude ranges are from 200 - 450 m AGL – depending on the topography at each location (Area of Interest). The camera sensor is also adjusted to meet the requirements for a GSD value of ≤ 5 cm. To achieve the optimized data quality, Ground Control Points (GCPs) were assigned as a requirement, and Independent Control Points (ICPs) were also surveyed to check the accuracy of the photo map. A number of the ICPs following the (SNI, 2019): minimum of 20 points for 50.000 Hectares.

With the standardization assigned before the data acquisition, the result of the 12 projects was processed (photo processing was using Agisoft Metashape Professional) and the results are delivered in Table 3.

Table 4. Output specification resulted from the 12 projects

Location	**Province**	**GSD (cm)**	**CE90 (m)**	**LE90 (m)**	**Horizontal: Indonesia National Standard (SNI) 8202-2019: Base map Accuracy**
1	Central Sulawesi	4-5	0,45	0,44	1:1000 Class 2
2	South Sumatera	4-5	0,13	0,17	1:1000 Class 1
3	Papua	4-5	0,28	0,74	1:1000 Class 1
4	East Kalimantan	4-5	0,12	0,25	1:1000 Class 1
5	South Sulawesi	8	0,13	0,29	1:1000 Class 1
6	Central Kalimantan	4-5	0,38	0,49	1:1000 Class 2
7	Riau	4-5	0,05	0,14	1:1000 Class 1
8	North Sumatera	4-5	0,07	0,37	1:1000 Class 1
9	Jambi	4-5	0,23	0,38	1:1000 Class 1
10	West Kalimantan	4-5	0,15	0,13	1:1000 Class 1
11	West Java	4-5	0,224	1,14	1:1000 Class 1
12	North Sumatera	4-5	0,2	0,36	1:1000 Class 1

4. DISCUSSION ON THE ASSESSMENT

The elements of evaluation to assess the quality of photo imageries from UAVs were compiled from the correspondence and discussion held in March 2021 – where the spatial data users in the Ministry of Agrarian Affairs and Spatial Planning were questioned about their expectations on the spatial data produced to support their business process. Of the 8 invited working units, 5 of them responded by delivering their explanation of how they expect the photo map should be to support their task. The responses are presented in the picture below, the update element became the most wanted element when it comes to the requirement of a photo map.

Figure 2. Expected elements of the photo map from users

Working units that are expecting updated data are the working unit that delivers the land parcel map (boundaries definition) and deal with land conflicts/issues. There is also a need to update data – related to monitoring land utilization (to control land use). ’Appropriate accuracy’ also appeared as a requirement for the working unit which delivers the land parcel map (boundaries definition), and a unit that defines the land value zone. The ’time series’ and ’varied’ data can be categorized into 1 group, as they mean that the more data available in the inventory which varies in the frequency of appearance. And the working unit that mentioned the needs are those who have land issues/conflicts as their core business.

As to ’update’, ’time-series’, and ’varied’ elements, the results from the 12 projects conducted were showing that the photo map can fulfill the requirement. Compared with the previous remote sensing product – High-Resolution Satellite Imagery, the photo map produced using UAV can meet the needs of the incidental project. The time for data acquisition can be adjusted to the prerequisite condition. However, on the element of ’whole coverage’, if it means the whole coverage of Indonesia, this can still be fulfilled but with some limited obligation due to possible obstacles. Among the obstacles from the 12 projects, extreme topography, and cloud coverage in the hilly area happened and became issues during the data acquisition. Therefore, whole coverage is still promising to be achieved with this method, but for some conditions where the location is in extreme topography, extreme wind speed, and hilly area, the photo map might not be optimally carried out and captured.

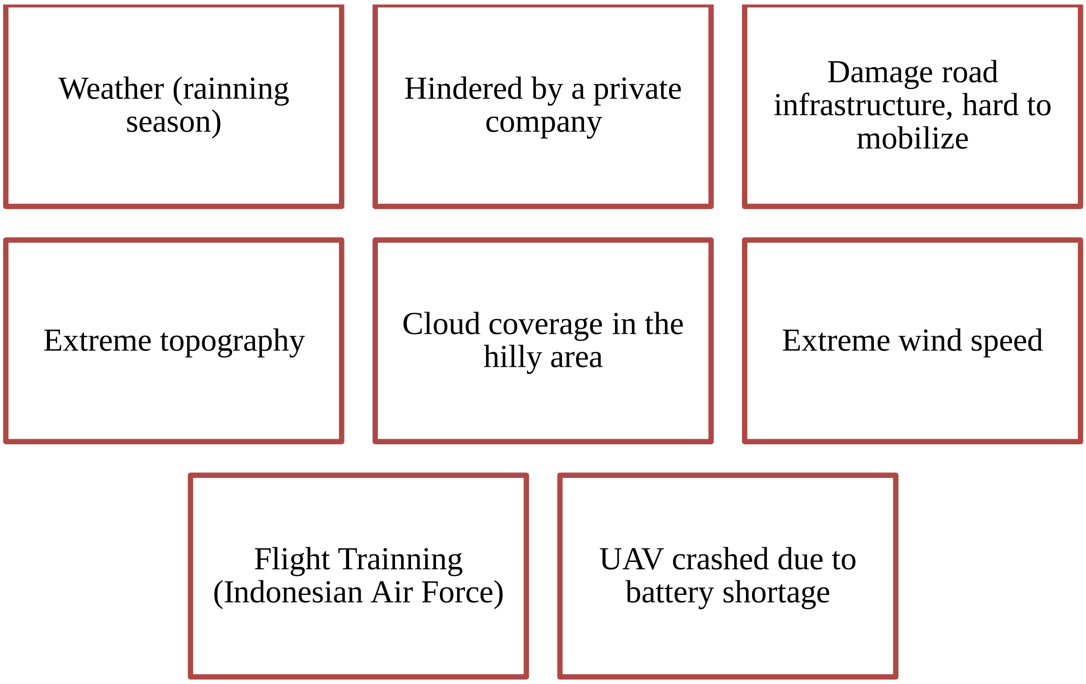


Figure 3. Obstacles during data acquisition

Spatial Accuracy

As can be seen in table 3, from the 12 photo map projects carried out, all locations have horizontal accuracy values (CE 90) that meet the specified technical specifications, while for vertical accuracy values (LE 90), 2 locations do not meet the specified specifications: location in West Java and Papua Provinces. For the output requirement of a GSD value of less than 5 cm, only 1 province does not meet these provisions, which is located in South Sulawesi.

Regarding vertical accuracy, to obtain the minimum specifications for vertical accuracy (LE90) below 75 cm, it is necessary to have a fairly even and tight distribution of Ground Control Points, as well as the high specifications of the UAV and the camera sensor. The photo map project in the provinces of West Java and Papua both used an assembled drone type with a Sony Alpha 6000 camera sensor, whilst the topographical conditions at the two locations are varying topography. The topographic condition is considered an obstacle throughout the data acquisition as it gave difficulties in capturing the imageries in these two AoI, where the UAV experienced crashes and went out of the flight path (see obstacles during data acquisition in Figure 3).

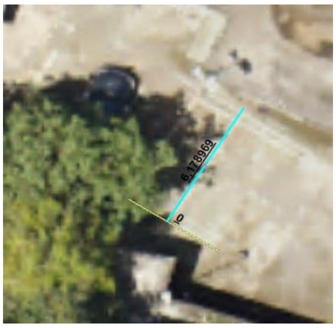
The topographical conditions in South Sulawesi are an area with complex topography – extreme valleys and slopes found at that location. This affected the flying height of the drones where it became vary greatly, even reaching a height of 1000 meters from the valley. This condition was quite challenging to achieve the minimum technical specification of 5 cm GSD. As part of the spatial accuracy evaluation, measurement of the line boundaries in the photo map was also carried out in 4 locations of the projects (see table 5). As can be seen, the disparity values are varied from 1 cm to 9,6 cm, this shows that the values are still within the tolerance accuracy.

Land administration involves several components, namely legal, institutional, technical, and social components. And as for the technical aspect, the data produced from the 12 projects has shown the quality of spatial data in terms of accuracy is appropriate for the cadastral purpose. The data is also very promising to be acquired in an adjusted schedule following the requirement of any user – thus it is more effective to provide more temporal resolution data. This resonates with Stocker et al (2022) who mentioned that photos from UAVs with their chance for high spatial and temporal resolution can contribute to reliable data and service to achieve effective land administration (goal of Framework for Effective Land Administration Approach/FELA).

Table 5. Measurement comparison from the field and the photo map

No	Object	Coordinate		D (Meter)	D' (Meter)	Disparity (Meter)
		Lat	Long			
1	Fence 	0° 57' 59,256" S	109° 45' 2,914" E	19	18,936	0,064
2	Volley Field 	0° 56' 34,487" S	109° 44' 50,757" E	18	18,04887	0,0489

No	Object	Coordinate		D (Meter)	D’ (Meter)	Disparity (Meter)
		Lat	Long			
3	Fence 	1° 0' 12,906" S	109° 46' 42,006" E	61	61,07793	0,0779
4	Volley Field 	7° 46' 11,700" S	108° 10' 43,200" E	8,9	8,962771	0,0628
5	Bridge 	7° 45' 58,724" S	108° 9' 15,965" E	3,574	3,608	0,034

No	Object	Coordinate		D (Meter)	D' (Meter)	Disparity (Meter)
		Lat	Long			
6	Badminton Field 	7° 42' 9,818" S	108° 10' 36,794" E	6,112	6,178969	0,067
7	Bridge 	3° 22' 8,200" S	120° 11' 37,200" E	4,6	4,610858	0,0109
8	Bridge 	3° 22' 6,900" S	120° 10' 42,200" E	4,943	5,039919	0,0969

No	Object	Coordinate		D (Meter)	D' (Meter)	Disparity (Meter)
		Lat	Long			
9	Volley Field 	3° 22' 3,653" S	120° 10' 33,422" E	9,06	9,118965	0,059

5. SUMMARY

The photo maps generated using UAVs show that it generally meets the specified technical specifications for cadastral purposes (especially meeting the horizontal accuracy values (CE 90). However, the result of vertical accuracy and GSD show that the extreme topography that affected the data acquisition process – caused a significant impact on the output of photo maps. Another important factor is the weather – although the whole project went according to plan, there were constraints regarding weather and poor road infrastructure throughout the project. This shows that the implementation of data collection using the UAV is indeed very flexible and can adapt to conditions, but in the preparation stage, it is necessary to allocate more time and apply more careful risk management so that the implementation of data collection in the field is not disrupted. Furthermore, considering there is an extended function of the Ministry of Agrarian Affairs and Spatial Planning (ATR/BPN) for managing land use besides land administration and cadastral purposes – it is very promising to conduct further research towards the utilization of land use – including monitoring and analyzing the changes and the utilization.

REFERENCES

Ramadhani, S. A., Kushendratno, A. W., & Heriyadi, W. Institutionalization of UAVs for Land Affairs and Spatial Planning in Indonesia.

Stöcker, C., Bennett, R., Koeva, M., Nex, F., & Zevenbergen, J. (2022). Scaling up UAVs for land administration: Towards the plateau of productivity. *Land use policy*, 114, 105930.

The Republic of Indonesia. Regulation of the Geospatial Information Agency regarding the Procedures for Providing Geospatial Information, Pub. L. No. 18 (2021). Indonesia.

Wahl, J.L., & Craig, B.A. (2003). Cadastral Survey Accuracy Standards.

BIOGRAPHICAL NOTES

Sheilla Ayu Ramadhani is a cadastral administrator in the Ministry of Agrarian Affairs and Spatial Planning from Indonesia. She has a bachelor's degree in Geodetic and Geomatic Engineering from Bandung Institute of Technology, Indonesia, and a master's degree in Land Administration from ITC, University of Twente, the Netherlands.

Rahmat Sidik is an analyst of survey and mapping in the Ministry of Agrarian Affairs and Spatial Planning from Indonesia. He has a bachelor's degree in Geodetic Engineering from the University of Gadjah Mada, Indonesia. Before his current assignment, he has working experience in the utilization of drones for palm oil plantations. He also has a pilot license for operating drones in Indonesia.

Fitriyani Hasibuan is the Secretary of the General Directorate for Survey and Mapping in the Ministry of Agrarian Affairs and Spatial Planning from Indonesia. She has a bachelor's degree in Geodetic Engineering from Bandung Institute of Technology, a Diploma in Photogrammetry from Stuttgart University, Germany, and a master's degree in Management. Mrs. Hasibuan is currently a Director Project for Acceleration of Agrarian Reform in Indonesia.

Hias Hardika Prabajati is a cadastral officer functioning as the Thematic Mapping Coordinator in the Land Office of Bekasi Regency, Indonesia. He has bachelor's degrees in Computer Science and Geodetic Engineering, and also a master's degree in Management.

CONTACTS

Sheilla Ayu Ramadhani
Ministry of Agrarian Affairs and Spatial Planning/National Land Agency
Sisingamangaraja 1
South of Jakarta
INDONESIA
Tel. +62-812-2000-1147
Email: sa.rmdhn@gmail.com
Web site: www.atrbpn.go.id