https://jurnal.unimed.ac.id/2012/index.php/geo/article/view/68287
https://doi.org/10.24114/jg.v17i2.68287 - (Vol 17, No 2 – 2025)
available at http://jurnal.unimed.ac.id/2012/index.php/geo
e-issn (2549-7057) & p-issn (2085-8167)

Comparison of Orthomosaic Accuracy Based on Unmanned Aerial Vehicle (UAV) Real Time Kinematic (RTK) Radio and RTK NTRIP in Padang City, West Sumatra

Muhammad Ismail[1]*, Bayu Wijayanto[2], Randi Proska Sandra[3], Wikan Jaya Prihantarto[1], Elisa Maiyenti[4], M Sriharta[5], Rahmat Fitrian[1], Mutiara Amelia Putri[1]
[1]Vocational School, Universitas Negeri Padang, Indonesia
[2]Department of Geography, Faculty of Social Sciences, Universitas Negeri Padang, Indonesia
[3]Department of Electronics Engineering, Faculty of Engineering, Universitas Negeri Padang, Indonesia
[4]Department of Civil Engineering, Faculty of Engineering, Universitas Negeri Padang, Indonesia
[5]Urban Spasial Indonesia, Indonesia

ARTICLE INFO
Article History:
Received: August 06, 2025
Revision: September 09, 2025
Accepted: September 09, 2025

Keywords:
Orthomosaic Accuracy
UAV
RTK Radio
RTK NTRIP

Corresponding Author
E-mail:
muhammadismail@fis.unp.ac.id

ABSTRACT
UAVs with RTK technology offer high-accuracy aerial mapping, with RTK Radio and RTK NTRIP as two correction methods affecting orthomosaic precision. While previous studies compared these methods in terrestrial surveys, their impact on UAV-based orthomosaics remains underexplored. This research evaluates and compares the accuracy of UAV-derived orthomosaics using RTK Radio and RTK NTRIP to provide practical guidance for optimal mapping applications. This research combined UAV RTK photogrammetry and GIS to produce high-precision aerial maps in two areas of Padang City with different topographies. Data were collected using DJI Mavic 3 Enterprise RTK with RTK Radio and RTK NTRIP techniques, supported by GCPs, BMs, and satellite imagery, then processed into orthomosaics for analysis. Accuracy was assessed using ICPs and statistical measures like RMSE to compare the spatial precision of both correction methods under varying terrain conditions. The results show a difference in mapping accuracy between RTK Radio and RTK NTRIP aerial photographs, with RTK Radio achieving 0.683 accuracy and 0.450 RMSE, while RTK NTRIP reached 0.563 accuracy and 0.371 RMSE. RTK Radio is more suitable for areas lacking CORS access but still requires GCP verification. RTK NTRIP performs better in urban areas with strong CORS networks. Combining both methods with adequate GCPs provides an effective solution for mapping in varied or densely vegetated terrains.

INTRODUCTION

Unmanned Aerial Vehicles (UAVs) or drones are technological innovations that have evolved significantly since their development in the mid-18th century, with continuous adjustments in both technology and applications. Initially prominent in the military, drones are now utilized at various levels while also presenting a spectrum of potential threats (Firmansyah & Puspitasari, 2021). In addition, the use of drones is also used to identify the phenomenon of forest areas and their changes (Fa'iq et al., 2022). toDrone technology can also be used to map administrative boundaries and estimate and map built-up land fields(Prihantarto et al., 2024; Ismail et al., 2024). Using drones for environmental mapping, natural resources, land use, aquatic and marine objects, and other themes is also widely carried out by various related parties.

UAV technology provides superior spatial and temporal resolution, is unaffected by clouds, and produces large-scale remote sensing imagery (Dlamini & Ouma, 2025; Warsito, 2021). This is achieved through camera sensors that capture objects on the Earth's surface. UAVs are equipped with high-resolution cameras capable of controlled movement (Stefano, 2020; Rauzan

& Yulianti, 2022). The accuracy of aerial imagery depends on planimetric accuracy, with GCPs serving as anchor points for map coordinates (Moniaga et al., 2024). Unlike satellite imagery, UAVs are more flexible and easier to operate with automated control, making them an effective alternative for mapping applications.

In aerial data acquisition, Post Processed Kinematic (PPK) and Real Time Kinematic (RTK) techniques are commonly used. PPK applies corrections from CORS or Virtual Reference Stations after the flight, using reference point data downloaded from the Indonesian Geospatial Reference System (SRGI) (Nakata et al., 2023). Different RTK technology, which can connect directly to a reference station in real time, uses a radio or internet connection (Broekman & Gräbe, 2021). For positioning using the RTK method, real-time data will collect phase data, pseudorange, and correction data from reference stations using NTRIP as a communication medium (Ashary et al., 2023).

Data acquisition techniques greatly influence the accuracy of the mapping. PPK's aerial photo acquisition technique is carried out by correcting the control points after acquiring aerial photos. It is different from RTK, which is carried out in real time at the time of acquisition of aerial images. This difference, of course, causes a difference in accuracy in aerial photographs. Using aerial photographs combined with the RTK method can help in terms of cost and scalability to produce precise aerial pictures with high and sharp resolution (Bina et al., 2025). However, there is no difference in spatial resolution between the two acquisition techniques above.

Using the RTK method makes it very easy for surveyors to obtain position or location data quickly without requiring a reference base at the mapping location based on DGPS procedure using a radio modem, so the process of sending data can be sent in real-time (Fiqri & Yulianandha, 2023; Budi et al., 2022). The acquisition of aerial photo data using RTK is increasingly relevant, with many UAV vendors such as DJI embedding RTK modules in their drones over the last five years. RTK is key in enhancing spatial accuracy for mapping applications (Sugandhi et al., 2023). Through RTK correction, the object's position always goes hand in hand with the aerial photo acquisition process.

The data generated from this RTK has high accuracy and is also spatially precise, so this data can be used for various jobs, such as surveying, construction, hydrographic surveys, and other related to mapping and generating spatial data (Kanplumjit et al., 2024). Usually, the accuracy resulting from this RTK method can reach 1-5 cm, where this accuracy range has reached a very good condition (Rizkia et al., 2022). RTK aerial photo acquisition technique generally consists of radio RTK and RTK Networked Transport of RTCM via Internet Protocol (NTRIP).

RTK NTRIP is a relative positioning method based on GNSS observations that applies GPS data correction via an internet connection. Utilizing a CORS station as a permanent reference enables real-time transmission of position corrections remotely from the base station (Bangun & Susilo, 2025). RTK NTRIP uses the RTCM format from the Radio Technical Commission for Maritime Services as the radio navigation and maritime communication standard. Unlike RINEX, which is used for post-processed data, NTRIP delivers real-time position corrections that can be applied instantly (Mukti & Hanafi, 2022).

However, factors that affect the accuracy of the RTK NTRIP method are influenced by the length of the baseline between the CORS station and the rover, and aspects of the observation environment also affect the observations (Ramadhon, 2020). Because the RTK NTRIP method uses a base station, which means that if the distance between the rover and the reference station (base station) is too far or obstructed by tall objects, it will block the base station signal to the rover (Fiqri & Yulianandha, 2023). So, the utilization of the RTK NTRIP method is open and accessible so that it's possible to perform positioning with a high level of accuracy, and it's no longer difficult to achieve positioning in real time (Gautama et al., 2024).

RTK Radio is a method that uses radio signals to transmit corrections from a base station in the BM field to the GNSS rover, applying Differential Data Code and Carrier Phase in real time (Ahmad et al., 2024). It can also be defined as a technique for transmitting correction data via radio waves to obtain accurate positions in the field Mahendra & Panuntun (2022). GCPs are crucial in research on orthomosaic accuracy comparisons using RTK UAV and RTK NTRIP because their positions directly affect aerial orthomosaic results (Arkalı & Atik, 2025). The number and distribution of GCPs must be considered, especially in varied topographic conditions (Widodo et al., 2023). Orthomosaic accuracy in aerial photography depends largely on GCP placement, number, and distribution under different topographies.

UAV technology provides detailed photo maps while improving spatial data quality and accuracy. These improvements can be supported by integrating terrestrial surveys, photogrammetry, and satellite observations (Fahruddin & Mujiburohman, 2024). Many previous researchers have researched the use of UAV technology. UAVs and GNSS can be used for accurate aerial photography, where UAVs are used to take photos, while GNSS acts as a reference point for UAV images to obtain precise images and precision of mapping (Marwan et al., 2020; Sugandhi et al., 2023). This research has the same objective related to using UAVs for mapping. However, the main study in this study is the application of RTK techniques to DJI drones, which has not been explored further.

The demand for fast and accurate mapping is very high in the modern era, especially in urban areas and regions with complex topography. Using UAVs with RTK technology provides an efficient solution in terms of time and cost. However, the presence of two correction communication methods, namely RTK Radio and RTK NTRIP, presents specific challenges in selecting the most appropriate approach depending on field conditions.

Several previous studies have compared the accuracy of GNSS using RTK Radio and RTK NTRIP, particularly in terrestrial measurements or land surveys. Research conducted Mahendra & Panuntun (2022) in Yogyakarta revealed that RTK Radio provided higher precision than RTK NTRIP in fourth-order measurements. Another study Maliak et al. (2022) in Makassar indicated that RTK Radio yielded better RMSE values for positioning than RTK NTRIP. However, those works focused more on ground-based measurements and did not extensively explore the application of both methods in UAV-based mapping for orthomosaic production. In fact, orthomosaic accuracy is additionally influenced by factors such as GNSS baseline length, distribution of ground control points, topographic conditions, and more complex photogrammetric processing. This research gap highlights the need for a deeper examination specifically addressing the comparison of RTK Radio and RTK NTRIP in aerial mapping.

This research aims to evaluate and compare the accuracy of UAV-derived orthomosaics obtained through RTK Radio and RTK NTRIP methods. It also seeks to identify how differences in correction techniques affect the spatial quality of the orthomosaic. Furthermore, this research is expected to provide practical recommendations for selecting an appropriate acquisition method that aligns with mapping conditions, thereby producing more accurate results that can be optimally applied to various spatial analysis needs.

RESEARCH METHODS

This research employed a combined photogrammetry approach using UAV RTK technology and a Geographic Information System (GIS). The UAV RTK method is known to produce high-precision aerial photographs with vertical accuracy up to ±2.5 cm even without Ground Control Points (GCPs) (Niu et al., 2024). The integration with GIS further ensured that spatial data could be processed and analyzed effectively to evaluate mapping accuracy.

Research Location

The research was conducted in Padang City, West Sumatra, focusing on two areas with different topographic characteristics. The first location was the coastal area of Padang Beach, which represents flat terrain with minimal obstructions. The second location was the Padang State Polytechnic area and its surroundings, characterized by undulating terrain with vegetation and built-up areas. The selection of these two sites was intended to assess how topographic variability influences UAV RTK mapping accuracy, since terrain characteristics have been shown to significantly affect orthophoto and Digital Elevation Model (DEM) quality (Zeybek et al., 2023).

Research Instruments

Several instruments were utilized to support this research, including:

1. UAV Dji Mavic 3 Enterprise RTK
2. GNSS Dji D-RTK2
3. Ground Control Point (GCP)
4. Benchmark (BM)
5. PlanetScope Satellite Imagery
6. SASPlanet Satellite Imagery
7. RBI Map of Padang City at a scale of 1:25,000

Data Collection Techniques

The data collection process began with UAV preparation and flight planning using GIS and Google Earth software. Each UAV battery covered approximately 10–20 hectares, with flight paths to avoid image gaps. The DJI D-RTK2 base station was installed at predetermined BM and GCP/ICP locations. Two data acquisition techniques were applied: RTK Radio with six GCP/ICP points and RTK NTRIP with eight GCP/ICP points. Data collection was performed autonomously based on the default DJI settings, with the UAV functioning as a GNSS rover to capture aerial photographs.

Data Processing Techniques

The acquired aerial photographs were processed using photogrammetry software to generate orthomosaics for RTK Radio and RTK NTRIP datasets. The orthomosaics were further processed and evaluated using GIS software to extract coordinate values and calculate mapping accuracy. This workflow ensured consistency in processing parameters across both correction techniques, allowing for a fair comparison.

Data Analysis Techniques

Data analysis focused on assessing the accuracy of the orthomosaics produced by RTK Radio and RTK NTRIP. Accuracy was evaluated using Independent Check Points (ICP) by calculating Root Mean Square Error (RMSE), mean coordinate deviation, and overall accuracy index. These statistical indicators provided a comprehensive assessment of spatial precision and consistency. The comparison between the two methods was then discussed concerning terrain conditions and external influencing factors such as signal quality, baseline length, and atmospheric conditions.

RESULTS AND DISCUSSION

Data Acquisition and Orthomosaic Generation

The research aims to compare the accuracy of mapping results using UAV technology with acquisition techniques using RTK Radio and RTK NTRIP. The research began with the initial stage, preparing the DJI Mavic 3 Enterprise UAV and the DJI D-RTK2 base station. The next stage is to prepare a flight plan according to the battery capability. Each battery can cover an area of 10-20 ha. In preparing flight plans using GIS and Google Earth software. However, the preparation of flight plans can also be done directly on the UAV remote control. Then, in preparing the flight plan, it must also ensure no gaps in each and include a number.

The DJI base station was installed on predetermined benchmarks, ground control points (GCP), and independent check points (ICP), with six points used for RTK Radio acquisition and eight points for RTK NTRIP. The research covered two areas with different terrain characteristics, namely the hilly eastern part of Padang City and the coastal area of Padang Beach. The limited availability of benchmarks in the hilly area restricted the number of control points, as only one benchmark could serve as a GCP, which may have influenced mapping accuracy. In contrast, the coastal site applied RTK NTRIP with eight distributed control points, providing better coverage across the area of interest.

Furthermore, aerial photo data was acquired using RTK Radio and RTK NTRIP. The data acquisition mechanism is carried out autonomously based on the DJI default settings. However, before acquiring aerial photographs, the UAV, which is assumed to be a GNSS rover, must identify the GCP and ICP coordinate points.

After that, the data acquisition process can be carried out according to the flight plan. The data processing stage is carried out after acquiring aerial photo data. Aerial photo data processing was carried out to obtain orthomosaic data using two techniques: RTK Radio and RTK NTRIP. Data processing was done using photogrammetry software. The orthomosaic data was processed again on GIS data processing software to obtain mapping accuracy information.

This research was conducted in two contrasting areas: the Padang State Polytechnic, with buildings and vegetation that cause signal interference, and the relatively open Padang Coastal area. In flat and open terrain, both RTK Radio and RTK NTRIP orthomosaics achieved high accuracy, although RTK Radio was more stable because it did not rely on internet connectivity. RTK NTRIP, however, was more advantageous for wider coverage without requiring a local base station. In hilly or obstructed terrain, both methods experienced reduced accuracy, making the choice of correction technique dependent on topographic conditions and internet availability.

Based on other studies, various errors were observed depending on the UAV flight altitude, terrain characteristics, and availability of GCP. The average mistake without GCP is around 0.040–0.50, while the error with GCP is around 0.30–0.37 in areas with topography between 440–500 m above sea level. Meanwhile, in another study using the RTK-NTRIP method in an area flanked by two buildings, the accuracy achieved from these measurements reached ≤5 cm. Furthermore, in another study using the RTK Radio method in an obstruction-free location, the accuracy of the RTK Radio method resulted in an RMSE value of 0.2571 m, with an average error of 0.135 m between points, and an RMSE value of 0.2509 m, and an average difference in land area of 4.778 m^2.

The accuracy comparison based on this latest study with previous studies may occur due to several factors, depending on the conditions of the measured area. Some factors, such as open areas without obstacles, have high accuracy with smaller RMSE values. Additionally, it depends on the flight altitude of the UAV and terrain characteristics, and in urban areas, it can produce high accuracy.

Based on the orthomosaic accuracy test results in Tables 1 and 2, differences between the orthomosaics produced using the RTK Radio and RTK NTRIP techniques can be observed. The orthomosaic generated by RTK Radio produced an RMSE of 0.450 m, whereas the orthomosaic from RTK NTRIP yielded a lower RMSE of 0.371 m. This indicates that, statistically, RTK NTRIP provides higher precision than RTK Radio at the tested ICP points. The mean coordinate deviation obtained with RTK Radio was 0.202 m, while RTK NTRIP produced a lower mean deviation of 0.138 m. This difference suggests that the systematic deviation of the RTK NTRIP orthomosaic is relatively smaller compared to RTK Radio. However, the accuracy index of the RTK Radio orthomosaic was recorded at 0.683, which is higher than the accuracy index of RTK NTRIP at 0.563. These findings indicate that although RTK NTRIP produced smaller mean errors and lower RMSE values, RTK Radio demonstrated better consistency across the distribution of test points.

The difference in accuracy values between orthomosaics produced using RTK Radio and RTK NTRIP is not solely determined by the correction method applied, but can also be influenced by various external field factors such as weather conditions, signal interference, and baseline distance. Three primary factors contributing to variations in the results are atmospheric conditions, communication signal interference, and the distance between the base station and the rover (UAV). In the RTK NTRIP method, CORS networks typically employ more advanced atmospheric correction models, making them more effective in mitigating atmospheric effects than RTK Radio.

Signal interference can result from physical obstructions, multipath reflections, or electromagnetic disturbances from other devices. RTK Radio highly depends on the line-of-sight quality between the base station and the rover. If obstructions are present, the radio signal may weaken or be disrupted, thereby reducing the stability of corrections. RTK NTRIP, while generally more resilient to physical obstructions, remains vulnerable to internet connectivity quality. If disruptions occur in the cellular network or data packets are lost, the corrections received by the UAV may be delayed, resulting in positioning errors.

The accuracy of RTK Radio also decreases as the distance between the base station and the rover increases, since the correction model loses precision over longer baselines. Its effective range is typically limited to only a few kilometers, depending on transmission power and topographic conditions. RTK NTRIP, on the other hand, is more flexible as it utilizes CORS reference networks that can cover longer baselines. However, the farther the UAV is from the reference station used by the NTRIP caster, the greater the likelihood of residual errors, which can reduce positional accuracy.

Accuracy Assessment of Orthomosaic Maps

To evaluate the accuracy of the orthomosaic maps generated using RTK Radio and RTK NTRIP techniques, a series of tests was conducted by comparing the orthomosaic coordinates with Independent Check Points (ICP). The results of this assessment provide a quantitative measure of positional deviation, expressed through Root Mean Square Error (RMSE), mean coordinate differences, and overall accuracy index. The detailed outcomes of these accuracy tests are presented in the following tables.

Table 1. Accuracy Test of Orthomosaic Map Results Based on RTK Radio Processing

No	Point Name	X (ICP Coordinates)	X (Orthomosaic Coordinates)	(D X)	(D X)^2	Y (ICP Coordinates)	Y (Orthomosaic Coordinates)	(D Y)	(D Y)^2	(D X)^2 + (D Y)^2
A	B	C	D	E	F	G	H	I	J	K
1	BM 01	663871,46	663871,431	-0,033	0,001	9899247,349	9899248,123	0,774	0,599	0,600
2	T2	664351,88	664351,800	-0,089	0,008	9899265,039	9899264,732	-0,306	0,094	0,102
3	PM 03	664504,44	664504,380	-0,067	0,004	9899510,905	9899511,124	0,219	0,048	0,052
4	T4	663488,42	663488,481	0,056	0,003	9899038,584	9899038,976	0,392	0,154	0,157
5	T6	663144,08	663144,395	0,312	0,097	9898881,695	9898881,448	-0,247	0,061	0,158
6	T7	663061,30	663061,002	-0,301	0,090	9899078,24	9899078,291	-0,233	0,054	0,145
							Amount		1,214	
							Average		0,202	
							RMSE		0,450	
							Accuracy		0,683	

(Source: Research Results, 2024)

The accuracy test results based on RTK Radio processing, as presented in Table 1, show that the mean coordinate deviation reached 0.202 m, while the RMSE value was 0.450 m. The accuracy index obtained was 0.683, indicating that the RTK Radio method maintained a relatively stable level of accuracy across Independent Check Points (ICP). These findings emphasize that RTK Radio is quite reliable, particularly when the availability of internet connectivity in the field is limited or unstable.

Another important aspect is that RTK Radio still requires a clear line-of-sight connection between the UAV rover and the base station. This condition makes the method more sensitive to topographic obstacles or physical barriers, which may influence the overall accuracy level. Even so, the relatively stable performance shown by the RTK Radio method makes it a viable option in locations with adequate visibility and minimal interference.

The same accuracy test was conducted on orthomosaic maps generated using the RTK NTRIP method. The detailed results of this assessment are presented in Table 2.

Table 2. Accuracy Test of Orthomosaic Map Results Based on RTK NTRIP Processing

No	Point Name	X (ICP Coordinates)	X (Orthomosaic Coordinates)	(D X)	(D X)^2	Y (ICP Coordinates)	Y (Orthomosaic Coordinates)	(D Y)	(D Y)^2	(D X)^2 + (D Y)^2
A	B	C	D	E	F	G	H	I	J	K
1	T1	650492,510	650492,567	0,057	0,003	9893550,485	9893550,615	0,130	0,017	0,020
2	T2	650476,866	650476,769	-0,097	0,009	9893564,728	9893564,552	-0,177	0,031	0,041
3	T5	650513,230	650513,430	0,200	0,040	9894526,069	9894525,979	-0,090	0,008	0,048
4	T6	650486,269	650486,046	-0,223	0,050	9894509,937	9894509,958	0,021	0,000	0,050
5	T7	650427,128	650427,072	-0,056	0,003	9895388,932	9895389,276	0,344	0,118	0,121
6	T8	650353,302	650353,400	0,098	0,010	9895395,733	9895395,496	-0,237	0,056	0,066
7	T11	650112,851	650112,426	-0,425	0,181	9897053,325	9897053,344	0,019	0,000	0,181
8	T14	650401,609	650401,005	-0,603	0,364	9896474,539	9896474,998	0,459	0,211	0,575
								Amount		1,101
								Average		0,138
								RMSE		0,371
								Accuracy		0,563

(Source: Research Results, 2024

The RTK NTRIP accuracy test results, shown in Table 2, indicate that the mean coordinate deviation was 0.142 m, with an RMSE value of 0.290 m and an accuracy index of 0.812. Compared to RTK Radio, the RTK NTRIP method demonstrated higher positional accuracy, consistent with the advantages of utilizing CORS-based corrections. These findings also emphasize the potential of RTK NTRIP for wider-area mapping applications where local base station deployment may not be feasible.

Figures 1 and 2 provide a visual comparison to further illustrate the distribution of deviations and accuracy differences between RTK Radio and RTK NTRIP.

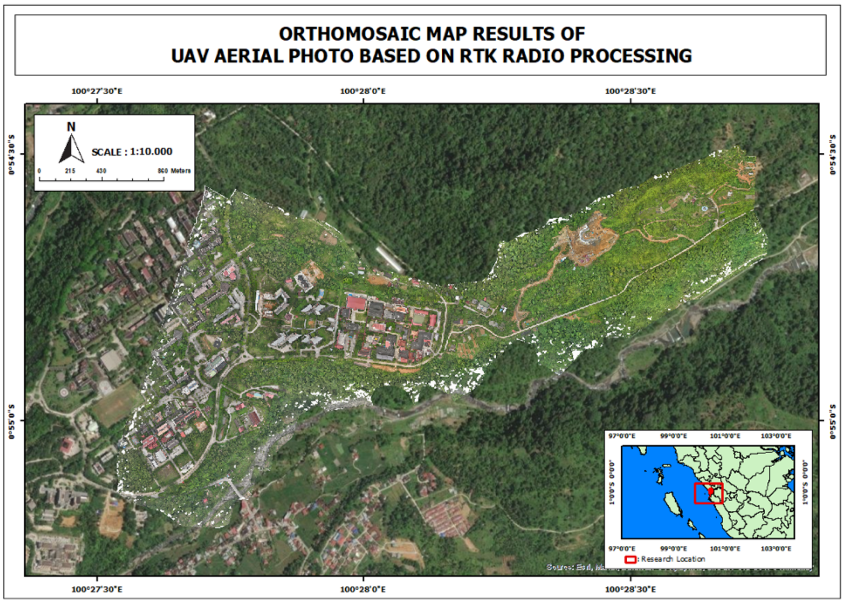

Figure 1. Orthomosaic Map Based on RTK Radio Processing (Source: Research Results, 2024)

Figure 1 shows the orthomosaic map generated using UAV aerial photos processed with RTK Radio. The visual output demonstrates that the method can produce a continuous and detailed mosaic that covers the area of interest in eastern Padang. The orthomosaic appears accurate in open spaces; however, slight positional discrepancies are noticeable in regions dominated by hills, vegetation, and built-up environments. These variations reflect the influence of terrain conditions on the stability of RTK Radio corrections, which rely heavily on maintaining a clear line-of-sight connection with the base station.

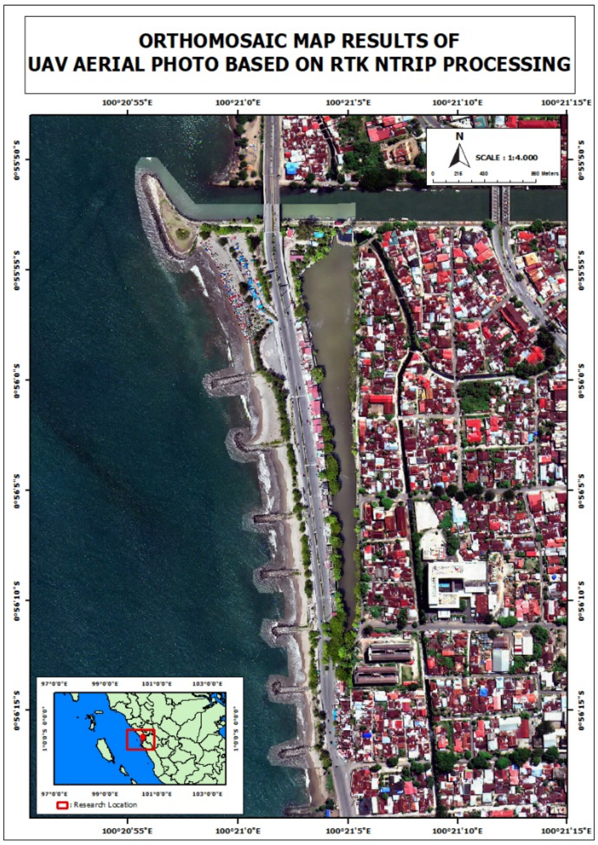

Figure 2. Orthomosaic Map Based on RTK NTRIP Processing (Source: Research Results, 2024)

Figure 2 presents the orthomosaic map generated from UAV aerial photographs processed using the RTK NTRIP method. The resulting orthomosaic provides a detailed and continuous representation of the Padang coastal area, showing both land and coastal structures with high positional accuracy. This visual output highlights the effectiveness of RTK NTRIP in producing precise spatial data without the need for a local base station, relying instead on correction data from CORS networks. The clarity of built-up areas, road networks, and coastal protection structures further illustrates the advantages of RTK NTRIP for wide-area mapping applications, particularly in urban environments where internet connectivity is available and stable.

Comparative Analysis and Influencing Factors

This research places two correction techniques, RTK Radio and RTK NTRIP, within a single uniform accuracy testing framework. The results show that accuracy cannot be generalized because it is influenced by topography and supporting infrastructure. The main finding is that RTK Radio provides more consistent results, with a higher accuracy index, while RTK NTRIP offers greater positional precision, with a lower RMSE. This indicates that the choice of correction method should depend on the mapping purpose, such as land change monitoring that requires consistency or detailed surveys that demand high positional precision.

These findings align with Mahendra & Panuntun (2022) those who compared GNSS with RTK Radio and RTK NTRIP for land measurement in Yogyakarta. They found that RTK Radio is superior in maintaining positional stability, especially with poor internet quality. This supports the present study's finding that RTK Radio remains reliable in areas with limited connectivity. In contrast, Rizkia et al. (2022) reported that RTK NTRIP provides higher accuracy for land mapping in urban areas. This is consistent with the current research, which found lower RMSE for RTK NTRIP. Nevertheless, RTK Radio retains an advantage in consistency across test points. This comparison demonstrates that the two methods do not cancel each other out, but each has strengths under different conditions.

Dlamini & Ouma (2025) Their research on large-scale topographic mapping using UAV and RTK-GNSS also emphasized the strong influence of field conditions on accuracy. They showed that areas with complex topography or dense vegetation tend to reduce data quality. Similarly, in this study, the accuracy of both RTK Radio and RTK NTRIP decreased in hilly or built-up areas, while it was higher in open coastal regions.

Besides the correction method, the number and distribution of Ground Control Points (GCPs) also affect accuracy. In this study, RTK Radio used six GCPs, while RTK NTRIP used eight. The higher GCP density in RTK NTRIP likely contributed to the lower RMSE. This is consistent with Widodo et al. (2023) those who highlighted the importance of GCP distribution in improving orthomosaic accuracy, particularly in regions with varied topography.

These results indicate that the choice of method should match field conditions. RTK Radio is more suitable for areas with limited internet access, while RTK NTRIP is better for urban or open areas with reliable CORS support. Combining both methods with adequate GCPs can produce more accurate maps for diverse purposes. The novelty of this research lies in clearly separating two dimensions of orthomosaic quality, consistency and positional precision, within a single testing framework. This enhances understanding from previous research by showing that RTK Radio and RTK NTRIP differ in accuracy and result stability. This highlights the importance of selecting a method based on mapping goals and field conditions.

CONCLUSION

Based on the results of this research, there is a notable difference in mapping accuracy between RTK Radio and RTK NTRIP aerial photographs. RTK Radio achieved an accuracy of 0.683 with an RMSE of 0.450, while RTK NTRIP reached 0.563 with an RMSE of 0.371. RTK Radio is more suitable for areas without CORS access but still requires GCP verification, whereas RTK NTRIP performs better in urban areas supported by robust CORS networks. Combining both methods with sufficient GCPs provides a practical solution for mapping in heterogeneous or densely vegetated terrains.

It is suggested that practitioners select the correction method based on field conditions, using RTK Radio in remote or CORS-limited areas and RTK NTRIP in urban or CORS-supported regions. Sufficient GCP placement should always be ensured to improve orthomosaic accuracy. For future research, exploring hybrid workflows that integrate RTK Radio and RTK NTRIP and analyzing the effects of varying GCP distributions, baseline lengths, and environmental factors could provide more comprehensive guidance for UAV-based mapping applications.

ACKNOWLEDGMENT

LP2M UNP funded this research through the 2024 beginner research scheme (contract number 1614/UN35.15/LT/2024). The author would like to thank LP2M UNP, which assisted with research facilities and infrastructure.

REFERENCE LIST

Ahmad, A. A., Sidabutar, Y. L., & Herwieany, A. S. (2024). Nirawak Untuk Survei Fotogrametri Pada Proyek Jalan (Comparison of Productivity and Accuracy of Unmanned Aerial Vehicles for Photogrammetry Surveys on Road Projects). Jurnal Jalan Jembatan, 41(1), 1–14.

Arkalı, M., & Atik, M. E. (2025). Accuracy Assessment of RTK, PPK, and PPP-AR Techniques for Direct Georeferencing in UAV-Based Photogrammetric Mapping. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives, 48(6), 325–330. https://doi.org/10.5194/isprs-archives-XLVIII-M-6-2025-325-2025

Ashary, R., Gumilar, I., & Bramanto, B. (2023). Reference System and Accuracy Evaluation of InaCORS RTK and Online Data Processing Services. IOP Conference Series: Earth and Environmental Science, 1276(1), 1–12. https://doi.org/10.1088/1755-1315/1276/1/012008

Bangun, B. H., & Susilo, Y. (2025). Efektivitas dan Perbandingan Pengukuran Bidang Tanah Menggunakan Metode RTK-NTRIP dengan Metode RTK-Statik (Studi Kasus Kota Batam pada Tahun 2025). El-Jughrafiyah: Jurnal Geografi Dan Terapannya, 05(02), 412–421.

Bina, S. M., Fujii, H., & Toriya, H. (2025). Innovative methodology for unlocking solar energy potential in Japanese urban areas: drone-based DSM and roof shape analysis in Akita City. Energy Conversion and Management, 345(1), 1–13. https://doi.org/10.1016/j.enconman.2025.120391

Broekman, A., & Gräbe, P. J. (2021). A Low-cost, Mobile Real-time Kinematic Geolocation Service for Engineering and Research Applications. HardwareX, 10(1), 1–30. https://doi.org/10.1016/j.ohx.2021.e00203

Budi, B. I., Rahesanita, D., Arifin, E. T. N., Jalaludin, A., Anjarwati, A., Nuramelya, P. J., & Ali, M. F. (2022). Perbandingan Vertikal Digital Terrain Model Dengan Pengukuran Gnss Metode Rtk-Ntrip (Studi Kasus : Wilayah Kampus Upi Bumi Siliwangi). Jurnal ENMAP (Environment and Mapping), 3(1), 19–27. https://doi.org/10.23887/em.v3i1.44781

Dlamini, S. M., & Ouma, Y. O. (2025). Large-Scale Topographic Mapping Using RTK-GNSS and Multispectral UAV Drone Photogrammetric Surveys: Comparative Evaluation of Experimental Results. Geomatics, 5(2), 1–23. https://doi.org/10.3390/geomatics502

0025

Fa'iq, M., JB, A. R., Afdal, M., Arkam, M. I., & Nursaputra, M. (2022). Pemanfaatan Teknologi Unmanned Aerial Vehicle Untuk Identifikasi Pemanfaatan Lahan Masyarakat Di Dalam Kawasan Hutan Pendidikan Universitas Hasanuddin. Jurnal Litbang Provinsi Jawa Tengah, 20(1), 109–116. https://doi.org/10.36762/jurnaljateng.v20i1.888

Fahruddin, M. F., & Mujiburohman, D. A. (2024). Pemanfaatan Teknologi Unmanned Aerial Vehicle (UAV) dalam Peningkatkan Kualitas Data Spasial Pertanahan. Kadaster: Journal of Land Information Technology, 2(1), 35–49. https://doi.org/10.31292/kadaster.v2i1.29

Fiqri, M. A., & Yulianandha, A. (2023). Analisis Pengaruh Panjang Baseline Pada Survei GNSS Metode RTK-NTRIP Terhadap Ketelitian Pengukuran Situasi. Prosiding Semsina.

Firmansyah, M. Z., & Puspitasari, P. (2021). Pemanfaatan Drone sebagai Bagian dari Kontra Terorisme: Tinjauan pada Regulasi dan Prosedur Tetap Pengamanan. Nakhoda: Jurnal Ilmu Pemerintahan, 20(1), 43–58. https://doi.org/10.35967/njip.v20i1.148

Gautama, J. I., Fajriyanto, F., & Rahmadi, E. (2024). Studi Kualitas Layanan Inacors Big Metode Rtk Ntrip Pada Berbagai Macam Obstruksi. Datum: Journal of Geodesy and Geomatics, 4(1), 36–45. https://doi.org/10.23960/datum.v4i1.5674

Ismail, M., Prihantarto, W. J., Susetyo, B. B., & Widyastuti, W. (2024). Pemetaan Estimasi Lahan Terbangun Menggunakan Teknologi Foto Udara Unmanned Aerial Vehicle (UAV) di Kelurahan Jawi-Jawi I, Kota Pariaman. Suluah Bendang: Jurnal Ilmiah Pengabdian Kepada Masyarakat, 24(1), 22–30. https://doi.org/10.24036/sb.05370

Kanplumjit, T., Kaewthong, N., Janthongpoon, J., & Buathongkhue, C. (2024). Accuracy Assessment of Thailand'S Network Real Time Kinematic (NRTK) for Unmanned Aerial Vehicle (UAV) Photogrammetry. International Journal of GEOMATE, 27(124), 40–48. https://doi.org/10.21660/2024.124.4607

Mahendra, G., & Panuntun, H. (2022). Perbandingan Pengukuran Tdt Orde 4 Menggunakan Gnss Metode Rtk Ntrip Dan Radio. Jurnal Nasional Teknologi Terapan (JNTT), 4(1), 1–12. https://doi.org/10.22146/jntt.v4i1.4691

Maliak, N., Puspita, I., Amaliah, A., Fajar Makassar, U., Negeri, P., & Pandang, U. (2022). Analisis Perbandingan Akurasi Penentuan Posisi GPS Geodetik menggunakan Metode RTK Radio dam RTK NTRIP (Comparative Analysis of Geodetic GPS Positioning Accuracy Using RTK Radio and RTK NTRIP Methods). Electrical and Telecommunication Journal (ELTEC), 3(2).

Marwan, M., Wirandha, F. S., Nizzamuddin, N., & Susanta, F. F. (2020). Comparison of Accuracy Aerial Photography UAV (Unmanned Aerial Vehicle) and GNSS (Global Navigation Satelitte System) for Mapping of Lambarih Village, Aceh Besar, Aceh. Journal of Aceh Physics Society, 9(3), 78–83. https://doi.org/10.24815/jacps.v9i3.17151

Moniaga, F., Kafrain, I. G. Y., & Piyoh, A. G. . (2024). Digitalisasi Pemetaan Topografi menggunakan Alat Drone serta Perhitungan Ketelitian dengan Ground Control Point (Gcp). Jurnal Teknik Sipil Terapan, 6(1), 1–12. https://doi.org/10.47600/jtst.v6i1.642

Mukti, F. D., & Hanafi, F. (2022). Uji Ketelitian Data GNSS dengan Metode NTRIP terhadap Variasi Multipath di Lingkungan Universitas Negeri Semarang. Jurnal Geografi: Media Informasi Pengembangan Dan Profesi Kegeografian, 19(2), 46–53. https://doi.org/10.15294/jg.v19i2.39094

Nakata, Y., Iwasaki, K., Shimoda, S., & Torita, H. (2023). Understanding Microtopography Changes in Agricultural Landscapes Through Precision Assessments of Digital Surface Models by the UAV-RTK-PPK Method without Ground Control Points. Smart Agricultural Technology, 5(1), 1–9. https://doi.org/10.1016/j.atech.2023.100269

Niu, Z., Xia, H., Tao, P., & Ke, T. (2024). Accuracy Assessment of UAV Photogrammetry System with RTK Measurements for Direct Georeferencing. ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 10(1), 169–176. https://doi.org/10.5194/isprs-annals-X-1-2024-169-2024

Prihantarto, W. J., Ismail, M., & Susetyo, B. B. (2024). Pemetaan Partisipatif Batas Korong Nagari dengan Memanfaatkan Teknologi Unmanned Aerial Vehicle (UAV). Suluah Bendang: Jurnal Ilmiah Pengabdian Kepada Masyarakat, 24(1), 12–21. https://doi.org/10.24036/sb.05330

Ramadhon, S. (2020). Pengaruh Lingkungan Pengamatan pada Ketelitian Horisontal GNSS dengan Metode RTK-NTRIP. Jurnal Nasional Pengelolaan Energi MigasZoom, 2(1), 27–35. https://doi.org/10.37525/mz/2020-1/249

Rauzan, M., & Yulianti, F. (2022). Pemanfaatan Drone untuk Identifikasi Penggunaan Lahan di Dayah Raudhatul Quran Tungkop Kecamatan Darussalam Kabupaten Aceh Besar. Jurnal Pendidikan Geosfer, 7(1), 105–113. https://doi.org/10.37598/abdimu.v3i2.1828

Rizkia, M. R., Murdapa, F., & Fadly, R. (2022). Efektivitas Dan Perbandingan Pengukuran Bidang Tanah Menggunakan Metode Rtk-Ntrip Dengan Metode Rtk-Radio. Datum: Journal of Geodesy and Geomatics, 2(01), 59–68. https://doi.org/10.23960/datum.v2i01.2659

Stefano, A. (2020). Pemanfaatan Drone dalam Pemetaan Kontur Tanah. Buletin Loupe, 16(02), 32–41. https://doi.org/10.51967/buletinloupe.v16i02.76

Sugandhi, N., Rakuasa, H., Zainudin, Z., Wahab, W. A., Kamiludin, K., Jaelani, A., Ramdhani, R., & Rinaldi, M. (2023). Pemanfaatan Unmanned Aerial Vehicle (UAV) Untuk Pemetaan Pengunaan Lahan di Sekitar Waduk Pondok Ranggon, Provinsi DKI Jakarta. ULIL ALBAB : Jurnal Ilmiah Multidisiplin, 2(7), 3109–3118. https://doi.org/10.56799/jim.v2i7.1741

Warsito, T. H. (2021). Perkembangan Drone Untuk Pemetaan Dan Pemanfaatannya Dalam Bidang Infrastruktur Permukiman. Jurnal Informatika Dan Teknik Elektro Terapan, 9(2), 51–55. https://doi.org/10.23960/jitet.v9i2.2426

Widodo, S., Farida, A., Maysyurah, A., & Widianto, A. (2023). Pemanfaatan Teknologi Drone Dalam Pemetaan Digital (Fotogrametri) Menggunakan Kerangka Ground Control Point (GCP) di Daerah Irigasi Waibu Distrik Salawati Tengah. Musamus Journal of Civil Engineering, 5(02), 36–43. https://doi.org/10.35724/mjce.v5i02.5078

Zeybek, M., Taşkaya, S., Elkhrachy, I., & Tarolli, P. (2023). Improving the Spatial Accuracy of UAV Platforms Using Direct Georeferencing Methods: An Application for Steep Slopes. Remote Sensing, 15(10), 1–22. https://doi.org/10.3390/rs15102700