Sustainable Rural Development Plan through UAV Drone Technology

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Received: 07 November 2025 | Revised: 28 November | Accepted: 02 December 2025

Abstract

The rapid advancement in UAV drone technology has paved the way for their widespread application in urban and rural environments. The field of urban /rural planning is one of the many areas in city life where "Unmanned Aerial Vehicles" (UAVs) and drones could find use. Compared to traditional surveying selections, drones may provide planners a more accurate, precise, flexible, and economical means of obtaining information. To maximize the public benefit from the use of 'UAV drone technology' in town planning, town planners and surveyors require flexible, practical drone regulations that address the several concerns adjacent the use of UAVs in urban spaces. The present study uses and applies 'Remote Sensing Technologies' and 'Unmanned Aerial Vehicles' for rural development in Papua New Guinea, with a focus on the Nomad District Planning in the Western Province of Papua New Guinea. The work aims to inspect the potential of remote sensing & UAVs in addressing the challenges faced by rural societies in terms of natural resource management, land-use planning, and infrastructure development. The study commences by providing an outline of the current state of rural development in Papua New Guinea and importance the specific issues faced by the Nomad District.

Keywords: *Papua New Guinea, Remote sensing, Rural development, Sustainable development, Unmanned aerial vehicles.*

1. Introduction

Papua New Guinea (PNG) is a nation with diverse landscapes, cultural richness, and unique challenges in rural development. The Nomad District, located in the Western Province, exemplifies these complexities. In recent years, the integration of Unmanned Aerial Vehicles (UAVs) and remote sensing technologies has gained prominence as a powerful tool for sustainable development in rural areas (A. Ren et al., 2025; Nax. F. et al., 2022; Pal o. K. et. al., 2024; G. Graja and T. Abdellatif, 2024; Mohsan, S.A.H. et al. 2024. These technologies have the potential to provide valuable insights into land use, land cover, and natural resource management, which are crucial for informed decision-making in rural development planning (Li et al., 2010). In the PNG's rugged terrain UAVs are game-changers for rural development. In current years, there has been a growing recognition of the potential of 'Unmanned Aerial Vehicles' and 'remote sensing technologies' in addressing the challenges faced by rural communities in terms of land-use planning, infrastructure development, and natural resource management (Sekac et. al, 2021; Varo et. al, 2019). These technologies offer opportunities for high-resolution data acquisition, flexibility, and relatively low cost, making them invaluable tools for rural development initiatives (Kieu & Law, 2021; Phang, S. K. et al, 2023; Saini, A. & Goundaliya, P, 2025; Zhang, Z & Zhu, Z, 2024). They have the potential to overcome the limitations of traditional data collection methods in remote and difficult-to-access regions. By utilizing UAVs and remote sensing technologies, the Nomad District in Western Province, Papua New Guinea can overcome these challenges and enable sustainable rural development. The study aims to investigate the application of UAVs and remote sensing technologies as tools for rural development while assessing the potential benefits and challenges of utilizing UAVs and remote sensing technologies in rural development planning, with a specific focus on the Nomad District of Western Province, Papua New Guinea. The researcher follows (i) To assess the current state of rural development in the Nomad District of Western Province, Papua New Guinea (ii) To examine the potential of UAVs and remote sensing technologies in addressing the challenges faced by the Nomad District in rural development (iii) To explore the use of UAVs and remote sensing technologies in collecting spatial data for rural and urban planning in the Nomad District (iv) To analyze the benefits and limitations of utilizing UAVs and remote sensing technologies in rural development planning in the Nomad District objectives. To provide recommendations and guidelines for the efficient and effective integration of UAVs and remote sensing technologies into rural development initiatives in the Nomad District of Western Province.

The study focuses on leveraging UAV technology to enhance rural development in the Nomad District. It encompasses the collection of high-resolution aerial imagery and the generation of detailed Digital Elevation Models (DEMs) and Digital Surface Models (DSMs). The research aims to use these datasets for zoning, infrastructure planning, environmental management, and community development projects. By integrating UAV-derived data with traditional survey methods, the study seeks to improve the accuracy and efficiency of rural development plans, ensuring sustainable and well-informed decision-making processes. Despite its potential, the study faces several limitations. UAV operations are subject to regulatory constraints, including flight restrictions and licensing requirements set by the Civil Aviation Safety Authority of Papua New Guinea (CASA PNG). Adverse weather conditions, such as heavy rain or strong winds, can also impact the quality and consistency of the aerial data. Additionally, the initial cost of UAV equipment and training for operators may be a barrier for widespread adoption. Data processing and analysis require specialized software and expertise, which might not be readily available in rural areas. Lastly, integrating UAV data with traditional survey methods necessitates careful calibration and validation to ensure accuracy, which can be time-consuming.

The study's importance lies in its ability to revolutionize rural development planning through the use of UAV technology. By collecting high-resolution aerial imagery and generating precise Digital Elevation Models (DEMs) and Digital Surface Models (DSMs), the study provides detailed and accurate data essential for informed decision-making. This technology enhances the accuracy of zoning, infrastructure planning, and environmental management, ensuring that development projects are well-aligned with the natural terrain and environmental considerations. The improved accuracy and efficiency offered by UAVs can lead to more sustainable and cost-effective development initiatives, ultimately benefiting the Nomad District's growth and resilience.

Papua New Guinea is a country with significant socio-economic challenges, particularly in rural areas (Poi et al., 2018). Rural communities in the Nomad District face limited access to basic services such as healthcare, education, and infrastructure. This hinders their overall development and contributes to high levels of poverty and inequality. PNG faces socio-economic challenges despite its natural resources. As of 2001, the per capita income was significantly lower than the world average and that of neighboring Southeast Asian countries (Auty, 1991). These economic disparities underscore the need for innovative approaches to rural development (Varo et al., 2019).

UAVs and remote sensing technologies have great potential to contribute to rural development in the Nomad District of Western Province, Papua New Guinea (Li et al., 2010,Antonio Minervino A. et al,2022). These technologies can provide valuable insights into land use, infrastructure, and natural resources, enabling informed decision-making and targeted interventions (Raj, Meghna et al., 2024; Preetilatha, T. et at., 2019; Sekac et al., 2016; Mandla, V. R et al, 2023; Xia, G. S et al, 2028; Zulkipi, M.A. et al, 2028; Sekac et al., 2017).

2. Methodology

2.1 Study Area

The study area for this research is the Nomad District of Western Province in Papua New Guinea (Figure 1). This district is a predominantly rural area with limited access to resources and services, making it an ideal case study for exploring the application of UAVs and remote sensing technologies in rural development. The Nomad District is characterized by diverse geographical features, including forests, rivers, and agricultural lands. It is also home to several rural communities that heavily rely on agriculture and natural resources for their livelihoods.

Nomad District, located in the Western Province of Papua New Guinea, experiences a tropical climate with high temperatures and humidity throughout the year. The region has a distinct wet season from December to June and a dry season from July to November. During the wet season, the area receives heavy rainfall, while the dry season is characterized by lower precipitation and higher temperatures.

2.2 Methodological Flow Chart

The workflow diagram (Figure 2) for this study outlines the systematic process followed, starting with data collection using UAVs to capture high-resolution aerial imagery of the Nomad District. Next, the data processing phase involves using software like Agisoft to create Digital Elevation Models (DEMs) and Digital Surface Models (DSMs), incorporating Ground Control Points (GCPs) for accuracy. Following this, data analysis is conducted to assess topographical features, inform zoning, and plan infrastructure. Finally, the integration and reporting phase consolidates the analyzed data into a comprehensive master plan for rural development, which includes visualization, stakeholder engagement, and adherence to regulatory requirements (Stephen John et al, 2022; Veal R. et al, 2019; Huany, M. et al,2022). This structured approach ensures thorough and accurate planning, leveraging modern technology to enhance traditional survey methods.

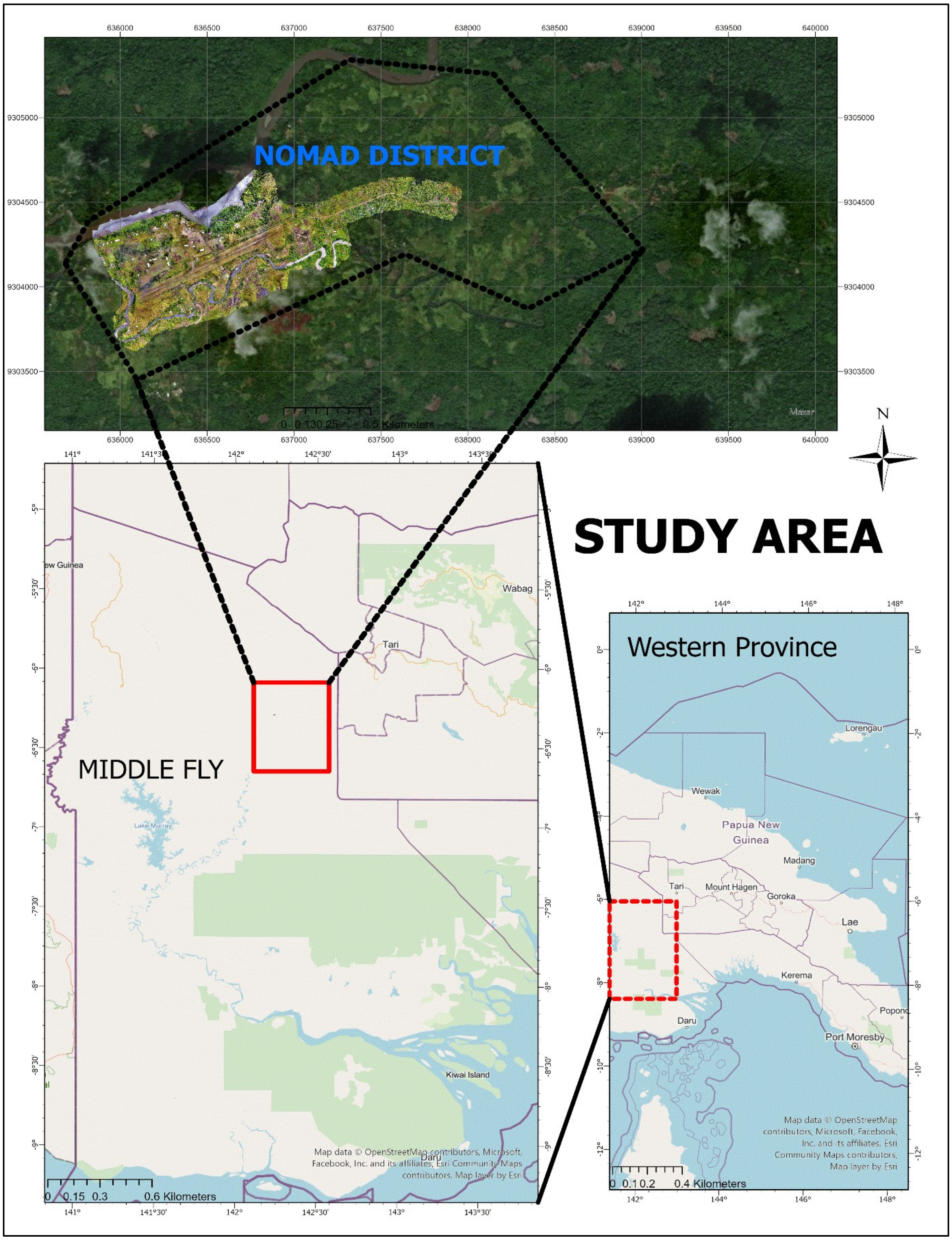


Fig. 1 Location map of the study area

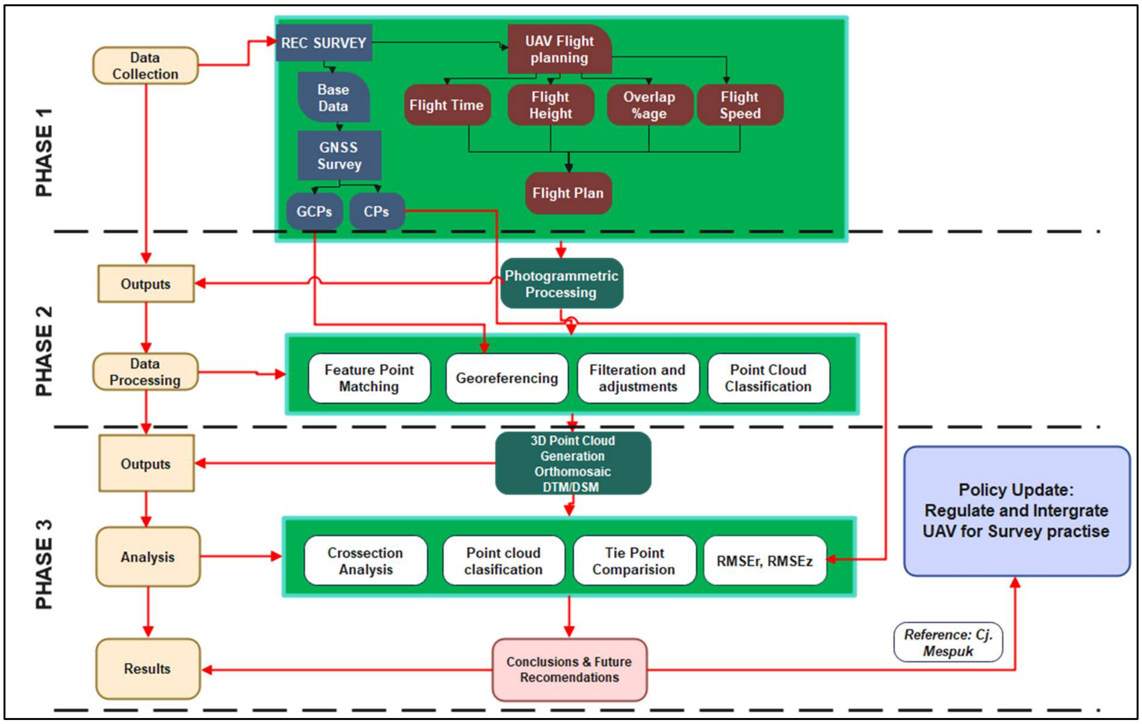


Fig. 1 Methodological flow chart

2.3 Deployment of UAV Aerial Surveys

After the establishment of control points, we commenced the UAV aerial surveys over the Nomad District study area. The UAV was programmed to fly a series of pre-planned autonomous missions at a flying height of 90 m above ground level, capturing overlapping aerial imagery at a ground sampling distance of 2.5 cm (Yuwono et al., 2018).

The project focused heavily on the UAV survey: carefully planning the flight missions, establishing GCPs, deploying the UAV, and post-processing the captured UAV images. We planned the flights for each type of survey at the same heights based on the area to capture and the time required to pre-plan the flights for all sites and autonomously deploy the UAV from takeoff to landing.

The qualitative and quantitative accuracy assessments of the UAV data products like Orthomosaic, DEM, and 3D point clouds were conducted using the established ground control points. After the UAV aerial surveys, we processed the images using Agisoft Metashape to generate the ortho-photos, DEM, and 3D point clouds.

2.4 UAV Flight Mission Planning

We meticulously scheduled all flights to obtain aerial photographs, autonomously deployed the UAV in accordance with its flight plan and returned after the mission's completion (Fig 3). The UAV operator utilized live Google Earth for flight mission planning. All photos were captured with a lateral overlap of 70% and a forward overlap of 70%, in line with the recommended 70% overlap for enhanced accuracy (Aggarwal et al., 2020; Luo et al., 2024; Zang et al., 2021). We upheld a standard velocity of 7.1 m/s across all locations. To attain superior accuracy in surveying, it is essential to operate the UAV at the lowest and safest altitude feasible, with a ground sampling distance (GSD) between 1.5 cm and 2.5 cm (Park et al., 2020). As a result, we conducted all flights at an altitude that would not yield a ground sample distance exceeding 2.50 cm/px. Agi soft Meta shape software post-processed all UAV-acquired photos, generating ortho-images, DSM/DTMs, digital elevation models, point clouds, and additional features.

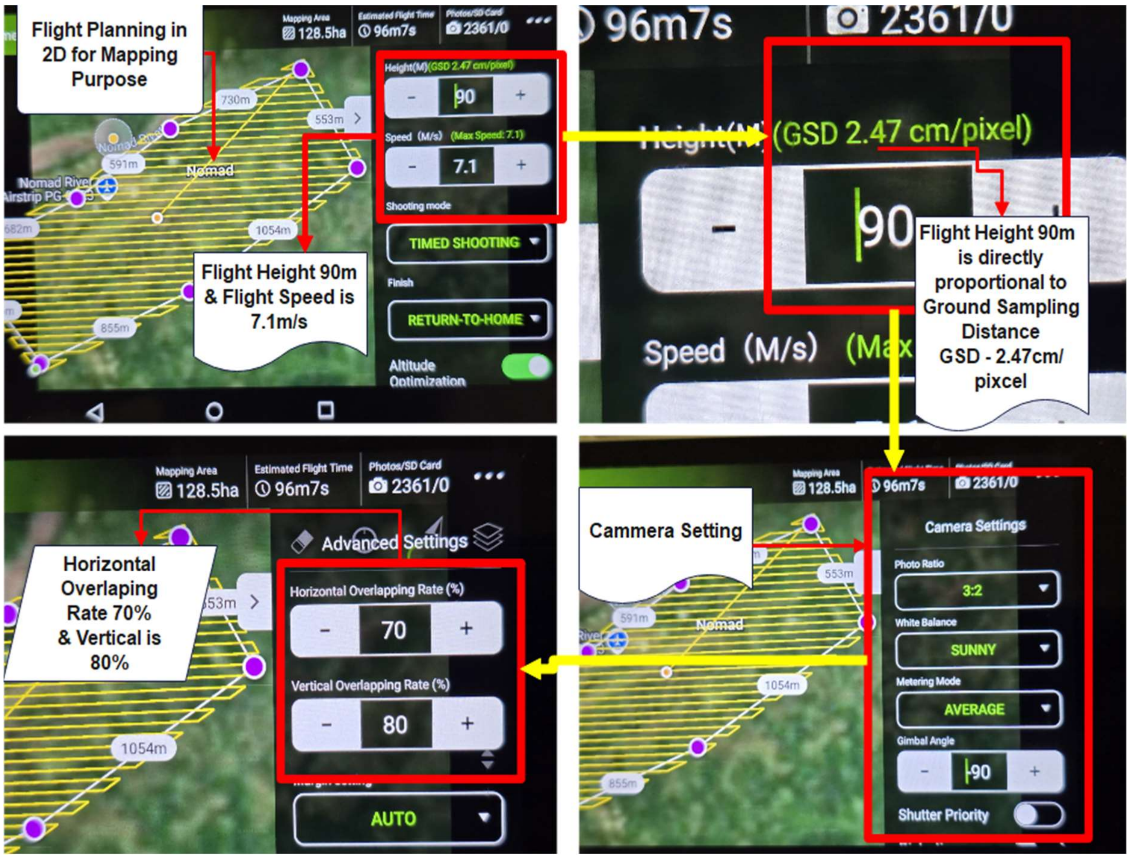


Fig. 3 UAV Flight Path

We utilized an HP desktop equipped with an i7 CPU and 16GB of RAM for processing, which demonstrated considerable speed and reduced the probability of system freezes, a frequent problem associated with processors inferior to i7 performance. The data sets generated by Agisoft were subsequently imported and processed with software such as Magnet Office or Civil CAD 3D to extract strings/lines and points for boundary pegs, as well as to create contours required for additional earthworks.

3. Results and Discussion

Utilizing the data collected through the UAV surveys and further processing using GIS software, this study aims to showcase the potential of these technologies in (a) generating high-resolution spatial data for infrastructure planning and development, (b) identifying and mapping land use/land cover patterns to support sustainable resource management, (c) enhancing decision-making processes for rural development through the provision of accurate and timely geospatial information, (d) evaluating the suitability and feasibility of UAVs and remote sensing as cost-effective and efficient tools for rural development planning in Nomad District, PNG.

3.1 Survey Control Points

Survey control points (Table 1) are the GCPs or ground control points, and CPs check points established using the Topcon Hyper SR GPS receivers. Provided below are the post-processed control points using Topcon Magnet Office Tools software.

Table 1. Post-processed survey control points from Topcon magnet office tools

Name	Grid Northing (m)	Grid Easting (m)	Elevation (m)	Std Dev n (m)	Std Dev e (m)	Std Dev u (m)	Std Dev Hz (m)	Geoid Separation (m)
GCP5	9303959.874	636401.299	90.837	0.001	0.001	0.002	0.001	76.186
GCP6	9303510.604	636224.524	93.305	0.001	0.001	0.003	0.002	76.172
GCP7	9304268.751	636004.85	88.153	0.003	0.004	0.009	0.005	76.182
GCP8	9304378.233	636293.257	90.612	0.002	0.003	0.005	0.003	76.192
GCP9	9304378.184	636657.809	91.09	0.001	0.002	0.002	0.002	76.201
GCP10	9304412.224	636961.453	94.086	0.001	0.001	0.002	0.001	76.21
GCP11	9304419.926	637248.703	98.679	0.001	0.002	0.004	0.002	76.217
AA430	9304228.14	636437.88	92.13	0	0	0	0	76.192
GCP12	9304540.525	637642.733	101.265	0.002	0.003	0.005	0.004	76.231
GCP13	9304505.751	637918.559	107.168	0.001	0.001	0.003	0.002	76.237
GCP14	9304454.253	638085.288	119.055					76.24
GCP15	9304529.761	638424.938	95.244					76.251
GCP16	9304392.938	638062.035	55.616					76.238
GCP17	9304281.128	637943.315	59.202					76.232
GCP1	9304185.047	636219.916	89.57	0.085	0.024	0.088	0.089	76.186
GCP2	9304032.926	636093.984	97.854					76.179
GCP3	9303885.59	636084.604	90.302	0.001	0.001	0.002	0.001	76.176
GCP4	9304114.227	636385.282	91.507	0.001	0.001	0.002	0.002	76.189

The above table illustrates the survey control points established on the ground using the Topcon Hyper SR GPS receivers. The base station was at PSM AA430. We fixed all vertical and horizontal positions using the base mark (PSM AA430). The ground control points indicated in red were not post-processed, as satellite observations were not accessible through the survey data collections. Nevertheless, we employed the satellite-observed survey control to geo-correct the remaining points that were captured, while excluding the points that were highlighted in red. The PNG 94 survey datum is employed to localize all vertical and horizontal survey controls. The figure 4 below shows the post processed GPS point occupations and observation results from the Topcon Magnet Office Tools software.

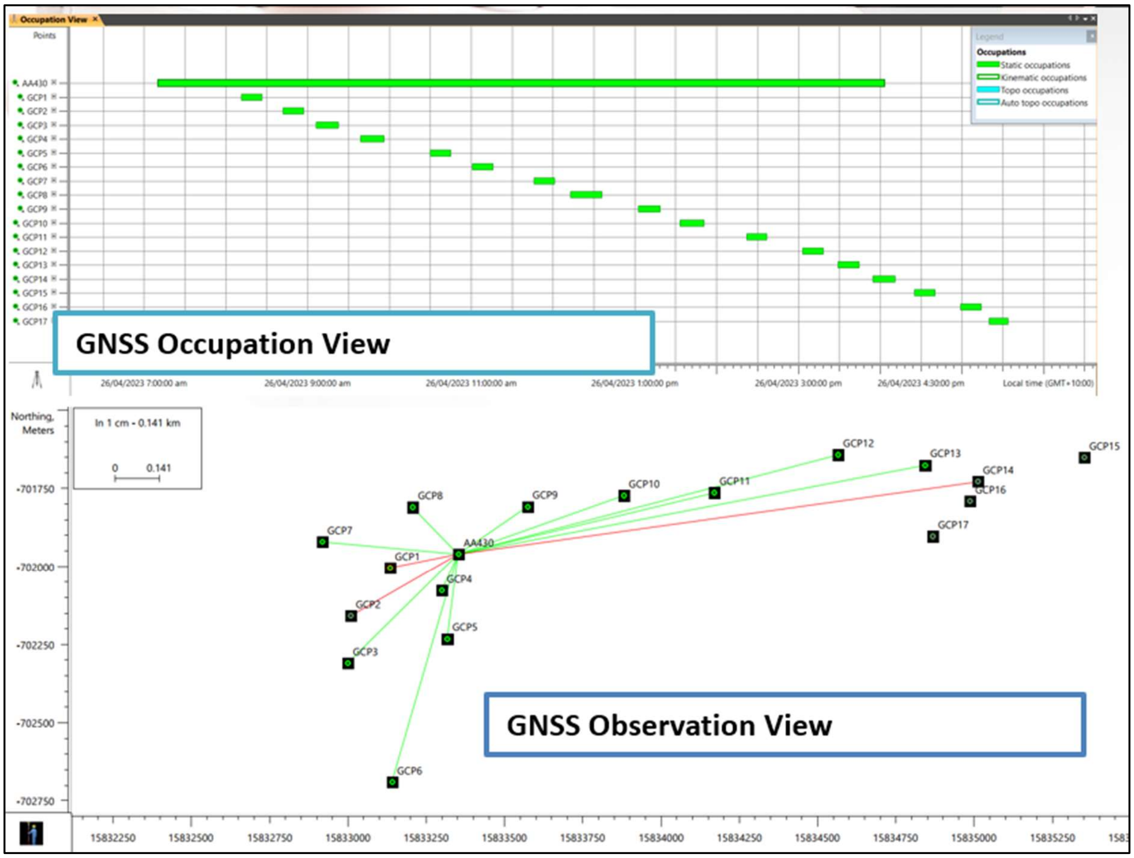


Fig. 4 Post-process report of the GPS point observation and station

The MAGNET Tools software suite was developed by Topcon to facilitate the processing, adjustment, and visualization of field-survey data obtained from GNSS equipment and total stations. Red and Green Lines: These lines typically denote distinct forms of data or measurements. For instance, red lines may suggest errors or areas that require transformation, while green lines may represent data points that have been correctly processed (Table 2). GNSS Data Results: We employ GNSS (Global Navigation Satellite System) data to identify precise locations on Earth. MAGNET Tools enables you to post process this data in order to enhance accuracy and rectify any errors. The table 2 below shows the root-squared mean error from the survey control result, which falls well within the survey's bounds.

Table 2. Individual points, including the precision results.

Point From	Point To	Start Time (26/04/23)	Duration	Precision (m)		dN (m)	dE (m)	dHt (m)	Method	Solution Type
				Horizontal	Vertical					
AA430	GCP5	10:29	0:15:41	0.001	0.002	-268.27	-36.58	-1.299	PP	Fixed
AA430	GCP6	11:00	0:15:38	0.002	0.003	-717.54	-213.4	1.155	PP	Fixed
AA430	GCP7	11:45	0:15:35	0.005	0.009	40.611	-433	-3.988	PP	Fixed
AA430	GCP8	12:13	0:23:12	0.003	0.005	150.093	-144.6	-1.519	PP	Fixed
AA430	GCP9	13:02	0:16:34	0.002	0.002	150.044	219.93	-1.031	PP	Fixed
AA430	GCP10	13:33	0:18:00	0.001	0.002	184.084	523.57	1.973	PP	Fixed

AA430	GCP11	14:21	0:15:15	0.002	0.004	191.786	810.82	6.574	PP	Fixed
AA430	GCP12	15:03	0:15:23	0.004	0.005	312.385	1204.9	9.173	PP	Fixed
AA430	GCP13	15:28	0:15:52	0.002	0.003	277.611	1480.7	15.082	PP	Fixed
AA430	GCP14	15:54	0:08:27						PP	Failed, No Satellites
AA430	GCP1	8:11	0:15:32	0.089	0.088	-43.093	-218	-2.567	PP	Fixed
AA430	GCP2	8:42	0:15:29						PP	Failed, No Satellites
AA430	GCP3	9:06	0:16:50	0.001	0.002	-342.55	-353.3	-1.844	PP	Fixed
AA430	GCP4	9:39	0:17:21	0.002	0.002	-113.91	-52.6	-0.627	PP	Fixed

The **Root Mean Squared Error (RMSE)** is a common metric used to evaluate the accuracy of a regression model. It measures the average magnitude of the errors between predicted and actual values1. Here's a breakdown of vertical and horizontal RMSE:

Vertical RMSE: This measures the vertical distance between the predicted values and the actual values. It's useful for assessing the accuracy of predictions in a vertical direction.

Horizontal RMSE: This measures the horizontal distance between the predicted values and the actual values. It's useful for assessing the accuracy of predictions in a horizontal direction.

The formula for RMSE is:

$$\text{RMSE} = \sqrt{\frac{\sum (P_i - O_i)^2}{n}} \quad (1)$$

Where: ***Pi*** *is the predicted value for the i-th observation,* ***Oi*** *is the observed value for the i-th observation,* ***n*** *is the number of observations*

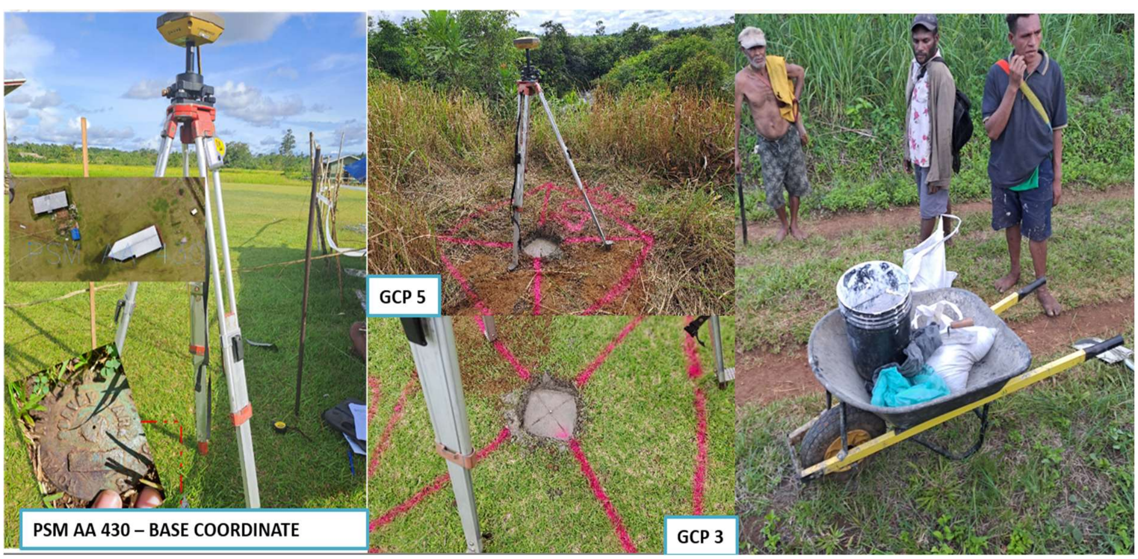
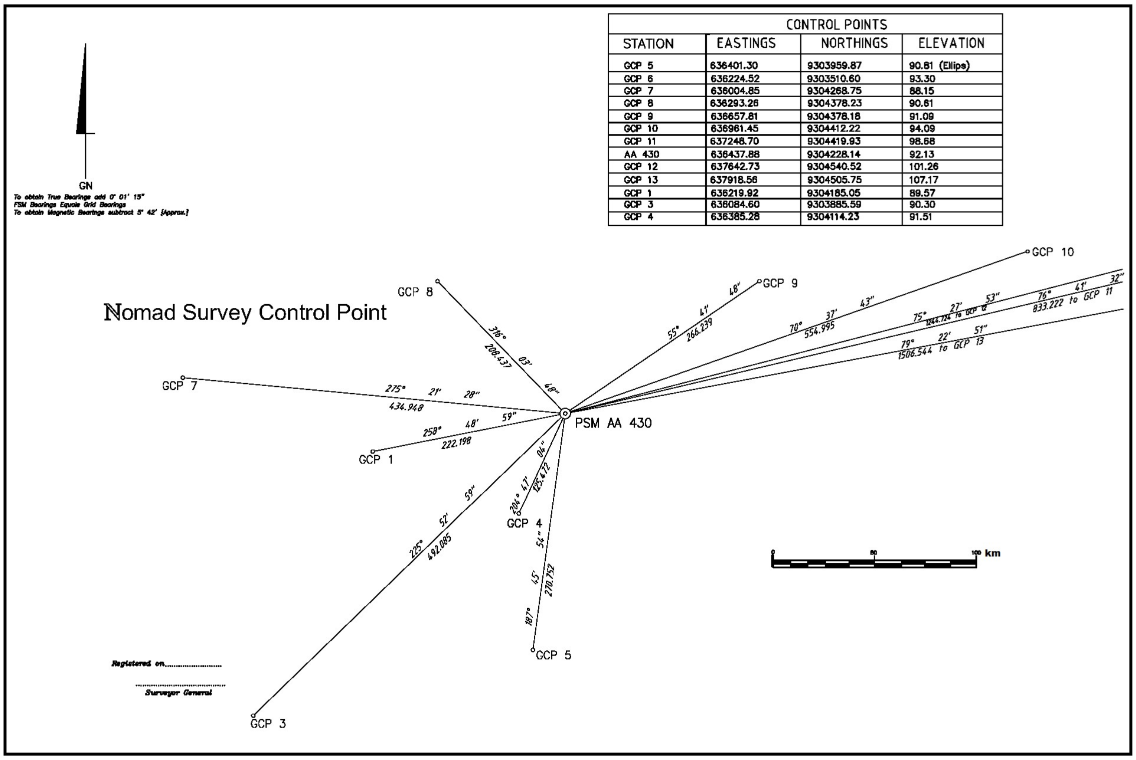


Fig. 5 Established new survey control points in the study area

The figure 5 above illustrates some of the ground control points established during the survey. The control points were named as GCP (ground control point) referenced from the base coordinate PSM AA 430. They are fixed reference points on the ground with known coordinates that help ensure the accuracy and precision of measurements taken by drones, total stations, or other surveying tools.

We carried out and plotted the final control survey in accordance with the survey directions, 1990 specifications, and criteria. Figure 6 below shows the results of the control survey that was carried out using static point positioning.



CONTROL POINTS			
STATION	EASTINGS	NORTHINGS	ELEVATION
GCP 5	636401.30	9303959.87	90.81 (Ellips)
GCP 6	636224.52	9303510.60	93.30
GCP 7	636004.85	9304268.75	88.15
GCP 8	636293.26	9304378.23	90.61
GCP 9	636657.81	9304378.18	91.09
GCP 10	636961.45	9304412.22	94.09
GCP 11	637248.70	9304419.93	98.68
AA 430	636437.88	9304228.14	92.13
GCP 12	637642.73	9304540.52	101.26
GCP 13	637918.56	9304505.75	107.17
GCP 1	636219.92	9304185.05	89.57
GCP 3	636084.60	9303885.59	90.30
GCP 4	636385.28	9304114.23	91.51

Fig. 6 Result of the survey control points plotted on Civil CAD (AUTO-CAD)

3.3 UAV/DRTK Survey

UAV surveys involve using drones equipped with sensors to capture aerial data. These sensors can include RGB cameras, multispectral cameras, or LIDAR payloads (Figure 7). The data collected is used to create geo-referenced maps, elevation models, 3D models, and more. UAV surveys are known for their efficiency, accuracy, and ability to access difficult terrains. The D-RTK 2 Mobile Station by DJI is a high-precision GNSS (Global Navigation Satellite System) receiver. It supports multiple satellite systems (GPS, BEIDOU, GLONASS, and Galileo) and provides survey-grade accuracy for various DJI enterprise drones. Land surveyors and civil engineers use the D-RTK 2 for precise positioning and data collection, making it a valuable tool. This study utilized the DJI Phantom 4 Pro quadcopter (D-RTK 2 Mobile Station) to gather comprehensive UAV survey data in the Nomad District. The drone captures the entire Nomad station, including proposed sites for development. We used the base control points as a reference and marked them to ensure the UAV output matched the ground truth. Due to power issues and battery shortages, we captured UAV data at different time intervals but still managed to capture the area of interest. The figure below displays the specifications and related information for the UAV. The camera model is FC6310R (8.8mmFL), flying altitude was at 90m, ground sampling distance was 2.07cm/pixel and the total area covered was 1.532 kilometer squared for both sites. We selected two sites for the UAV deployment: one at Nomad

Station and another at a proposed administrative site, where we used ground control points for UAV purposes and adjustments. This research will focus on the second site, especially for UAV procedures and discussions.

3.3.1 UAV Flight – Site A

The UAV survey at site A involves capturing an ortho-photo image of all nomad stations, including the established ground control points. Procedure for adjustments and georeferenced images will be elaborated on the UAV flight captured on the second site (Site B). We positioned all ground control points using PSM AA 430 as the base reference marks.

Together with the assistance of the locals, we set up the GCP boards, and we deployed the UAV drone to collect multiple images for Nomad Station. We used the GCP for site A, which adjusts and geo-corrects the survey control points based on GPS observations made on the survey controls.

Figure 8 below shows the georeferenced image captured for Nomad Station, which is referred to as site A. We made all necessary adjustments, but it wasn't necessary to focus on the UAV adjustment in detail, especially for site A.

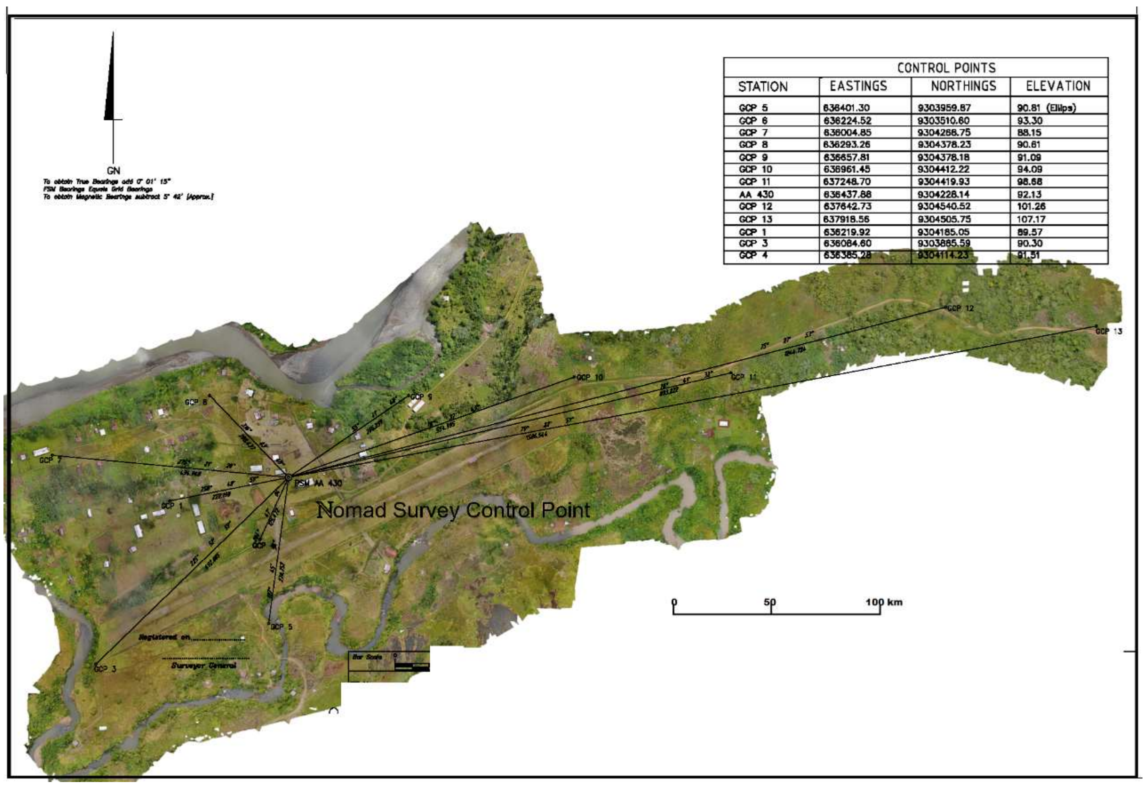


Fig. 8 UAV data collected overlaid on the Survey control points for site A: Check

The map overlays the DEM data and applies the color ramp to the elevation values for the Nomad station. The Figure 9 below is color-coded, where each color represents a specific elevation range.

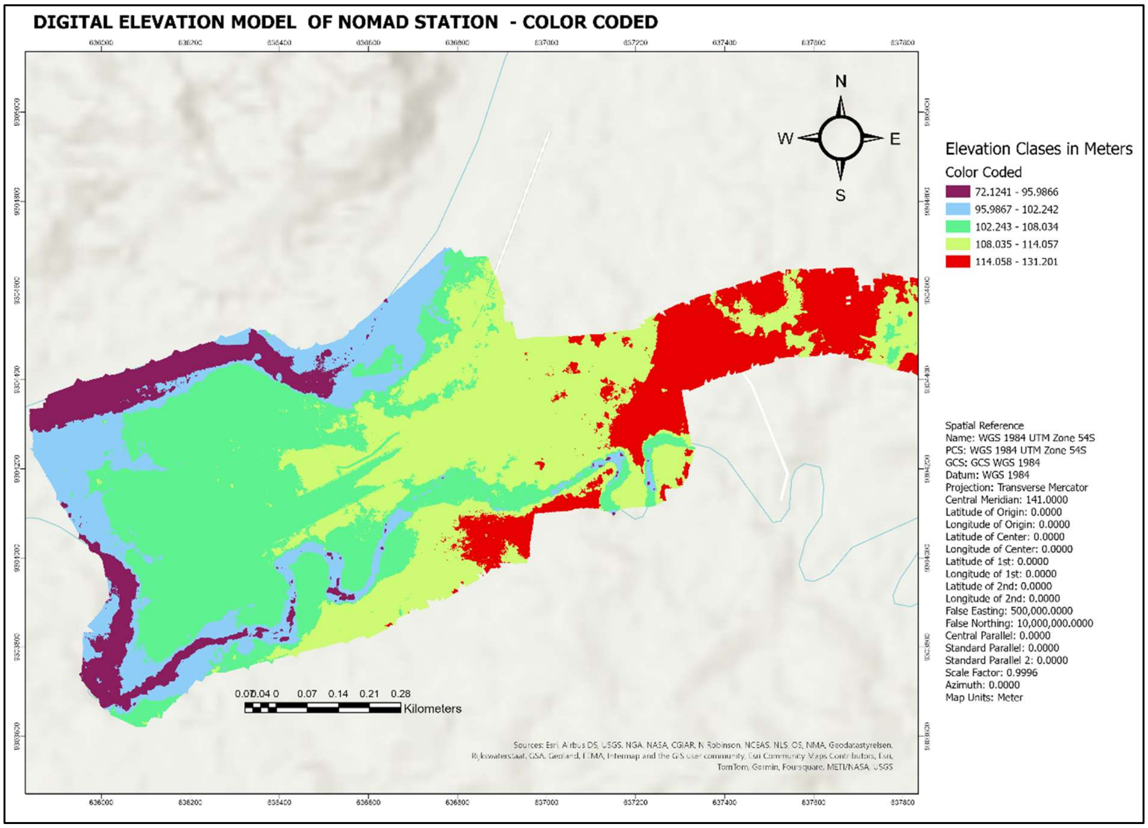


Fig. 9 Color coded digital elevation map for Nomad District Site A

We identified potential construction sites and selected specific locations for rural development using the created elevation model. We selected a couple of proposed sites for development: the residential site, the hospital site, and the police station headquarters. Using the UAV data for Site A, Figure 10 below shows the proposed subdivision of the residential site and airport extension.

Fig. 10 Proposed residential site that was allocated using the UAV image.

We used the analyzed terrain data to establish subdivision zones for the sites. By leveraging this data, we design more efficient and accurate site layouts, taking into account the natural features and topography. Figure 11 shows the proposed site for the hospital and police station.

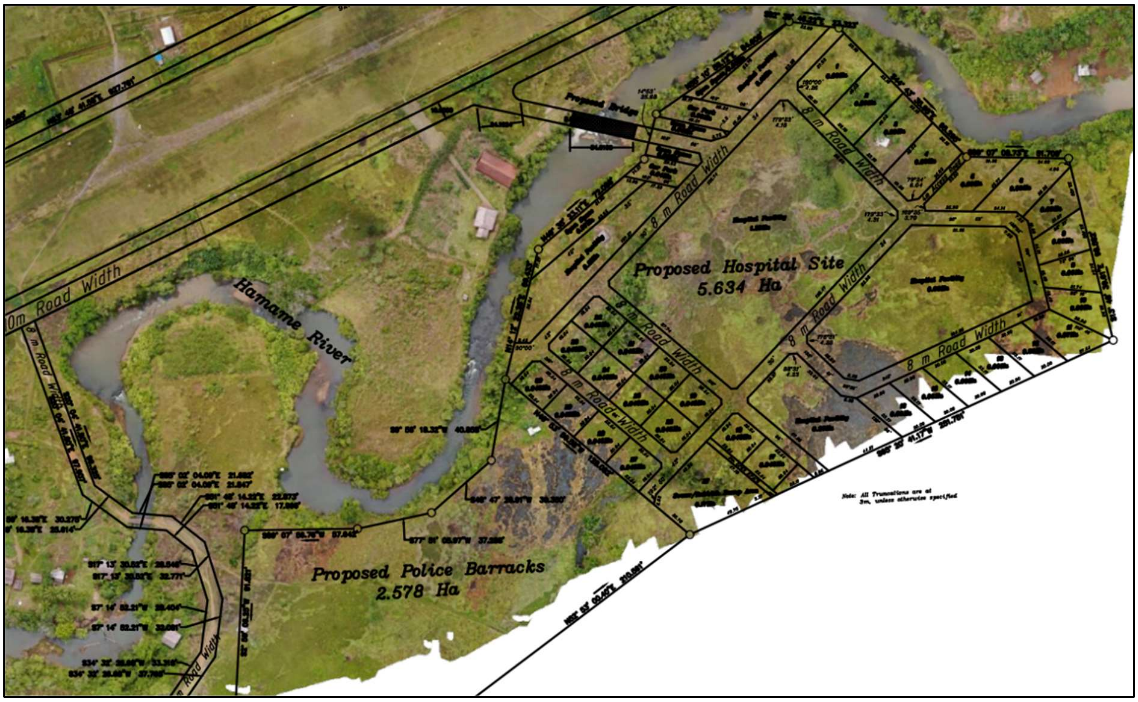


Fig. 11 Proposed Police Station and the hospital site for Nomad District

Following are the steps taken into consideration with the planning act to create subdivision zones using terrain analysis

- Data Collection: Gather high-resolution terrain data using UAV surveys, GNSS, or other methods.
- DEM Creation: Generate a Digital Elevation Model (DEM) to visualize the terrain in detail.
- Slope Analysis: Use the DEM to analyzed slopes, which can influence where roads, buildings, and utilities are best placed.
- Watershed Analysis: Identify drainage patterns to ensure proper water management and reduce the risk of flooding.
- Subdivision Layout: Design the subdivision layout by incorporating the terrain data, ensuring optimal land use and minimal environmental impact.
- Zoning: Assign different zones based on the terrain features, such as residential, commercial, and recreational areas.

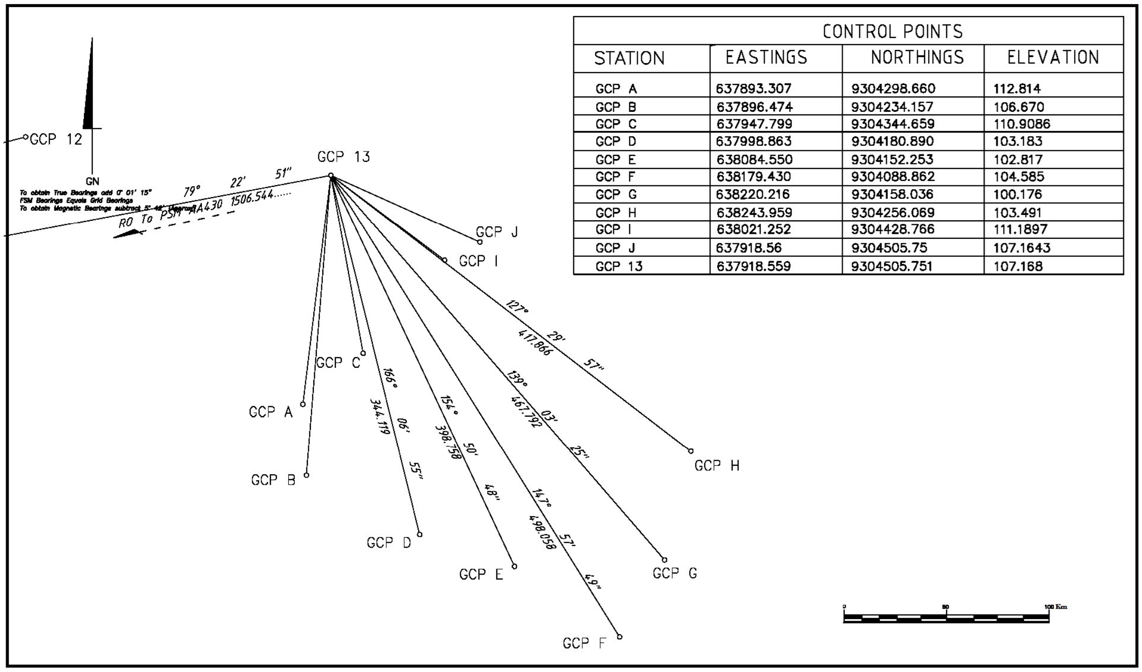
We developed the subdivision master plan for Nomad District using UAV survey data, which integrates high-resolution aerial imagery and terrain analysis to create an accurate and efficient layout. The UAVs captured detailed topographical data, enabling the creation of a Digital Elevation Model (DEM). This model highlights the area's slopes, elevation changes, and natural features, informing the placement of infrastructure such as roads, utilities, and drainage systems. By analysing this data, we designate specific zones for residential, commercial, recreational, and other uses, ensuring optimal land use while minimizing environmental impact. Additionally, the UAV data facilitated a 3D visualization of the subdivision, helping stakeholders and the community understand the proposed development. This visualization included detailed representations of the terrain, infrastructure, and subdivision zones, ensuring that all aspects of the plan were considered and aligned with regulatory requirements. The use of UAV survey data significantly improved the accuracy and efficiency of the planning process, resulting in a well-structured and sustainable master plan for the Nomad District. Following is a master plan generated from the result of the UAV data obtained during the survey (Figure 12).

Fig. 2 Master plan created from the deployment of the UAV on Site A

3.3.2 UAV Flight – Site B

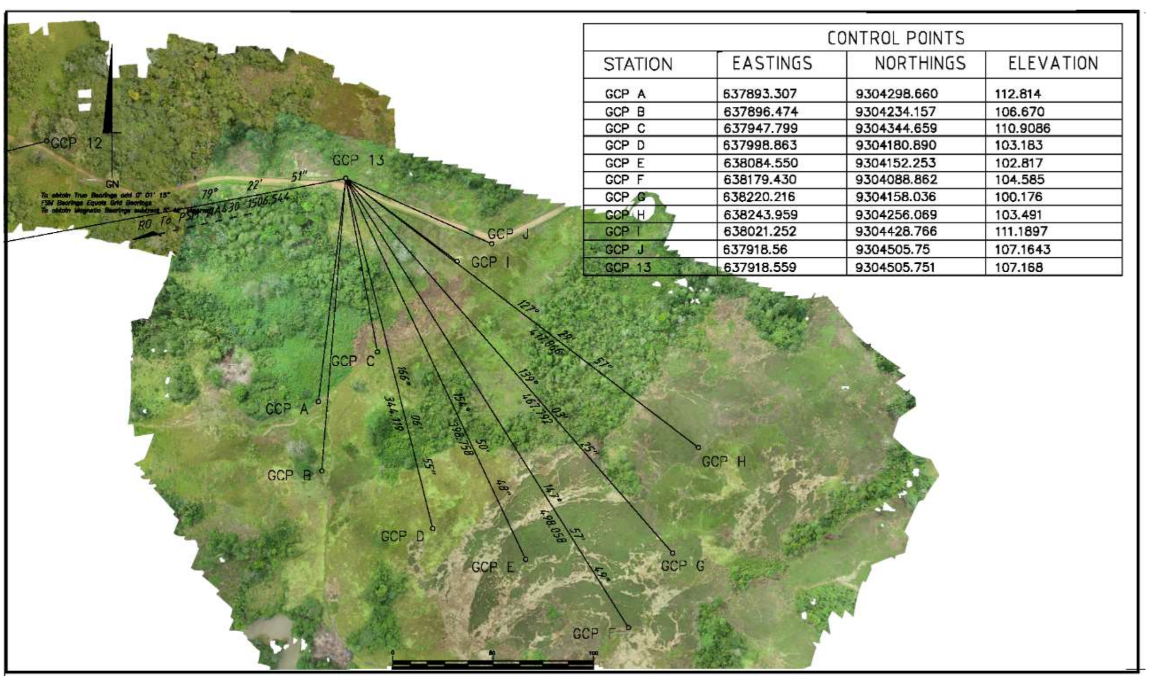
We executed the UAV plan for site B using the same approach as site A. We employed all necessary steps and procedures, following the methods previously explained. Ground control point 13 (GCP 13) served as the reference station for site B, and we conducted an RTK survey using the Topcon Hyper SR to determine the survey ground control point for the UAV. Figure 13 below shows the survey control points for site B.

The UAV survey results, after being post-processed with Agisoft Metashape using the established Ground Control Points (GCPs), provided highly accurate and detailed terrain models. The integration of GCPs allowed for precise georeferencing, significantly improving the spatial accuracy of the data. This process enabled the generation of a high-resolution Digital Elevation Model (DEM) and orthomosaics images, revealing intricate details of the surveyed area. These outputs facilitated a comprehensive analysis and visualization of the terrain, supporting informed decision-making for the subdivision planning and other land management activities in the Nomad District. Figure 14 shown below is the result after post processing.



CONTROL POINTS			
STATION	EASTINGS	NORTHINGS	ELEVATION
GCP A	637893.307	9304298.660	112.814
GCP B	637896.474	9304234.157	106.670
GCP C	637947.799	9304344.659	110.9086
GCP D	637998.863	9304180.890	103.183
GCP E	638084.550	9304152.253	102.817
GCP F	638179.430	9304088.862	104.585
GCP G	638220.216	9304158.036	100.176
GCP H	638243.959	9304256.069	103.491
GCP I	638021.252	9304428.766	111.1897
GCP J	637918.56	9304505.75	107.1643
GCP 13	637918.559	9304505.751	107.168

Fig. 3 The survey control point for site B was referenced from GCP 13.



CONTROL POINTS			
STATION	EASTINGS	NORTHINGS	ELEVATION
GCP A	637893.307	9304298.660	112.814
GCP B	637896.474	9304234.157	106.670
GCP C	637947.799	9304344.659	110.9086
GCP D	637998.863	9304180.890	103.183
GCP E	638084.550	9304152.253	102.817
GCP F	638179.430	9304088.862	104.585
GCP G	638220.216	9304158.036	100.176
GCP H	638243.959	9304256.069	103.491
GCP I	638021.252	9304428.766	111.1897
GCP J	637918.56	9304505.75	107.1643
GCP 13	637918.559	9304505.751	107.168

Fig. 4 Post-processed result for the UAV data together with the ground control points for Site B.

We established the GCPs for site B, deployed the UAV drone, as shown in the orthomosaic image above, and collected data for the proposed redevelopment and town planning site. The local authorities have agreed to permit rezoning and town planning at the aforementioned site (Site B). In accordance with the agreement, we deployed the UAV. We post processed the UAV data, as shown in the following figure15. This result aided us in conducting critical analyses for the planning of rural town zoning.

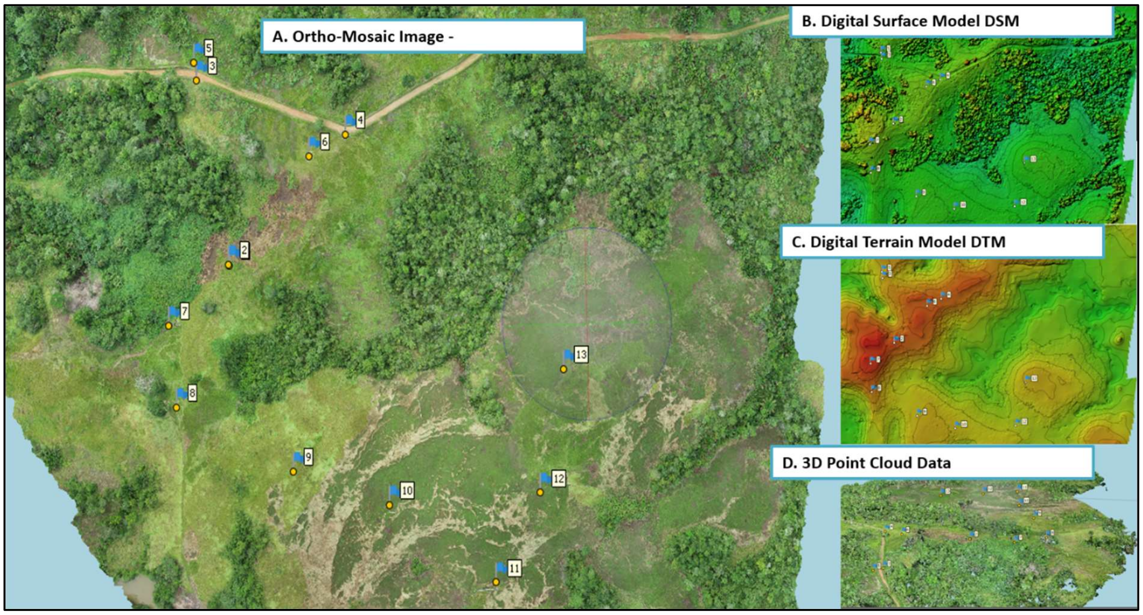


Fig. 5 Post-process the result of site B together with the results of the DTM, DSM, and point clouds.

The post-processed UAV data, enriched with high-resolution imagery and precise Digital Elevation Models (DEMs), proved invaluable for rural planning. By leveraging Ground Control Points (GCPs) for georeferencing, the data provided an accurate and detailed representation of the terrain. Planners could analyze topographical features, identify suitable locations for infrastructure development, and make informed decisions about land use. This detailed information facilitated the creation of sustainable and efficient rural development plans, ensuring that new projects harmonized with the natural landscape while addressing the needs of the community.

Moreover, the UAV data enabled us to assess environmental impacts and preserve natural resources. The high-resolution orthomosaic images helped in monitoring vegetation cover, water bodies, and land usage patterns. This comprehensive view allowed for more effective zoning, ensuring agricultural areas, residential zones, and community facilities were strategically placed to optimize land use and minimize disruption. As a result, the incorporation of UAV technology in rural planning enhanced the overall planning process, leading to more resilient and well-organized rural development projects.

Using UAV data, the zoning for Nomad was meticulously planned by analyzing high-resolution aerial imagery and Digital Elevation Models (DEMs). The precise data allowed planners to identify and map out zones for residential, commercial, agricultural, and recreational purposes. This approach ensured that each zone was optimally placed to utilize the natural terrain, improve infrastructure efficiency, and maintain environmental sustainability. By incorporating detailed topographical information, the zoning plan enhanced land use planning, resulting in a well-organized and functional layout that supports the community's growth and development. Figure 16 below shows the zoning that was done for site B after the UAV post processed results.

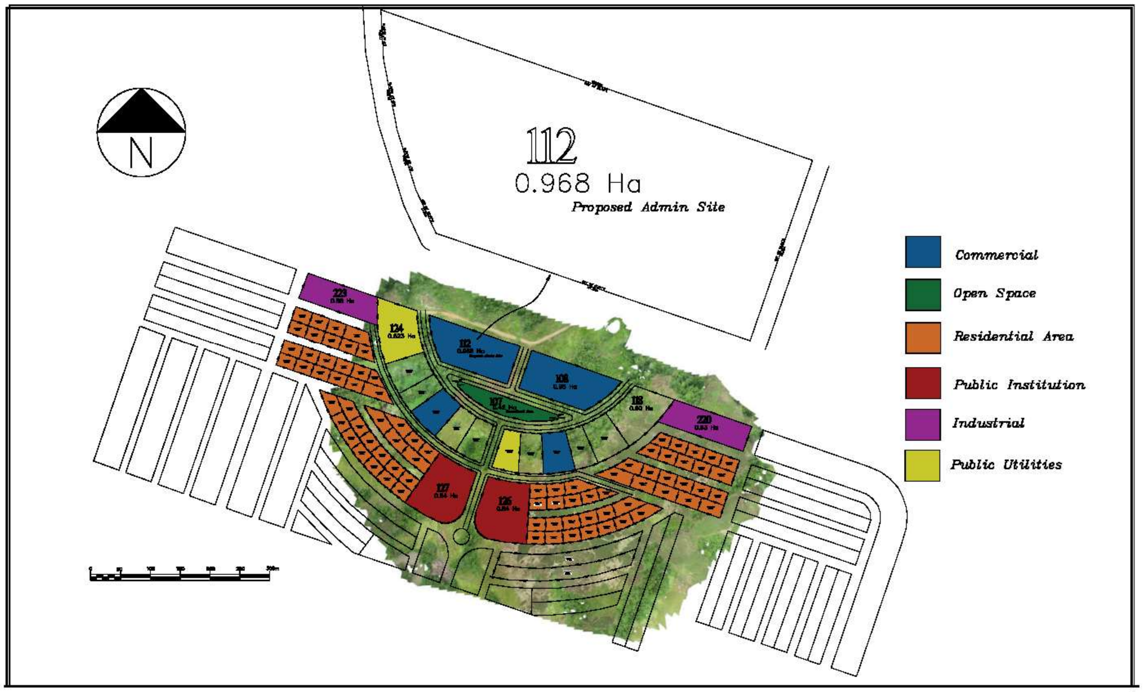


Fig. 16 Post-Processing Zone and subdivision on site B

The proposed subdivision allotment for the admin building site at Nomad Station was meticulously planned using UAV survey data. The data enabled precise identification of suitable locations and detailed mapping of the terrain. This information was crucial for optimizing land use, ensuring the proposed site was ideal for construction, and aligning with overall zoning plans for the area. Further details included infrastructure layouts, environmental assessments, and integration with existing facilities, providing a comprehensive plan to support future development and administrative needs at Nomad Station. The local authority proposed a master plan for the new site at Nomad, aiming to foster sustainable development and meet community needs. Leveraging UAV survey data, the plan detailed strategic zones for residential, commercial, and public infrastructure, including a new administrative building. This comprehensive approach ensured that each zone was optimized for its intended use, taking into account terrain and environmental factors. The master plan also integrated essential infrastructure, such as roads and utilities, ensuring a well-organized and functional layout that supports the growth and development of the Nomad community.

High-resolution UAV survey data was employed to meticulously design the zoning and subdivision for Nomad's rural development. This data facilitated the development of a detailed Digital Elevation Model (DEM) and the precise terrain analysis. In order to guarantee optimal land utilization and minimal environmental disruption, the resultant zoning plan strategically designated areas for residential, commercial, agricultural, and recreational use. Planners were able to optimize efficiency and sustainability by coordinating infrastructure development with the natural landscape through the integration of topographical data. Additionally, the subdivision layout included the establishment of Ground Control Points

(GCPs) to guarantee data integrity and precise georeferencing. This facilitated the development of a comprehensive master plan that included critical infrastructure such as roads, utilities, and drainage systems. The plan also encompassed specific allotments, such as the proposed site for the new administrative building at Nomad Station which is attached on the appendices, to guarantee that all community requirements were addressed. In general, the utilization of UAV technology considerably enhanced the planning process, resulting in a functional and well-organized layout that facilitates the Nomad community's long-term growth and development.

3.4 Policy and Requirement for UAV survey practise in PNG

In Papua New Guinea, UAV surveying is regulated by the Civil Aviation Safety Authority of Papua New Guinea (CASA PNG). For commercial operations, UAV operators must obtain a drone pilot license, demonstrating their adequate training and qualification. CASA PNG requires the registration of both commercial and hobbyist UAVs. To ensure safety and compliance with aviation standards, the regulations restrict UAVs from flying above 400 meter and from operating at night. Although it's not mandatory, we recommend remote identification for UAVs to improve tracking and safety.

Additionally, we encourage, but do not require, commercial UAV operators to have insurance to cover potential liabilities. Government drone operations also need to adhere to these regulations, including registration, but they are exempt from the remote ID and insurance recommendations. These regulations ensure safe, responsible, and effective use of UAV technology in surveying, mapping, and other applications, promoting public safety and protecting privacy while integrating UAVs into professional practices.

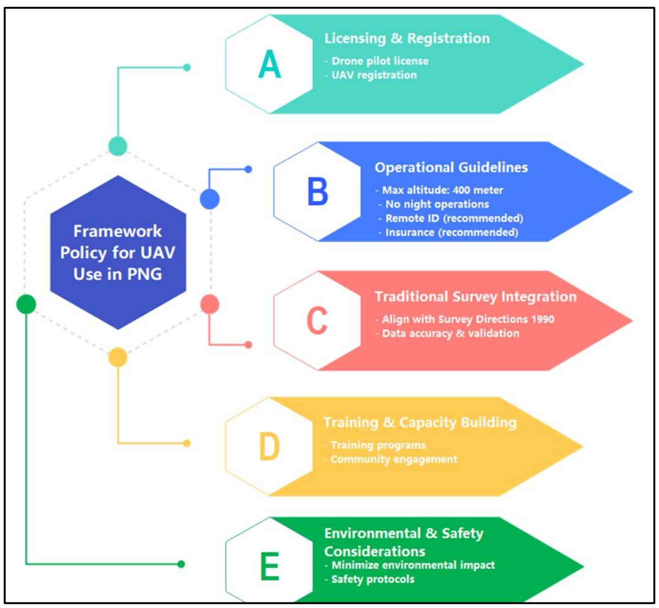


Fig. 17 Policy framework to control and regulate drone survey in PNG.

Figure 17 captures the essential elements of a robust policy framework for UAV use in surveying, aligned with the 1990 Survey Directions. It emphasizes regulatory compliance, operational guidelines, integration with traditional methods, training, capacity building, and environmental and safety considerations. The proposed policy framework for UAV (Survey

Drone) use in Papua New Guinea (PNG) is designed to integrate modern UAV technology with traditional surveying practices, as guided by the Survey Directions 1990. The framework includes several key components:

- **Licensing and Registration**: UAV operators must obtain a drone pilot license from CASA PNG for commercial operations, and all UAVs must be registered, ensuring proper documentation and accountability.
- **Operational Guidelines**: UAVs are restricted to flying below 400 meters and are prohibited from night operations to ensure safety. While remote identification is recommended for enhanced tracking, it is not mandatory. Insurance for UAV operations is also recommended but not compulsory.
- **Integration with Traditional Methods**: The framework emphasizes aligning UAV surveying with the guidelines established in the Survey Directions 1990, ensuring the consistency and accuracy of data. It also calls for careful calibration and validation of UAV data against traditional survey data.
- **Training and Capacity Building**: Implementing comprehensive training programs for UAV operators is essential to ensure proficiency in both UAV technology and traditional surveying methods. Community engagement is encouraged to build local capacity and sustainability.
- **Environmental and Safety Considerations**: UAV operations should minimize environmental impact, particularly in sensitive areas. Strict safety protocols must be established to protect operators and the public.

This policy framework aims to enhance the efficiency and accuracy of surveying practices in PNG, leveraging UAV technology while ensuring regulatory compliance, safety, and community involvement.

4. Conclusion and Recommendations

The application of unmanned aerial vehicles (UAVs) and remote sensing technologies presents a transformative opportunity for rural development in Papua New Guinea (PNG), particularly in the remote areas of PNG. The integration of these technologies facilitates efficient resource management, land use planning, and socio-economic development by providing accurate and timely data on land cover, population distribution, and environmental changes. For instance, the use of high-resolution remote sensing imagery enables the identification and mapping of rural residential areas, which is crucial for effective planning and management of rural resources. Furthermore, advanced algorithms and machine learning techniques enhance the capabilities of remote sensing in detecting land use changes and classifying scenes, thereby supporting sustainable development initiatives.

UAV and remote sensing technologies has demonstrated significant potential in supporting rural development planning in Nomad District, Papua New Guinea. The high-resolution spatial data obtained through UAV surveys has enabled the generation of detailed infrastructure plans, identification of land use and land cover patterns, and enhancement of the decision-making process for rural development initiatives.

We can make several recommendations to maximize the benefits of UAV and remote sensing technologies in the Nomad District:

- First, it is essential to invest in capacity building and training for local stakeholders to ensure they can effectively utilize these technologies for planning and development purposes. This includes developing educational programs that focus on remote sensing applications in agriculture, land management, and environmental monitoring.

- Second, fostering partnerships between government agencies, local communities, and academic institutions can facilitate the sharing of knowledge and resources, leading to more comprehensive and inclusive development strategies.
- Finally, continuous monitoring and evaluation of the implemented strategies using remote sensing data will be crucial for assessing their impact and making necessary adjustments to enhance effectiveness.

Environmental constraints, data quality issues, economic factors, and integration challenges limit the application of UAVs and remote sensing technologies for rural development in PNG. To fully realize the benefits of UAV applications, addressing these limitations requires a multifaceted approach that includes technology investment, training, and the establishment of collaborative frameworks.

The strategic application of UAV and remote sensing technologies in the Nomad District of PNG holds significant promise for advancing rural development. By leveraging these tools, stakeholders can make informed decisions that promote sustainable growth, improve living conditions, and enhance the overall resilience of rural communities in Papua New Guinea.

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