An Integration of Geomatics to Develop a DCDB for Peri-Urban Customary Land - A Case Study of Igam- Block Settlement, Lae

Resila Karipal[1*], Lewi Kari[2] and Camilla Yanabis Kwaudi[3]

School of Surveying and Land Studies, PNG University of Technology, Lae, Papua New Guinea

[1]resila.karipal@pnguot.ac.pg, [2]lewi.kari@pnguot.ac.pg, [3]camilla.kwaudi@pnguot.ac.pg

***Corresponding author**

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Abstract

This study integrates GNSS surveys, UAV technology, and GIS applications to develop a Digital Cadastral Database (DCDB) for customary-owned land in a peri-urban settlement. The research addresses persistent challenges, including overlapping boundaries and title duplication, which have hindered land development in Papua New Guinea. The DCDB aims to resolve these issues by enabling precise monitoring and management of cadastral information in a digital format. A combination of survey techniques was employed, and their accuracy and precision were evaluated against the linear error limitations outlined in the 1990 Urban Class Two Survey Direction. A key finding highlights a knowledge gap in leveraging DCDBs for customary land to attract investors and promote development. The study advocates for cost-effective methods, such as drone imagery and vector data from subdivision designs, as viable solutions for surveying customary land. Results indicated a high level of positional accuracy, with uncertainties at a ***90%-95%*** *confidence level conforming to Urban Class Two standards. The achieved accuracy ranged between* ***±0.001m*** *and* ***±0.02m*** *for all methods utilized. The study recommends adopting modern technologies for cadastral monitoring and storage, implementing cost-effective surveying techniques, expediting project timelines, and minimizing positional misalignment and distortion when creating digital databases using GIS software.*

Keywords: *Customary Land, DCDB, GIS, GNSS, Peri-Urban settlement, Survey Class Standards, UAV*

1. Introduction

Cadastral surveying is essential for the technical measurement and legal delineation of land parcels, ensuring compliance with established laws and standards. Advances in technology, such as the Global Navigation Satellite System (GNSS), have revolutionized traditional methods by providing highly accurate coordinates within minutes. This technology enables efficient ground positioning, offering significant improvements over conventional techniques when rigorously tested to meet standards like the 1990 Survey Direction.

A Digital Cadastral Database (DCDB) serves as a foundational spatial system for representing legal land attributes, including coordinates, boundary vectors, and relationships between parcels. This system relies on connecting cadastral data to geodetic datums, ensuring accuracy and traceability in compliance with national and international standards for positional and local uncertainty. Traditionally, DCDBs were created by digitizing scanned cadastral maps using GIS software, but modern techniques such as unmanned aerial surveying have enhanced this process. By combining GNSS and UAV technologies, spatial data can be localized to PNG94, improving accuracy and cost-effectiveness in database development.

In Papua New Guinea, the surveying industry has faced challenges transitioning to digital methods, with the DCDB remaining largely unchanged for over two decades. This stagnation has led to issues such as title duplication and overlapping surveys, complicating land administration. To address these issues, the adoption of modern surveying and GIS technologies is critical. According to McKibben and the PNG Surveyors Board (2022), the Office of the Surveyor General must rigorously validate these advancements to ensure their effective implementation.

This study is significant as it addresses these challenges by leveraging GNSS and GIS technologies to develop a DCDB for the Igam Block Settlement. The cadastre serves as a continuously updated spatial information system, enabling precise boundary definitions and supporting various societal functions. The study also aligns with the Papua New Guinea Development Strategic Plan 2010–2030, empowering landowners and the government with accurate land information to facilitate development and monitor urbanization progress.

The research is guided by four objectives: investigating land tenure and creating an ILG sketch map, demarcating cadastral boundaries with GNSS/GPS, applying aerial photogrammetry to visualize the settlement layout, and designing a DCDB for development purposes. These objectives aim to establish a reliable framework for land administration and development in Papua New Guinea.

2. Materials and Methodology

2.1 Digital Cadastral Framework for Customary Land

Spatial data essential for this endeavor were collected directly through field observations using precise technical survey measurements. To ensure the reliability and accuracy of the data, a rigorous quality assurance process was meticulously applied.

2.2 Customary Land Tenure

According to Papua New Guinea's Land Act of 1996, the land tenure system is categorized into two primary types: Alienated Land Tenure and Customary Land Tenure**.** Within the study area, the land falls under the Customary Land Tenure system, as defined by the Land Act.

Customary land, under the Land Act of 1996, refers to land owned or possessed by an automatic citizen or a community of automatic citizens. This ownership is based on proprietary or possessory rights that originate from and are governed by custom. This definition underscores the pivotal role of local customs and traditions in determining land ownership and possession rights, which are central to the land tenure system in the study area.

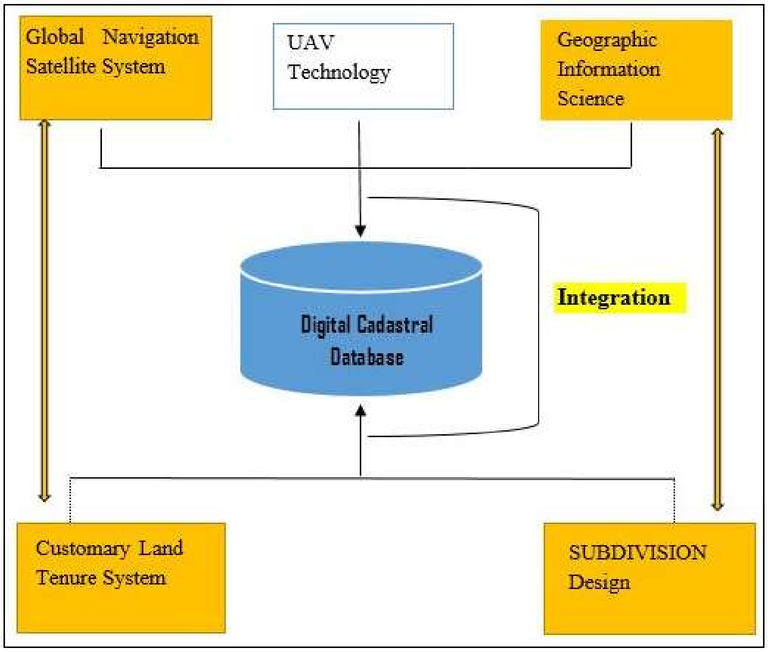

Fig. 1 Model to create DCDB in Customary Land

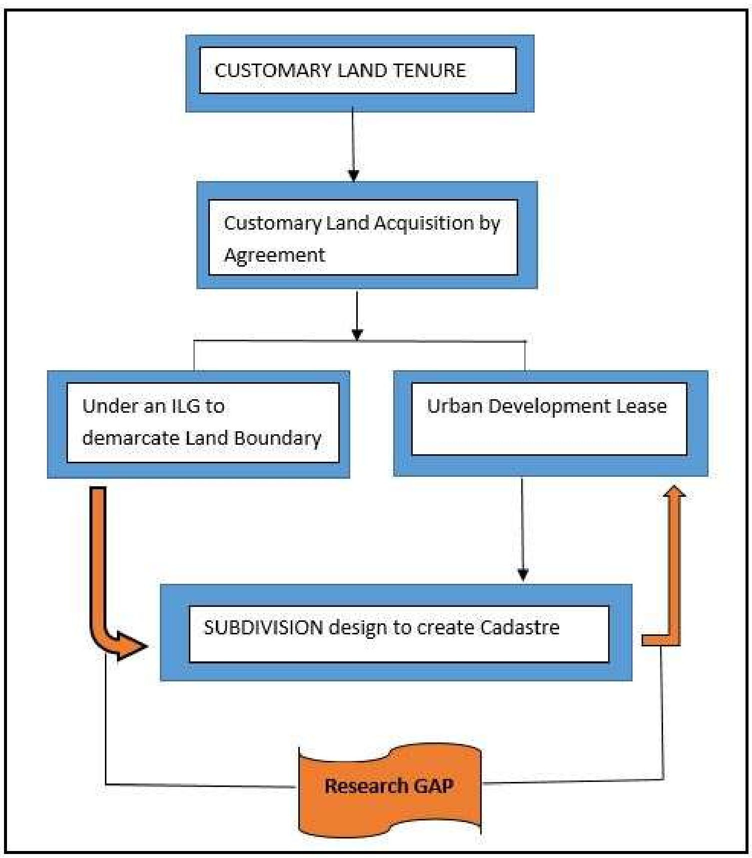

Fig. 2 Customary Land Acquisition by Agreement

2.3 Research Area

The Igam-Block Settlement is situated in the Lae North suburb of Lae District, along Independence Drive, directly across from the PNG University of Technology. The settlement's customary boundary extends from the existing cadastral boundary of East Taraka, reaching to the PNG Defence Force Barracks (Igam Barracks). Known locally as Sukoc Village, the land parcels subdivided for settlement are owned by various clan members, who act as landlords for portions of the land under the Asitua ILG.

The research focused on a portion of the Asitua ILG, specifically the Poa Bumang area in Sukoc Village. The land area for Portion 1043/1044 C Poa Bumang covers 4.762 hectares, with an average elevation ranging from 53 meters to 60 meters, and a variation of approximately ±0.9 meters.

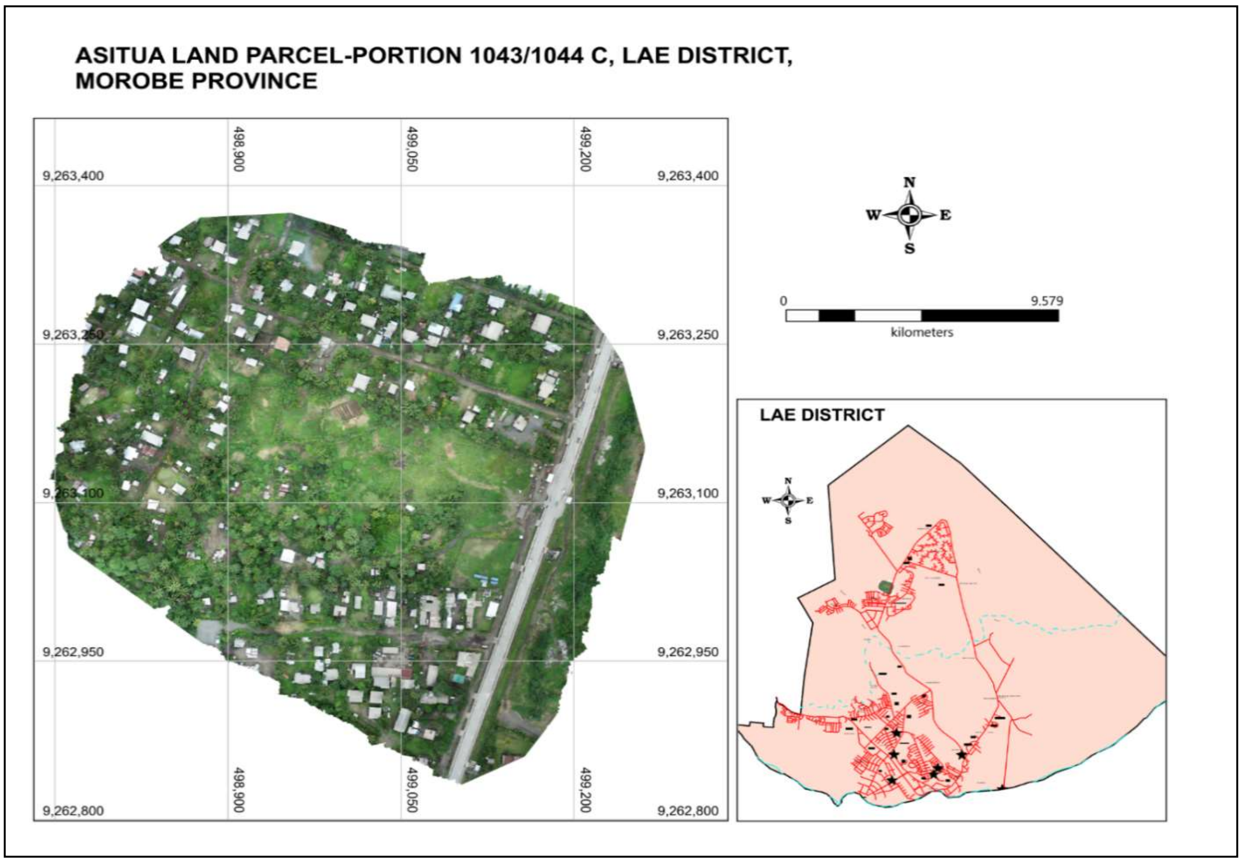

Fig. 3 Poa Bumang in Sukoc Village

2.4 Methodology Workflow

The research project adheres to the five-phase model established by the Project Management Institute (PMI). This project management approach was selected and implemented to ensure efficient management and successful delivery of the project objectives. By following these structured phases, the project aims to achieve its desired outcomes effectively and systematically.

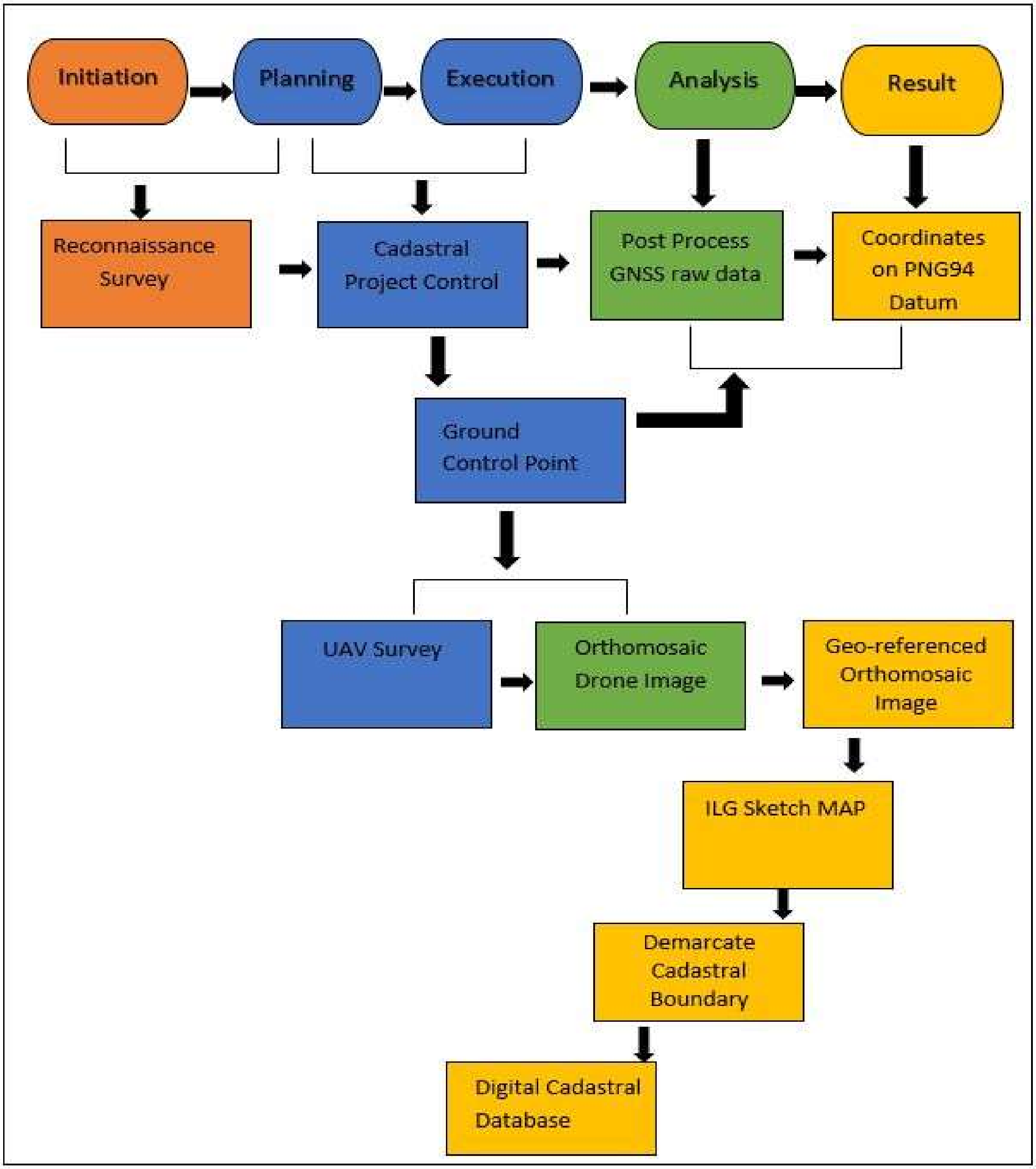

Fig. 4 Methodology workflow to develop DCDB

The 5-Phase Model was followed rigorously throughout the data collection process to effectively develop the Digital Cadastral Database (DCDB). Each phase was implemented to ensure the project objectives were achieved efficiently and systematically.

1. **Initiation:** In this initial phase, the study area was identified, and an open dialogue was initiated with the Customary Landowner to gather essential information. This step laid the foundation for the project, ensuring that all necessary details were obtained before proceeding with project planning and execution. After reviewing the gathered information, an agreement

was reached with the landowner, securing approval to move forward. A sketch map of the Incorporated Land Group (ILG) was also developed.

2. **Planning:** During this phase, a reconnaissance survey of the Area of Interest (AOI) was conducted. A survey network was pre-planned, identifying potential sites for establishing survey control marks. Additionally, the appropriate survey techniques for data acquisition, such as cadastral boundary data and Ground Control Points (GCPs), were determined to ensure accurate measurements.
3. **Execution:** In this phase, the team mobilized to the project site to begin data capture. Cadastral boundary data were surveyed using a comprehensive approach, starting with main Control GNSS observations and followed by Fast Static GNSS observations to establish GCPs. UAV surveys were then conducted in sequence based on the GNSS observations. After data collection, a quality check was performed on the raw data to ensure its integrity before moving to the next phase.
4. **Analysis:** This phase involved downloading and processing the raw data collected during the execution phase. The measurements stored in the survey instruments were retrieved and processed using CAD and GIS software for further analysis. Quality assurance checks were conducted to verify the data against the allowable precision and accuracy standards outlined in the Survey Direction of 1990. This phase served as a critical checkpoint, ensuring the accuracy of the data before proceeding to the final phase.
5. **Result:** In the final phase, further analysis and manipulation of the data were conducted to meet the project objectives. The design and development of maps and databases were finalized and presented, marking the successful completion of the project and the achievement of its goals.

2.5 Cost Estimates

A significant cost difference (Table 1) was observed between the conventional method and the integrated method using GNSS/GPS and RTK drone technology. The integrated method resulted in a considerable reduction in project expenses. Specifically, the conventional method incurred approximately 59% higher costs compared to the integrated approach. This demonstrates that the integrated method, utilizing GNSS/GPS and RTK drones, is more cost-effective and advantageous for Cadastral Survey applications.

2.6 DCDB Model

This was the final phase of the project, involving the development of the Digital Cadastral Database (DCDB) for Poa Bumang Portion 1. During this stage, the GIS application was fully implemented, encompassing data input, storage, analysis, and representation. The DCDB model was created as an overlay of the subdivision design and orthomosaic raster image, represented as the Title Cadastre Model (TCM), along with the Table of Cadastre Inventory.

Table 1: Costing for conventional method using Total Station vs. Integrated Method

Total Station

No	Instrument	Remarks	Hire Rates /day	Costings
1.	4 X GNSS Topcon Hyper SR receiver	-Main Survey Control for a day -GCP observation for a day.	K500/set	K2400
2.	1 X DJI Phantom 4 RTK Drone with GNSS Base Receiver without Memory Card	1 Day drone flight	K1000 + operator	K1000
	Accessories			
3.	4 X Aluminium tripod stand	2 tripod /set for 2 days	K20	K80
4.	4 X tape measure 3m	2 days for GNSS observation	K20	K160
5.	1 X high speed memory Card 128 GB	New Purchase	K120	K120
6.	1 X sledge hammer 3 X bush Knife 1 X spade 1 X cement bag 1 X 12mmX 1.2m deformed bar (per cut of 30cm X 6) 1X 50mmX 50mm X 1.5m timber (per cut for wooden peg 30cm X5)	New Purchase	K500	K500
Total Costings for Instrument + Accessories = **K4,260.00**				

No	Personnel	Remarks	Rate/hour for Short term project	Costing
	2 X graduate surveyor	8hours/day for 2 days	K177.84	K2,845.44
	1X Trainee Surveyor	8hours/day for 2 days	K138.32	K2,213.12
Total Costings for Personnel = **K5,058.56(As per ASPNG scale of fees)**				
Total Costings for Project = K9,318.56				

Integrated Method (GNSS & UAV)

No	Instrument	Remarks	Hire Rates /day	Costings
1.	1 X Total Station	-Main Survey Control for a day. - Identification Survey for a Day. - Detail Topographic Survey for 5 days	K300 X 7	K2100
	Accessories			
3.	3 X Aluminium tripod stand	7 days for field work	K20	K420
4.	3 X tape measure 3m	7 days for field work	K20	K420
5.	2 X single prism & pokko stick	7 days	K60	K840
6.	1 X sledge hammer 3 X bush Knife 1 X spade 1 X cement bag 1 X 12mmX 1.2m deformed bar (per cut of 30cm X 6) 1X 50mmX 50mm X 1.5m timber (per cut for wooden peg 30cm X5) 3X two-way radio	New Purchase	K500	K1300
Total Costings for Instrument + Accessories = **K5080.00**				

No	Personnel	Remarks	Rate/hour for Short term project	Costing
	2 X graduate surveyor	8hours/day for 7 days	K177.84	K9,959.04
	1X Trainee Surveyor	8hours/day for 7 days	K138.32	K7,745.92
Total Costings for Personnel = **K17,704.96 (As per ASPNG scale of fees)**				
Total Costings for Project = **K22,784.96**				

Fig. 5 Vector Data input

Fig. 6 Data Storage

Fig. 7 Data presentation

Fig. 8 Data Analysis

3. Results and Discussions

3.1 Cadastral Boundary

The cadastral boundaries of Portion 1043C and 1044C were fixed and projected to the PNG94 Datum using AutoCAD software for datum transformation. The cadastral boundaries were then aligned with the common reference system, PNG94, to enable further GIS analysis. Datum transformation was necessary to adjust and fix the existing cadastral boundary before developing the cadastral map for the portion. The original cadastral data was based on the Australian Geodetic Datum 1966 (AGD66), which needed to be converted to the National Datum of Papua New Guinea (PNG94) to reduce distortion and minimize positional uncertainties. The transformation was applied by shifting the data in Lae by approximately 121m east and 160.5m north (Stanaway, 2023). This shift was carried out using AutoCAD for the cadastral plot and was applied to the boundary. The transformation included a rotation of 37°00’45” over a distance of 201 meters. These identified shifts and transformations significantly reduced distortion errors to approximately 201 meters.

Therefore, prioritizing datum transformation to a common reference system, such as PNG94, is crucial in preventing issues like encroachments and overlapping surveys. This was a key challenge addressed in the project, and the measurement techniques used should be consistently applied to monitor and prevent such issues in future surveys.

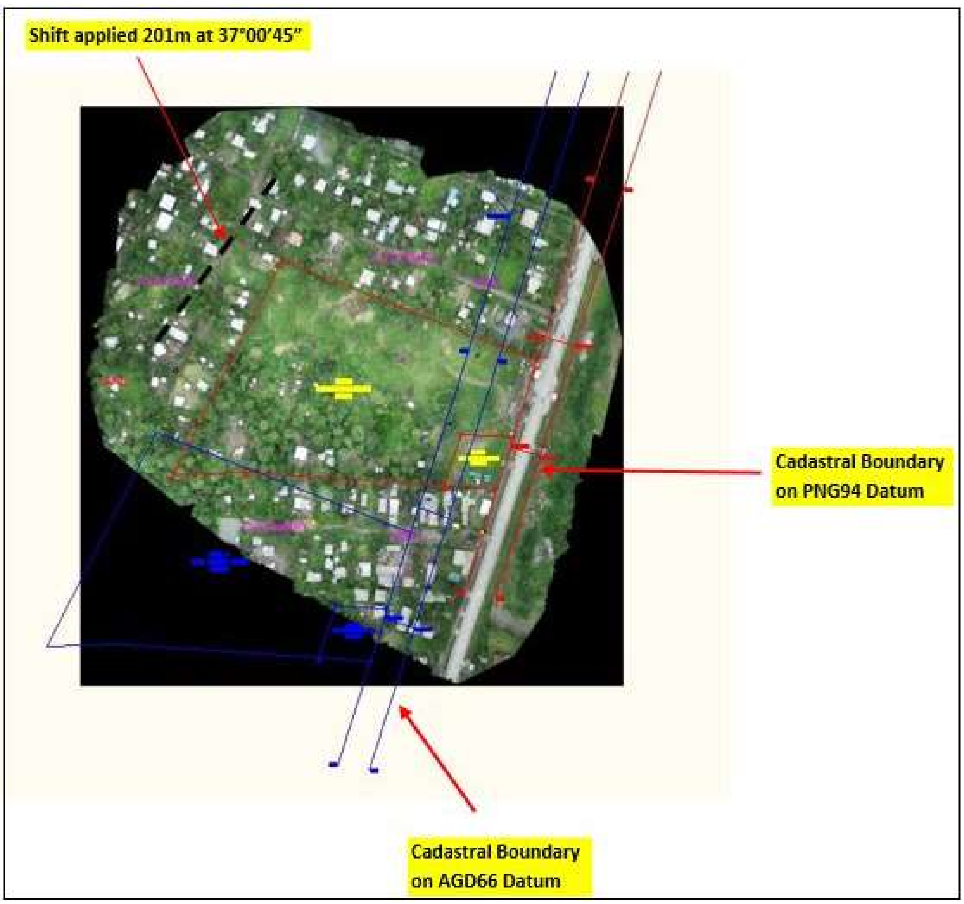

Fig. 9 AGD 66 transformations to PNG94 Datum

The integration of GNSS Survey, UAV technology, and GIS applications has successfully developed a Digital Cadastral Database. The datasets were analyzed and quality-checked to verify their accuracy and precision. The positional accuracy of the survey measurements was thoroughly examined and found to be within the allowable linear error of ±0.5m for Urban Class Two surveys. The GNSS Survey results (Figure 10) demonstrate the accuracy and certainty of position measurements, ensuring quality assurance. For both horizontal and vertical measurements, the RMS error ranged from ±0.001m to ±0.003m, providing a high-quality assurance level with 95% confidence. These measurements are acceptable compared to the allowable accuracy of ±0.5m.

In photogrammetry, the spatial resolution of images plays a crucial role in determining accuracy during GIS analysis. The Ground Sampling Distance (GSD) reflects spatial resolution and is based on the drone's flight altitude and camera specifications. For the DJI Phantom 4 RTK drone, flying at 70m altitude, the GSD was 1.9cm/pixel. For an Urban Class Two Survey, the flight altitude should not exceed 109m to maintain a minimum GSD of 3cm/pixel, which is the acceptable spatial resolution for cadastral information within a ±0.05m accuracy.

The positional accuracy of the captured features contributes to the uncertainty of the sparse point cloud. The accuracy depends on the Ground Control Points (GCPs) used for georeferencing. The standard deviation of the point cloud measures precision—lower standard deviations indicate higher precision. With a GSD of 1.9cm/pixel, the RMS error from the drone's GPS fixing was initially outside the allowable accuracy. However, by using GCPs, the error reduced significantly from 81.737m to 0.028m, achieving a much lower standard deviation and higher precision. At a 90% certainty level, the horizontal accuracy was 0.032m, and the vertical accuracy was 0.050m, both of which meet the allowable accuracy for Urban Class Two Survey (±0.50m). The vertical accuracy can be improved further, but for a 2D cadastral survey model, the accuracy is considered acceptable.

In conclusion, georeferencing the sparse point cloud is essential for achieving the required accuracy and precision in Urban Class Two or any cadastral survey that integrates UAV data. The results show that the accuracy and precision of the measurements are acceptable and reliable, ensuring the correct positioning of features. Survey files can be adjusted to the reference system to prevent boundary overlaps or encroachments.

3.2 Subdivision Design

The conceptual design was developed to create a cadastral layout for the Digital Cadastral Database, based on the 4.762 ha land area. This design included 96 subdivided residential blocks, each ranging from 0.02 ha to 0.06 ha. Additionally, the design incorporated a recreational area (1 block of open space) for residential use, 2 light commercial areas, the existing Stonegate market, and a proposed area for small and medium-sized enterprises (SMEs). The SME area is intended to accommodate businesses like a supermarket or a BSP agent, helping to reduce the need for residents to travel to Lae City for shopping or banking services.

3.4 Title Cadastre Model (TCM)

The TCM was developed as a representation of the DCDB with an inventory of cadastral database information. The raster image was made transparent to display the Cadastre as shown in Figure 10.

Adjustment Summary

Adjustment type: Plane + Height, Minimal constraint
Confidence level: 95 %
Number of adjusted points: 7
Number of plane control points: 1
Number of used GPS vectors: 11
A posteriori plane UWE: 2.292983 , Bounds: (0.5700877 , 1.431083)
Number of height control points: 1
A posteriori height UWE: 2.392314 , Bounds: (0.4076763 , 1.601874)

GPS Observation Residuals

Name	dN (m)	dE (m)	dHt (m)	Horz RMS	Vert RMS
CS 01–CS 02	108.888	-293.347	-0.746	0.001	0.002
CS 01–CS 06	-207.288	-65.225	-1.663	0.001	0.003
CS 01–PSM 9799	-605.545	572.035	-3.072	0.001	0.001
CS 02–CS 03	-165.636	-68.739	-0.817	0.001	0.002
CS 02–PSM 9799	-714.437	865.379	-2.325	0.001	0.002
CS 03–PSM 9799	-548.803	934.109	-1.503	0.001	0.001
CS 04–CS 05	-130.159	354.357	0.223	0.001	0.002
CS 04–CS 06	42.003	408.368	1.780	0.001	0.001
CS 04–PSM 9799	-356.261	1045.631	0.359	0.001	0.001
CS 05–PSM 9799	-226.103	691.275	0.121	0.001	0.002
CS 06–PSM 9799	-398.259	637.262	-1.421	0.001	0.001

Adjustment Summary

Adjustment type: Plane + Height, Minimal constraint
Confidence level: 95 %
Number of adjusted points: 5
Number of plane control points: 1
Number of used GPS vectors: 6
A posteriori plane UWE: 1.583655 , Bounds: (0.3478505 , 1.668832)
Number of height control points: 1
A posteriori height UWE: 3.212386 , Bounds: (0.1590597 , 1.920937)

GPS Observation Residuals

Name	dN (m)	dE (m)	dHt (m)	Horz RMS	Vert RMS
CS 06–GCP 01	164.387	-6.821	0.897	0.002	0.002
CS 06–GCP 02	100.509	-18.290	0.631	0.001	0.001
CS 06–GCP 03	144.035	-104.232	0.152	0.001	0.002
CS 06–GCP 05	3.365	-222.681	-0.734	0.002	0.003
GCP 02–GCP 03	43.526	-85.946	-0.470	0.001	0.001
GCP 02–GCP 05	-97.149	-204.396	-1.378	0.001	0.002

GPS/GCP/3D Errors Details

GPS	Mean	Standard Deviation	RMS Error
X Error (meters)	1.621	3.913	4.235
Y Error (meters)	-3.040	3.657	4.756
Z Error (meters)	-81.498	6.093	81.725
Total			81.737

GCP	Mean	Standard Deviation	RMS Error
X Error (meters)	-0.000	0.000	0.000
Y Error (meters)	0.000	0.000	0.000
Z Error (meters)	0.000	0.000	0.000
Total			0.000

3D	Mean	Standard Deviation	RMS Error
X Error (meters)	0.009	0.019	0.021
Y Error (meters)	0.012	0.022	0.025
Z Error (meters)	0.022	0.043	0.048
Total			0.028

	Absolute	Relative
Horizontal Accuracy CE90 (meters)	0.000	0.032
Vertical Accuracy LE90 (meters)	0.000	0.050

Fig. 10 Summary of Results

Under Part Nine, sub-clause 9.22 of the Survey Direction 1990, it is a legal requirement that the allocation of legal descriptions for new land parcels be delegated by the Surveyor General's office. Initially, this task is managed by Senior Title Officers and then passed on to other designated officers within the Department. For this study, the Title Cadastre Model (TCM) will be developed following the approval of the subdivision design by the Physical Planning Board and the allocation of legal descriptions for the new parcels of land.

The TCM provided is a Cadastre Vector Model, overlaid onto the Orthomosaic image, serving as a base map at a 1:100 scale. Once the subdivision design and legal descriptions are approved, the data can be transferred to the Digital Cadastral Database (DCDB). The proposed method for data transfer involves digitally lodging the subdivision design as a Vector Model, overlaid onto the Orthomosaic image. The cadastral data can then be digitized along the subdivision vectors to create digital files of points, lines, and polygons, along with a database containing legal descriptions. The Inventory data (Figures 11 and 12) shows the expected output of legal descriptions for the project.

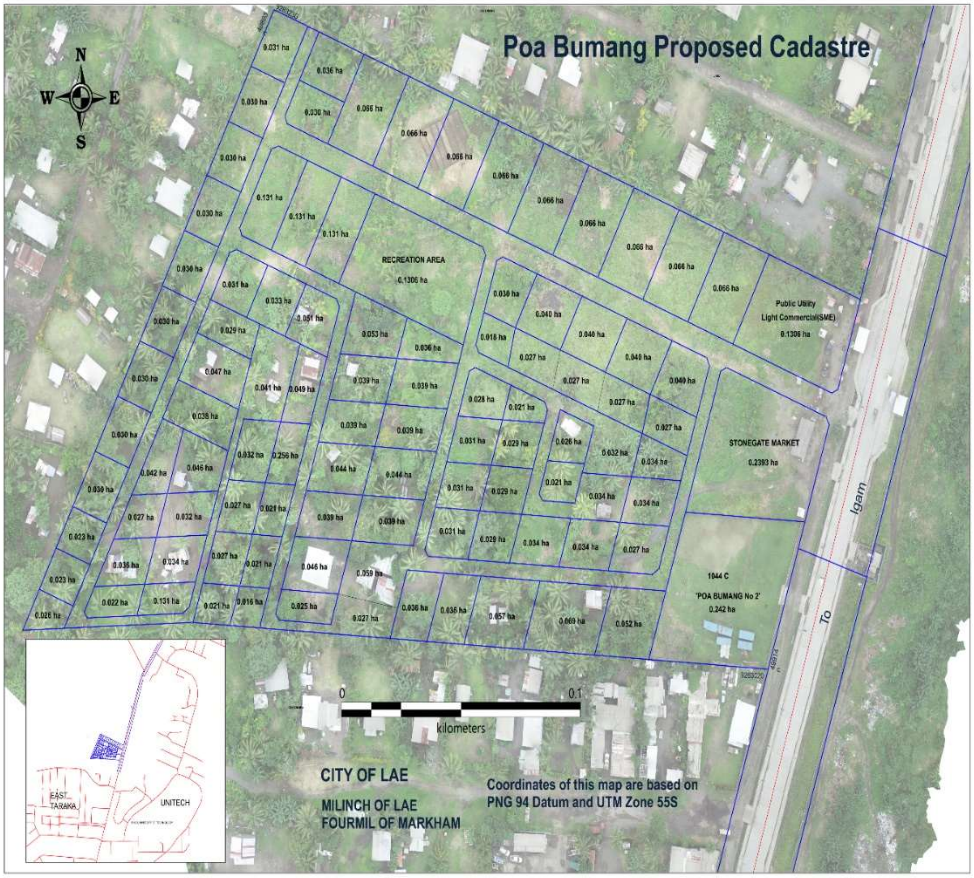

Fig. 11 Topographical Cadastral Map with Subdivision

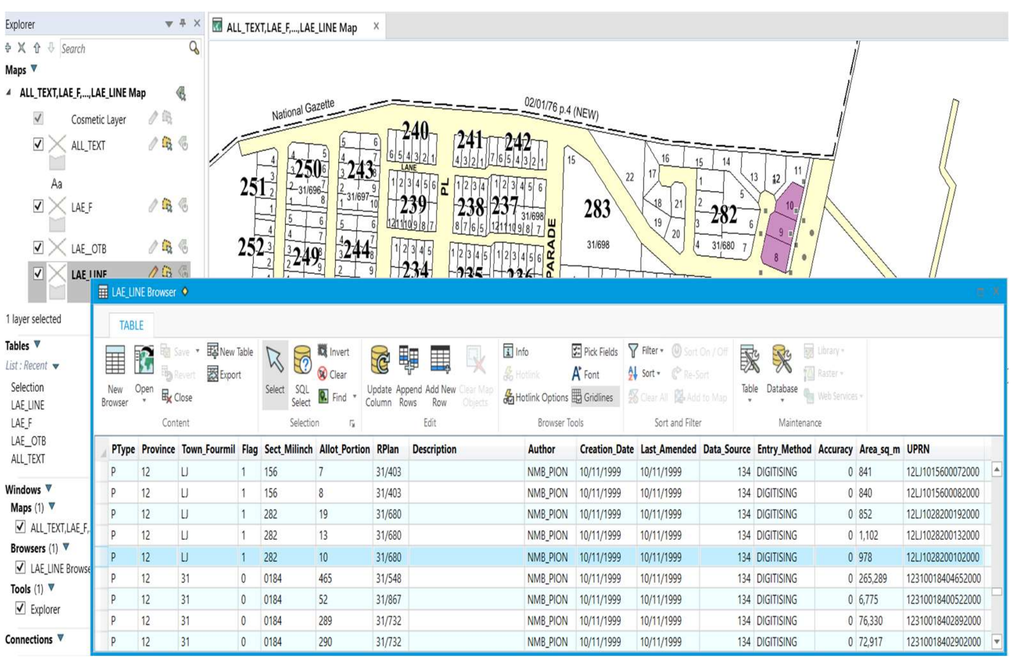

Fig. 12 Database Inventory (Source: NMB,1999)

4. Conclusion and Recommendations

The proposed theory is highly significant for urban settlements in Lae City and holds the potential to be applied nationwide. Land conflicts resulting from developments are a common issue, often aggravated by the lack of basic information about land rights and boundaries. Land surveyors play a vital role in addressing these challenges by adapting the cadastral system to accommodate such issues, thereby supporting the tenure system and enhancing GIS data accuracy.

Ensuring fixed and transformed coordinates for boundaries within a common reference system is crucial. The integration of GIS databases enables precise registration and management of boundaries within the tenure system. In the digital age, technology allows the use of up-to-date, real-world coordinates, improving the accuracy of land boundaries and related information. In Papua New Guinea, where 97% of land is customary and only 3% is alienated, land development faces significant challenges. Access to land for development is a major barrier due to the complexities of the Land Tenure System, which impedes the smooth progress of planned developments. However, the proposed approach aligns with the Papua New Guinea Development Strategic Plan 2010-2030. By updating land boundaries and establishing a comprehensive cadastre, both landowners and the government can access accurate information on land rights and boundaries. This process empowers landowners and enables the government to monitor and measure progress in land registration and urbanization, in line with international directives and national development goals.

In summary, implementing the proposed theory addresses current land development challenges and supports national development strategies. It empowers landowners and the government, ensuring a secure and well-managed land market that contributes to the nation’s growth and progress.

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Author's Biographies

Resila Karipal is a Lecturer in the Surveying section of the School of Surveying and Land Studies, under the Faculty of Built Environment at the Papua New Guinea University of Technology (PNG Unitech). A Papua New Guinean citizen, she earned her Bachelor in Surveying from PNG Unitech in 2017. She worked as a Technical Officer in the School of Surveying from 2017 up until her recent appointment to academia in 2024. She also has a Master of Philosophy in Surveying from the PNG Unitech.

Lewi Kari is a Lecturer and Deputy Head of the School of Surveying & Lands Studies at the PNG University of Technology, Lae, Morobe Province. He graduated with a Degree in Cartography from the Papua New Guinea University of Technology and has a Master's Degree in Spatial Science and Technology from the University of Southern Queensland, Australia.

Camilla Yanabis Kwaudi is a Lecturer with the GIS Section in the School of Surveying & Land Studies at the Papua New Guinea University of Technology. She has a Bachelor's Degree in Cartography and a Master of Philosophy degree in Geomatics from the Papua New Guinea University of Technology.