SUITABILITY OF UNMANNED AERIAL VEHICLES TO SUPPORT COMMUNAL LAND REGISTRATION IN ZIMBABWE

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Keywords:
UAVs, GNSS, Surveying, Land Registration, Communal Land

ABSTRACT :

Poor land registration in some regions is linked to continued reliance on conventional cadastral tools such as Total Stations and GNSS, which are costly, complex, and time-consuming. Communal lands are most affected, often facing disputes, evictions, and uncompensated land acquisitions due to unclear land rights. Documenting and recognising communal land rights is vital to ensure tenure security and alleviate unnecessary and forced evictions. Unmanned Aerial Vehicles (UAVs), known for their cost-effectiveness and flexibility, are emerging as an alternative tool for cadastral surveying.

This study assessed UAV suitability for communal land surveying in Zimbabwe, comparing it to GNSS in legal recognition, accuracy, cost, and time. UAVs extracted coordinates from 20 Ground Control Points (GCPs), and 6 GCPs generated orthophoto compared satisfactorily to GNSS coordinates of the same points. Accuracy remained consistent with both GCP counts, and UAV-derived data met Class C error limits under Zimbabwe's Land Survey Regulations. Thus, UAV orthophotos are suitable for Communal land surveys under current legislation. UAVs proved faster and cheaper for data collection. Though effective, legal updates are needed to recognise UAVs formally. Further research is recommended to automate coordinate extraction from orthophotos for efficiency.

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1.0 INTRODUCTION

Globally, only a few countries have achieved complete land registration and cadastral systems (Frank & Madaleine, 2018), leaving nearly 70% of the world's population mainly in developing countries without secure, registered land rights (Stöcker et al., 2019). Rural and marginalised communities, particularly women, are most affected, as their land rights are often overlooked or treated as secondary if at all considered (Mbiba, 2001). Although land registration can reduce evictions and large-scale land acquisitions, many governments fail to formally recognise overlapping and secondary rights (Lengoiboni et al., 2017). While countries such as Nicaragua, Vietnam, Tanzania, Namibia, and Rwanda have advanced communal land registration, Zimbabwe's customary lands remain largely unregistered due to high surveying and registration costs (Kurwakumire & Chaminama, 2012).

Land registration relies on cadastral maps defining land parcels (Williamson, 1997), traditionally produced using costly technologies such as GNSS and total stations (Mantey & Tagoe, 2019; Koeva et al., 2020). Recent advances in UAV technology provide a lower-cost alternative through high-resolution orthophotos that support boundary identification and participatory mapping (Pérez et al., 2013). Although UAV-based cadastral frameworks exist in North America, Kenya, and South Africa (Stöcker et al., 2017), Zimbabwe has not formally adopted UAVs for communal land mapping.

In countries including Zimbabwe, Laos, and Namibia, land occupiers bear registration costs (Kasita, 2011; Mafa et al., 2019), increasing the need for affordable approaches. UAVs are therefore promoted to strengthen tenure security for underrepresented groups (Zevenbergen et al., 2013) and have been successfully applied in communal and cadastral mapping in Namibia, Kenya, and Myanmar (Benassi et al., 2017; Lauterbach, 2021; Stöcker et al., 2019). Despite this potential, UAVs remain rarely used for formal land tenure mapping (Stöcker et al., 2019), and in Zimbabwe, UAV-derived data have not been systematically compared with conventional GNSS datasets. While UAV procedures are broadly consistent internationally, cadastral applications require locally adapted approaches aligned with legal and institutional frameworks (Chipofya et al., 2021). This study, therefore, compares UAV and GNSS datasets in terms of legal recognition, accuracy, cost, and time, using fieldwork, secondary data, and stakeholder interviews to assess the suitability of UAVs for communal land registration in Zimbabwe.

1.2 PROBLEM STATEMENT

Zimbabwe's communal lands, established under the Tribal Trust Lands Act of 1965, constitute about 40% of the country's land area (Chambati & Mazwi, 2020). The Communal Land Act of 1980 and the Traditional Leaders Act of 1998 require the surveying, mapping, and registration of these lands to safeguard residents' rights to reside, build, cultivate, and pasture livestock (Nyoni, 2016). However, weak enforcement has left nearly 70% of communal land residents without formal proof of ownership, exposing them to evictions by the state or private entities (Kurwakumire & Chaminama, 2012; FAO, 2009). Historically, communal lands have been subject to displacement, from the Land Apportionment Act of 1930 and the Tribal Trust Lands Act of 1965 to post-independence relocations for dams, mining, and agricultural projects (Mbiba, 2001; Mandihlare, 2013; Dhliwayo & Refiloe, 2020; HRW, 2021). Many communities were resettled in marginal ecological areas (maruzevha), including Gokwe, Sanyati, and Lupane (Nyoni, 2016). Recent cases such as Chilonga and Uzumba demonstrate how the absence of registered land rights enables evictions for commercial farming and mining activities (HRW, 2021; NewsDay, 2021). The Kaseke people of Uzumba (mining operations) were advised that they do not own the land occupied for years, as they have no title deeds.

Integrating communal land rights into the national cadastre is therefore critical (Kurwakumire & Chaminama, 2012). While conventional cadastral surveys are accurate, they are slow and costly (Koeva et al., 2017). UAVs offer a potentially cost-effective alternative, but their application must account for Zimbabwe's technical, legal, and social context (Subedi, 2016; Chipofya et al., 2021). The main question is whether UAV-derived data comply with the Land Survey (General) Regulations (LSR) SI 727 of 1979 and how they compare with GNSS surveys in terms of legal recognition, accuracy, cost, and efficiency. This study therefore aims to assess the suitability of UAVs for cadastral mapping of communal land in Zimbabwe by (i) reviewing existing cadastral approaches, legal frameworks, and institutional arrangements, (ii) comparing UAV and GNSS surveys in terms of cost, time, and accuracy, and (iii) evaluating UAV integration into participatory land recordation, including stakeholder perceptions from land surveyors, mapping experts, academic institutions, and the Department of the Surveyor-General (DSG), with recommendations for future adoption.

2. BACKGROUND LITERATURE

2.1 Land Tenure in Zimbabwe

Zimbabwe recognises five main land tenure types: freehold, leasehold, permit, communal, and unalienated state land. Freehold grants exclusive ownership, while leasehold allows temporary use ranging from 5 to 99 years. A1 permits provide occupational rights without commercial trading, and customary tenure is collectively administered by traditional leaders, with ownership held by families, tribes, or lineages. Unalienated state land includes protected areas and heritage sites (Moyo & Chambati, 2013; Maguranyanga & Moyo, 2006). Communal land, which constitutes a significant portion of Zimbabwe's rural landscape, remains largely unregistered despite usufruct rights granted under the Tribal Trust Lands Act (1965) and the Communal Land Act (1980). Legal requirements for surveys and Village Registration

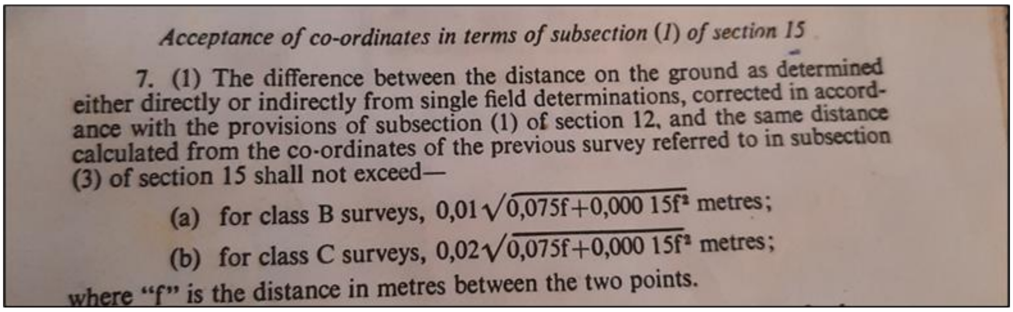
Certificates under the Traditional Leaders Act (1998) and recommendations from the 1994 Commission of Inquiry into Appropriate Agricultural Land Tenure Systems have yet to be fully implemented (Chambati & Mazwi, 2020; Mafa et al., 2019).

2.2 Cadastral Surveying and Opportunities for UAVs

Cadastral boundaries in Zimbabwe are traditionally surveyed by registered land surveyors using taping, traversing, or GNSS, with high accuracy as required under the Land Survey Act. These surveys are approved by DSG and generally recorded in the deed system at the Deeds Registry Department. Communal areas are excluded as they rely on unsurveyed general boundaries that are legally recognised but lack formal registration. Innovative approaches such as the Fit For Purpose (FFP) methods used in Ethiopia, Ecuador, and Rwanda offer scalable, cost-effective mapping for communal lands (Van Oosterom et al., 2009; Todorovski et al., 2021). Therefore, UAV-based surveying presents a promising opportunity to fill these gaps, enabling the integration of communal lands into Zimbabwe's formal registration system while improving accuracy, efficiency, and legal recognition (Williamson, 1997; Zevenbergen, 2002).

2.3 Comparisons of UAVs and GNSS

This study compares UAV- and GNSS-based surveying methods within Zimbabwe's cadastral framework, focusing on legal recognition, accuracy, cost, and time. These factors are critical given the requirements of the Land Survey Act and the high cost and duration of conventional surveys, which have limited cadastral coverage in communal areas.



Acceptance of co-ordinates in terms of subsection (1) of section 15

7. (1) The difference between the distance on the ground as determined either directly or indirectly from single field determinations, corrected in accordance with the provisions of subsection (1) of section 12, and the same distance calculated from the co-ordinates of the previous survey referred to in subsection (3) of section 15 shall not exceed—

(a) for class B surveys, $0{,}01\sqrt{0{,}075f+0{,}000\,15f^2}$ metres;

(b) for class C surveys, $0{,}02\sqrt{0{,}075f+0{,}000\,15f^2}$ metres;

where "f" is the distance in metres between the two points.

Figure 1: Error Limits from the Land Survey Regulations: Second Schedule.

The study assesses the conformity of UAV and GNSS datasets with accuracy standards in LSR by comparing allowable error limits (Fig 1) with observed distance residuals. This evaluation determines whether UAV-based surveying can provide a legally acceptable accuracy. Class A surveys determine control point positions, Class B surveys cover townships, and Class C encompasses all other surveys; communal land surveys therefore fall under Class C.

3. MATERIALS AND METHODS

3.1 Case Study Area

The research was conducted in Stockholm village, Goromonzi District, Mashonaland East Province. The settlement consists of 15 households allocated A1 Fast Track Land Reform plots, covering 305.83 hectares (80.34 ha arable, 216.66 ha grazing, 8.83 ha village site). Subsistence farming is the main livelihood. Stockholm was selected due to existing surveyed beacons Survey Record (SR31058) for accurate comparison between GNSS and UAV-derived coordinates, a dense geodetic network, simple linear boundaries, minimal disputes, and the suitability for participatory surveying. The local leadership and residents were well informed of the study.

3.2 Research Design and Data Sources

A mixed-methods case study approach was adopted, combining quantitative spatial data with qualitative stakeholder perspectives. Primary data were collected through GNSS surveys, UAV imagery, participatory boundary beaconing, questionnaires, semi-structured interviews, and field observations. Cost data were obtained from the DSG, private surveyors, and the researcher's professional experience. Secondary data included government publications, archived surveys, and relevant literature. Regulatory approvals were obtained from the Ministry of Lands, Agriculture, Water and Rural Development (MLAWRD) and the Civil Aviation Authority of Zimbabwe (CAAZ).

3.3 GNSS Surveying and Ground Control

GNSS observations were conducted using a Trimble R4 receiver operating in RTK mode, referenced to four national trigonometrical stations (Figure 2b) and transformed to the local Gauss coordinate system based on the Clarke 1880 ellipsoid as part of calibration. A beacon relocation survey of the previously surveyed parent parcel SR31058 was undertaken using GNSS (Figure 2c). Temporary UAV-visible signals (Figure 3a) were placed directly over the beacon centre marks to ensure detectability on the orthophoto and enable coordinate extraction for geometric positional comparison. Twenty well-distributed ground control points (GCPs) were surveyed using GNSS and marked with 12 mm iron pegs (40 mm length), with temporary UAV targets placed before image acquisition (Figure 3a). These GCPs were used to georeference UAV imagery and to evaluate boundary positional accuracy, including assessment of the effect of reducing the number of GCPs to six during orthomosaic processing.

3.4 Participatory Boundary Beaconing

Participatory boundary demarcation was a core component of data collection (Figure 3b). The District Lands Officer and Village Head introduced the research team and mobilised landholders. Boundaries were jointly identified and agreed upon under the guidance of local leadership. At each boundary corner, a 12 mm iron peg was installed and fixed using GNSS, with a temporary UAV-visible signal placed over the centre mark to ensure detectability in aerial imagery. Boundary disagreements were resolved through community mediation led by the Village Head and senior villagers. All 15 plots were fully beaconed, and boundary corners were cleared of obstructions to improve image visibility. Following the first UAV flight, landholders constructed cairns (Figure 3b)over the beacon centre marks. A second UAV flight was conducted over part of the study area to assess the positional accuracy and visibility of cairn monumentation relative to GNSS-derived coordinates.

(a) (b) (c)

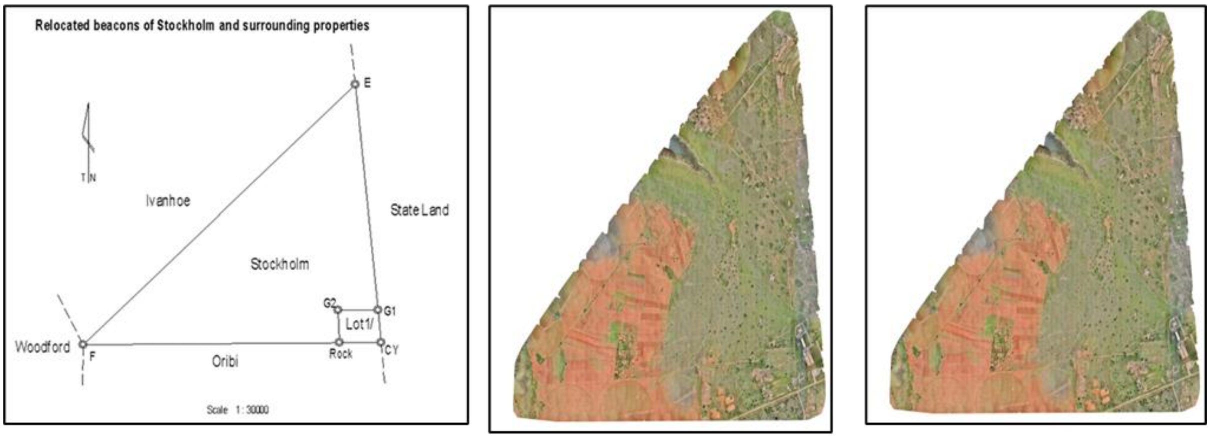
Figure 2: (a) UAV temporal signals, (b) National Geodetic Trig Station for calibration, (c) Relocation of parent property beacons as recorded in SR31058.

3.4 UAV Image Acquisition and Processing

UAV image acquisition was carried out using an eBee X fixed-wing UAV planned in Pix4D Capture. Approximately 360 ha were surveyed at an altitude of 144 m, with 80% forward and 70% side overlap. The first flight covered the entire study area, while the second covered a reduced area to support comparative analysis.UAV imagery was processed in Pix4Dmapper to generate orthomosaics (Figure 4b &4c). Boundary coordinates extracted from orthophotos were compared with GNSS-derived coordinates using root mean square error (RMSE) and ground sampling distance (GSD) metrics. Spatial analysis and visualisation were performed in CAD software.

(a) (b)

Figure 3: (a) Ground Control Points, (b) Participatory beaconing



(a) (b) (c)

Figure 4: a) Stockholm beacons, b) Othomosaic from 20 GCPs, c) othomosaic from 6 GCPs

3.5 Questionnaires and Interviews

Lastly, two questionnaires were administered: one to landholders (14 respondents) and another to land surveying and mapping professionals (26 respondents from private practice, public service, and academia). The questionnaires included closed- and open-ended questions assessing perceptions of land surveying, UAV suitability for cadastral mapping, and institutional and legislative requirements. Semi-structured interviews were conducted with senior officials from the MLAWFRD, a Provincial Lands Officer, the University of Zimbabwe's Department of Geoinformatics Chairperson, and the Surveyor-General of Zimbabwe. A deductive analytical approach was used to examine professional and institutional perceptions of UAVs relative to conventional cadastral surveying methods.

4.0 RESULTS

4.1 Legislative Acts, Policies, and Government Documents

Zimbabwe's **Constitution of 2013** defines land as a finite national resource and guarantees every citizen the right to acquire, hold, occupy, and use agricultural land without discrimination (GoZ, n.d.-b). This is supported by the **National and Gender-Sensitive Land Policy (2019 draft)**, which prioritises communal land registration and aligns with FAO Voluntary Guidelines for Responsible Governance of Tenure (Chambati & Mazwi, 2020). The **Communal Land Act (Chapter 20:04)** vests communal land in the President, with administration delegated to Rural District Councils (RDCs) and traditional leaders (GoZ, n.d.-a). The Act provides for occupation and use permits but allows state authorities to withdraw such rights. The **Traditional Leaders Act (Chapter 29:17)** mandates the surveying and mapping of communal villages, filing of surveyed diagrams, and issuance of **VRCs** and settlement permits (GoZ, 2020f). Despite these provisions, no communal village has been formally registered in Zimbabwe to date.

The **Land Acquisition Act (Chapter 20:10)** created the A1 settlement model, classified as organised communal land from which MLAFWRD issues a permit. Additionally, the **Land Commission Act (Chapter 20:29)** authorises the issuance of permits, leases, and other tenure documents after cadastral surveys (GoZ, 2017) on that land acquired under the Land Acquisition Act. The formal registration and upgrading to title deeds are then governed by the **Deeds Registry Act (Chapter 20:05)**, which requires an approved geometrically framed diagram produced by the DSG (GoZ, 2020a). The **Land Survey Act (Chapter 20:12)** and the **Land Survey (General) Regulations of 1979** regulate cadastral surveys for all land classes, including communal land (GoZ, 2020c; Government of Zimbabwe, 2019). These regulations specify accuracy standards, beaconing requirements, and error limits under the Second Schedule for land registration. While orthophotos are currently recognised only for curvilinear boundaries, the regulations do not explicitly prohibit UAV-derived data, suggesting that amendments rather than replacement of legislation are required.

4.2 Institutions

Several institutions are involved in land administration and registration in Zimbabwe. The **Ministry of Lands, Agriculture, Fisheries, Water, and Rural Resettlement (MLAFWRD)** administers A1 settlements and issues occupation and use permits based on settlement layout plans. The **Department of the Surveyor General (DSG)** is responsible for cadastral surveying standards and record keeping, while the **Deeds Registry Office** registers surveyed land. The **Ministry of Local Government** oversees vested land administered by RDCs and traditional leaders (Government of Zimbabwe, 2020d). These institutions are legally capable of registering communal land if surveys are conducted in accordance with existing regulations.

4.3 Technologies

Conventional cadastral surveying tools used in Zimbabwe include theodolites, EDMs, total stations, tapes, and GNSS. These tools have rarely been applied to communal land for registration purposes. The DSG currently uses UAVs mainly for updating maps, while MLAFWRD uses aerial photographs, satellite imagery, and handheld GPS for planning communal settlements. UAVs are therefore already accepted for mapping purposes but have not yet been integrated into formal cadastral registration workflows.

4.4 Legal Framework Regarding UAVs and GNSS

The operation of UAVs in Zimbabwe is regulated by SI 271 of 2018, which requires UAV registration, licensing, and flight authorisation (GOZ, 2018). Furthermore, the Land Survey Act and Land Survey regulations do not prescribe specific survey instruments, implying that GNSS and UAVs may be used provided they meet accuracy standards and are approved by the DSG. The Survey Regulations Board Circular 1 of 2002 provisionally supports GNSS use for cadastral surveys, indicating that similar guidance could be extended to UAV-based surveys.

4.2 Comparison of UAV and GNSS Observations in Participatory Surveying

4.2.1 Cost Comparison

Cost analysis shows that UAV surveys are substantially more economical than GNSS surveys. For systematic surveying of the 15 plots, UAV orthophoto generation costs about US$9 per hectare, compared to US$32 per hectare for GNSS surveys based on SRB tariffs. The researcher's experience yielded comparable estimates of US$11 per hectare for UAV surveys and US$26 per hectare for GNSS. These findings demonstrate the cost-effectiveness of UAVs, particularly for large-scale communal land surveying.

4.2.2 Time Comparison

Based on SRB tariffs and quotations from service providers, GNSS surveys were estimated to require approximately five days to complete boundary data acquisition, compared to one day for UAV surveys. During fieldwork, the researcher required four days using GNSS and three days using UAVs to collect equivalent datasets. Both service provider estimates and the researcher's practical experience confirm that UAVs significantly reduce fieldwork duration, highlighting their suitability for rapid and efficient communal land surveying.

4.2.3 Accuracy comparisons between UAV orthophoto extracted coordinates and GNSS coordinates.

Coordinate comparison of GNSS and UAV orthophoto (20GCPs)
Coordinates extracted for the boundaries of the 15 plots from the UAV-generated orthophoto (Fig 7) were compared to GNSS-measured corresponding beacon points as shown in Table 1.

Table 1: Coordinate comparison of GNSS and UAVs orthophoto (20 GCP)

Beacon	Ygnss (m)	Xgnss (m)	Yuav (m)	Xuav (m)	dy (m)	dx (m)
1a	-46941.773	1955659.939	-46941.702	1955659.935	-0.071	0.004
1b	-47264.664	1955689.440	-47264.651	1955689.370	-0.013	0.070
2a	-47345.788	1956037.826	-47345.716	1956037.699	-0.072	0.127
2b	-47148.148	1956049.576	-47148.090	1956049.590	-0.058	-0.014
2c	-47112.261	1955907.826	-47112.267	1955907.710	0.006	0.116
2d	-47115.736	1955873.807	-47115.722	1955873.700	-0.014	0.107
…..	…..	…………...	……..	……..	…..	…….
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14b	-47892.348	1954716.172	-47892.373	1954716.261	0.025	-0.089
14c	-48148.715	1954914.101	-48148.700	1954914.155	-0.015	-0.054
14d	-48019.892	1955004.734	-48019.824	1955004.660	-0.068	0.074
15a	-46842.469	1956063.585	-46842.450	1956063.520	-0.019	0.065
15b	-46568.736	1956029.322	-46568.672	1956029.208	-0.064	0.114
15c	-46819.933	1955806.391	-46819.882	1955806.322	-0.051	0.069

The comparison yielded mean residuals of −0.057 m (Y) and 0.041 m (X), with standard deviations of 0.041 m and 0.068 m, respectively, resulting in an overall positional RMSE of 0.106 m. Further analysis shows small positional differences, with most planimetric offsets below 0.15 m in both the X and Y directions. The majority of discrepancies are clustered around 5–10 cm, indicating strong agreement between the two datasets. These results demonstrate that UAV-derived orthophotos can achieve positional accuracy comparable to GNSS measurements for communal land boundary mapping under controlled conditions. Descriptive statistics and a residual scatter plot (Figure 5) illustrate the error distribution and identify potential outliers.

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation	Variance
dy	34	-0.181	0.037	-0.05668	0.041164	0.002
dx	34	-0.097	0.15	0.04068	0.067714	0.005
Valid N (listwise)	34					

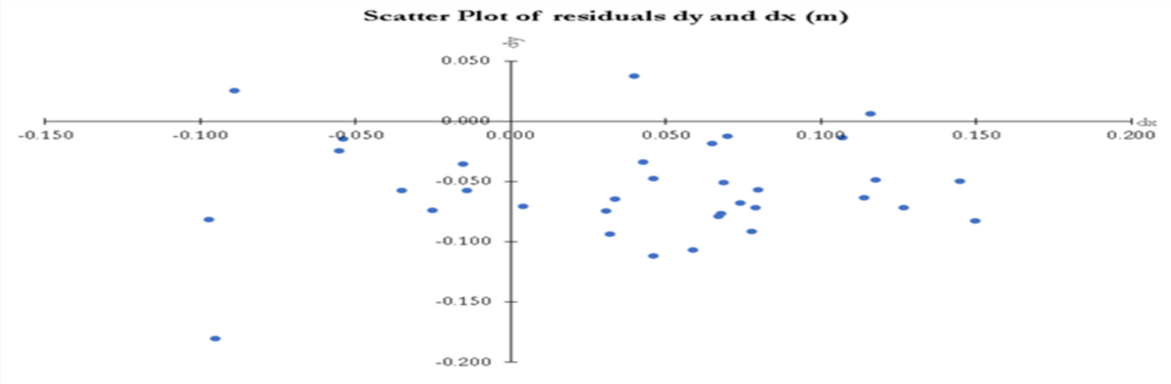

Figure 5: Descriptive statistics and scatter plot of the comparison residuals (20 GCP orthophoto)

Coordinate comparison of GNSS and UAV orthophoto (6 GCPs)

The second orthophoto (Figure 4c), georeferenced using six well-distributed GCPs, produced mean residuals of −0.046 m (Y) and 0.109 m (X), with standard deviations of 0.050 m and 0.068 m, respectively, yielding a positional RMSE of 0.096 m.

Coordinate comparison of GNSS and orthophoto (placed beacons with cairn)

Coordinate comparison between GNSS and beacons with cairns (Fig. 3b) showed mean residuals of -0.011 m in Y and 0.010 m in X, with a positional accuracy (RMSE) of 0.144 m. Although the mean residuals are low, the higher standard deviations of 0.091 m in Y and 0.112 m in X indicate greater scatter around the means. These residuals are also larger compared to those obtained from the 20- and 6-GCP orthophotos.

Error limits calculation as stated in the Second Schedule of the LSR

The LSR specifies that displacements between beacons derived from new and existing survey coordinates must not exceed prescribed error limits. In this study, coordinates of found beacons (SR31058) were extracted from the 20 GCPs georeferenced orthophoto. Join distances between beacons were computed and compared with corresponding distances derived from the original SR31058 coordinates (Fig 4a). Resulting displacements were evaluated against the Class B and Class C error limits defined in the Second Schedule of the LSR, as presented in Table 2.

Table 2: Displacement residuals and Class B and C error tolerance limits.

Limits of Error- Second Schedule of LSR of 1979 (meters)							
Beacons	**GNSS**	**UAV**	**SR31058**	**UAV-SR**	**Displacement**	**Class C Tolerance**	**Class B Tolerance**
CY - G1	294.990	295.014	294.997	0.017	0.017	0.1186	0.0593
CY - G2	477.466	477.508	477.564	-0.056	0.056	0.1674	0.0837
CY - Rock	363.808	363.906	363.929	-0.023	0.023	0.1373	0.0687
CY - E	2364.035	2364.088	2364.336	-0.248	0.248	0.6374	0.3187
CY - F	2593.315	2593.303	2593.799	-0.496	0.496	0.6938	**0.3469**
G1 - G2	350.694	350.743	350.679	0.064	0.064	0.1338	0.0669
G1 - Rock	448.088	448.038	448.011	0.027	0.027	0.1596	0.0798
G1 - E	2069.075	2069.075	2069.340	-0.265	0.265	0.5647	0.2824
G1 - F	2584.487	2584.422	2584.797	-0.375	0.375	0.6916	**0.3458**
G2 - Rock	294.147	294.090	294.132	-0.042	0.042	0.1184	0.0592
G2 - E	2068.095	2068.202	2068.420	-0.218	0.218	0.5645	0.2823
G2 - F	2236.427	2236.303	2236.748	-0.445	0.445	0.6059	0.3030
Rock - E	2360.241	2360.292	2360.548	-0.256	0.256	0.6364	0.3183
Rock - F	2229.507	2229.397	2229.870	-0.473	0.473	0.6042	**0.3022**
E -F	3353.161	3353.097	3353.586	-0.489	0.489	0.8804	0.4403

All tested join displacements fall within the allowable limits for Class C surveys, indicating that UAV-derived orthophoto coordinates are suitable for Class C surveying, provided the monumentation is authorised by the DSG. Figure 6 provides a visual summary of the results in Table 2. When tested against the stricter Class B error limits, some displacements exceeded the allowable thresholds.

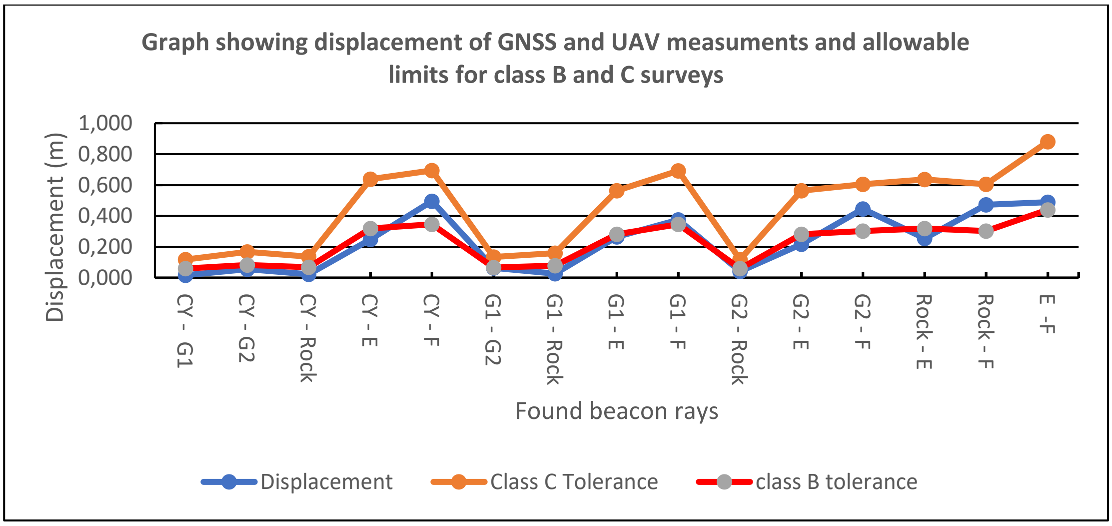

Figure 6: Displacement and allowable limits for Class B and C surveys.

Comparison to previous investigations

The positional accuracies obtained in this study compared favourably with those reported in previous research. Mantey and Tagoe (2019) reported georeferencing RMSE values of 0.053 m and 0.031 m, with coordinate differences means Δx and Δy of 0.120 m and 0.111 m, while Yurtseven (2019) reported RMSE values of 0.064 m and 0.085 m. Amissah et al. (2021) recorded coordinate differences means Δx and Δy of 0.27 m and 0.51 m at one site in Ghana, and −0.142 m and 0.245 m at a second site. In contrast, this study achieved lower georeferencing RMSE values of 0.007 m and 0.013 m using 20 GCPs, and 0.003 m and 0.002 m using 6 GCPs. The corresponding mean coordinate differences were 0.040 m (Δx) and −0.057 m (Δy) for 20 GCPs, and 0.109 m (Δx) and −0.046 m (Δy) for 6 GCPs. Although extracted-coordinate accuracy is seldom reported, these results are comparable to, and in some cases exceed, those documented in earlier studies.

4.3 Potential Integration of UAVs in Communal Land Recordation

UAV-generated orthophotos show strong potential for participatory communal land surveying in Zimbabwe, particularly through reduced survey time and costs for landholders. Government institutions including MLAFWRD, the Ministry of Local Government, the DSG, Rural District Councils (RDC), and traditional leaders, stand to benefit from faster data acquisition and improved land administration. Questionnaire results indicate higher acceptance of GNSS due to its established legal framework, with 69% of respondents rating it convenient to use compared to 23% for UAVs. Although 76% disagreed that UAVs are currently more efficient than GNSS, 46% identified UAVs as the future of surveying. GNSS achieved consistently high effectiveness ratings (mean score = 9/10), while UAVs scored lower, particularly for safety, privacy, and data quality (mean score = 6/10). These perceptions reflect regulatory and institutional uncertainty rather than technical limitations, underscoring the need for **legal and institutional reforms** to fully integrate UAVs into cadastral surveying and communal land registration.

5. ANALYSIS AND DISCUSSION

5.1 Legislative Acts and Policies

Zimbabwe's Constitution (2013) and supporting legislation, including the Communal Land Act, Traditional Leaders Act, Land Acquisition Act, and Land Commission Act, protect citizens' land rights, yet implementation gaps persist. VRCs are legally envisaged but none have been issued, and they are not recognised by the DSG or Deeds Registry Department, leaving communal lands vulnerable to disputes and potential evictions. Interviews with DSG, MLAFWRD, and University of Zimbabwe officials revealed reluctance to survey communal land due to perceived low value and high costs. Awareness of land related legislations is limited, with all Stockholm landholders and 62% of professionals unaware of relevant Acts. Despite these challenges, the 2019 draft National Land Policy advocates registration of all land, including communal holdings to enhance tenure security and protect women's rights. While the Land Survey Act sets cadastral standards, communal lands are largely excluded. UAV-derived orthophotos achieving Class C accuracy could be formally recognised through SRB amendments. Similarly, the 2019 Manual for Systematic Land Registration, intended to reduce costs and streamline registration, remains largely unimplemented.

5.2 Institutions, Technologies and Legal Framework for UAVs and GNSS

Key institutions managing communal land include MLAFWRD, DSG, RDCs, and traditional leaders. No communal land has been formally surveyed since the 1998 Traditional Leaders Act, and compliance with the Land Survey Act limits registration. GNSS is widely accepted, and UAVs are increasingly used by DSG for topographic mapping, while the University of Zimbabwe integrates both technologies into its curriculum, indicating growing institutional readiness. GNSS use is partially regulated, but UAVs lack formal recognition. Civil Aviation (Remotely Piloted Aircraft) Regulations exist, yet 80% of professionals are unaware, and DSG lacks the capacity to certify UAV or GNSS instruments, creating uncertainty. Field results showing Class C UAV accuracy support provisional SRB authorisation for UAV-based communal surveys.

5.3 Comparison of UAV and GNSS for Participatory Surveys

UAV surveys proved more cost- and time-efficient than GNSS, reducing per-hectare costs and field time. Service providers suggested a one-day turnaround, while researcher fieldwork confirmed completion in three days, compared to five for GNSS. Additionally, UAV-derived coordinates from orthophotos georeferenced with 6 or 20 GCPs) achieved accuracy differences within Class C limits. Even with cained beacons, deviations were acceptable. Using fewer GCPs did not significantly reduce accuracy, confirming efficient adjudication with lower costs and time, consistent with previous studies (Pérez et al., 2013; Mantey & Tagoe, 2019; Amissah et al., 2021) and Stocker (2019). In that regard, communal land adjudication can be done using fewer GCPs saving on time and cost.

5.3 Beneficiaries and Stakeholders evaluation

The adoption of UAVs benefits landholders by enabling faster land mapping, formalising land rights, and improving access to finance and development opportunities. Institutions can plan, manage, and register lands more efficiently. The individual area of a plot generated from coordinates of UAV and GNSS surveys showed negligible area differences of approximately ~2 m², confirming the reliability of UAVs for cadastral purposes. The difference is insignificant and highly unlikely to cause any boundary dispute or loss of land. However, UAV participatory mapping is best suited to unsurveyed areas, as existing boundaries may reveal encroachments, as shown in Figure 7. That implies UAV mapping is best done on land that does not have existing registered boundaries. While GNSS remains primary, stakeholders increasingly view UAVs as the future of cadastral surveying. Willingness from DSG and MLAFWRD to consider UAV regulations, coupled with UAV training at the University of Zimbabwe, indicates growing institutional support for integrating UAVs into Zimbabwe's cadastral framework.

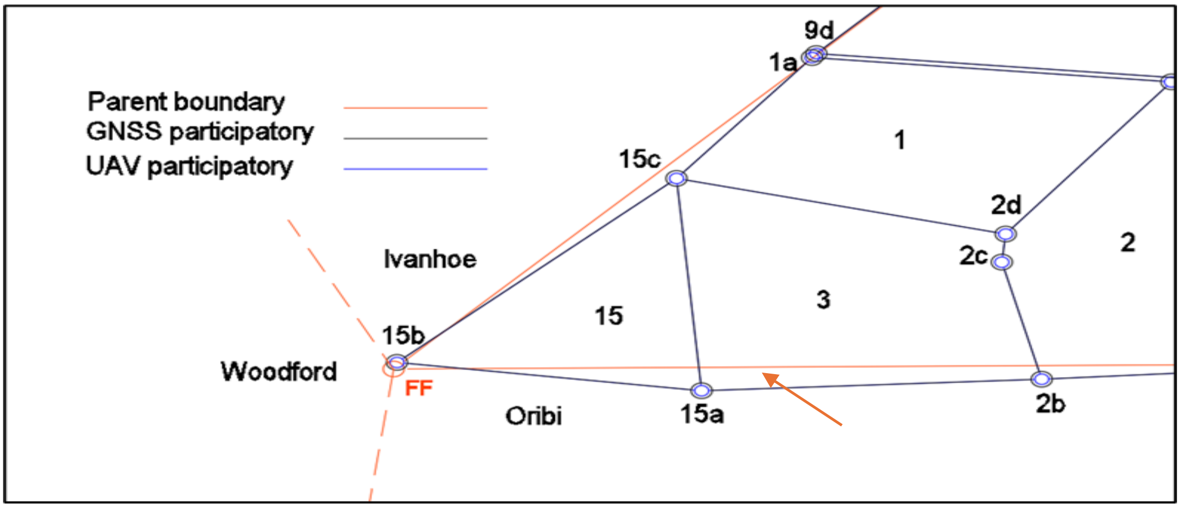

Figure 7: Part of the General Plan of Stockholm plots showing possible encroachments

6. CONCLUSION AND RECOMMENDATIONS

UAV-based surveys are cost-effective, faster, and more accurate for Class C communal land surveys, even with fewer GCPs. Adoption would benefit landholders, government agencies, and professionals, supporting participatory mapping and tenure formalisation. UAVs, integrated with GNSS and supported by legislative reform, represent a viable future tool for communal land surveying in Zimbabwe. Recommendations for future research include the development of an automated coordinate extraction algorithm to streamline orthophoto processing and reduce manual errors, and the testing of low-cost UAV platforms for cost-effective boundary mapping. Furthermore, the academic institutions, stakeholders, DGS, and the SRB are to jointly establish standardised UAV-GNSS field protocols, specifying flying height, image overlap, camera resolution, GSD, and the number of GCPs per hectare for communal land surveys. Coordination between DSG, CAAZ, and academic institutions is critical for equipment testing, regulatory reform, and broader adoption. UAVs, when legally recognised and supported by GNSS, can transform participatory cadastral surveying and enhance tenure security for communal landholders.

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