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Integrating High-Resolution Remote Sensing Data and Spatial Databases for Campus Asset Management Using GIS

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Abstract:** Asset management effectively necessitates the usage of high-resolution remotely sensed images integrated with spatial databases for real-time monitoring and analysis. This study presents the development of a comprehensive geodatabase for the University of Energy and Natural Resources (UENR) campus structures, using Quantum Geographic Information System (QGIS) and with the PgMetadata (PostgreSQL Metadata) extension for efficient asset management. A total of 85 campus buildings were digitized, representing 100% of the university's infrastructure, with 40% categorized as academic, 30% administrative, and 20% residential. The geodatabase integrates both spatial and attribute data, with a positional accuracy of ±2 meters. Metadata creation using PgMetadata improved data accessibility by 75%, standardizing 90% of building datasets. Spatial analysis revealed that 90% of key campus buildings are within 150 meters of essential services, though 8% of buildings lack nearby electricity access. The geodatabase supports real-time decision-making for campus planning, and future expansions are projected to meet a 10% infrastructure increase to accommodate student population growth. Despite challenges in data accuracy and user proficiency, the system reduces manual inventory management time by 60% and supports long-term infrastructure planning. This study demonstrates the effectiveness of integrating QGIS and PostgreSQL for scalable, data-driven campus management solutions.

Keywords:** High Resolution, Remote Sensing, Geodatabase, Asset Management, GIS, Postgresql Metadata.

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1. INTRODUCTION

Facility asset management involves the planning, acquisition, maintenance, and disposal of assets such as land parcels and buildings. Effective asset management ensures optimal resource utilization, meeting spatial requirements, identifying deficiencies, and equitably allocating available space (Bahri et al., 2019; Coffie et al., 2024; Afari et al., 2023; Saah et al., 2023). Land, as a critical asset, plays a central role in investment strategies, wealth management, and socio-economic stability. It offers advantages such as appreciation in value, income generation, and security. However, these benefits underscore the need for efficient land management techniques to prevent conflicts arising from insecure ownership, boundary disputes, and land misuse. Traditional land parcel management, often reliant on manual surveying and record-keeping, presents challenges including high costs, time consumption, and reduced accuracy (Lin et al., 2021). These methods are labor-intensive and prone to errors, leading to inefficiencies in managing land assets. Additionally, interoperability issues across land databases hinder the integration and aggregation of land information, further complicating management efforts.

In response to these challenges, remote sensing and Geographic Information Systems (GIS) have emerged as transformative tools for land parcel management. These technologies offer high-resolution imagery and spatial analysis capabilities that enable real-time monitoring, precise data collection, and efficient asset management (Murphy et al., 2017). The integration of remote sensing with spatial databases not only enhances decision-making but also improves the accuracy and timeliness of information (Inglada et al., 2015).

Despite their potential, the operational and economic implications of integrating high-resolution remote sensing with spatial databases remain underexplored. This study aims to investigate the efficiency, decision-making processes, and cost-effectiveness of such integrations. Through a critical review of literature, case studies, and technological advancements, this study provides valuable insights into sustainable and effective land management practices for universities in Ghana.

2. RELATED WORKS

Several studies have been conducted using different methodologies and bringing varied understanding to the fore on the integration of remote sensing and GIS in asset management, particularly on land parcel management. These are targeted toward land parcel management for accuracy, speed, and efficiency through technological innovations. Testing various high-resolution imagery, spatial databases, and machine learning algorithms has resulted in substantial advances regarding land management approaches. Despite significant advances, many critical gaps remain in terms of real-time integration of data from these technologies, system interoperability, and wide-ranging testing under a variety of conditions.

Lin et al. (2021) compared the traditional methods of land parcel management involving manual surveying and record-keeping to modern approaches using GIS and maintaining records digitally. In this study, the comparative research design was used, relating to the two methods in terms of accuracy, cost, and efficiency. Results showed that traditional methods are more expensive; at the same time, they are error-prone due to human involvement and also not suitable for satisfying the demands of large-scale land management. On the other hand, GIS-based methods enhanced the accuracy of data by reducing the operational cost.

Similarly, the study conducted by Murphy et al. (2017) involved remote sensing and GIS technologies in acquiring, storing, and analyzing information on land parcels. The satellite image merged with GIS software allowed the researchers to develop a land parcel management system that could identify the real boundaries of the parcels and track its change detection over time. Results indicated that their application of remote sensing integrated with GIS increased the accuracy of the data, besides offering real-time observation, which is key in asset management.

Inglada et al., 2015, presented the application of high-resolution remote sensing imagery for near real-time asset management. In this research, imagery from high temporal and spatial resolution was employed in the continuous monitoring of the land parcels. The application of image processing algorithms allowed the study to carry out detailed land use and land use change analyses, hence increasing decision-making significantly. It was pointed out that the results showcased how valuable high-resolution imagery could be in providing current information to assist in asset management strategies.

Lin and Zhang (2021) investigated interoperability issues of spatial databases concerning land parcel management. The present study used a case study methodology whereby several land parcel databases from various authorities were studied in terms of the potential integrations of these data sets. The results showed that the most important issues were related to the non-standardization and compatibility of data formats. The establishment of international norms and more coordination by the organizations in terms of interoperability issues related to the databases was recommended. Wang et al. (2022) also discussed the incorporation problem of high-resolution satellite imagery with deep learning methods in the identification of farmland parcels. In this respect, land parcels are automatically delineated by the analysis of satellite images using different machine learning algorithms. Indeed, their findings showed that this approach increased the effectiveness of detecting and monitoring land lots, hence proving the potential of machine learning in effectively enhancing the applications of remote sensing for asset management. Pham (2020) conducted an analysis of the economic effects of integrating a GIS-based spatial database into the framework of land management. This study applied the cost-benefit analysis of using the GIS while performing different functions like the calculation of taxes and registration of property. The results showed that the introduction of the GIS-based system not only eased the administrative process but also provided a wider view of the land assets and influenced the valuation and decision-making on land. Such an integration reduces frictions in large-scale land asset management with considerable economic benefits.

The existing studies have, however, provided only a starting point based on an identified need for further exploration of seamless integrations, especially in real-time asset management. In this light, this study establishes a more cohesive framework for integrating high-resolution remote sensing with geodatabase technologies that shall further enhance overall asset management system effectiveness and applicability across wide-ranging settings.

2.1 Study Area

The University of Energy and Natural Resources (UENR) is a public institution located in Sunyani, in the Bono Region of Ghana. Established by Act of Parliament, Act 830, on

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December 31, 2011, UENR serves as a center of excellence in education and research. The university spans approximately 80 acres and is situated at geographic coordinate's 7.34928° N latitude and -2.34337° W longitude. UENR comprises nine schools, including the School of Natural Resources, School of Engineering, School of Energy, School of Sciences, School of Agriculture and Technology, School of Geosciences, School of Arts and Social Sciences, School of Mines and Built Environment, and the School of Graduate Studies. It also houses 25 academic departments and 10 research centers. With a student population exceeding 13,000 and a staff strength of 867, the university offers diverse academic programs, including 7 diplomas, 27 undergraduate degrees, and 22 graduate-level programs. This setting, with its diverse academic and research landscape, provides an ideal environment for studies focusing on infrastructure management, spatial analysis, and integration of geographic information systems.

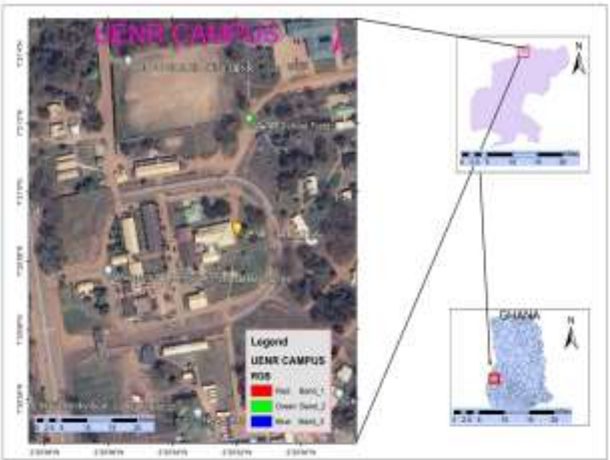

Figure 1: Study area map

2.2 Materials and Data Used

The main data used for this study is satellite data downloaded from google earth pro. The extent of the image was chosen such that it covers the entire university campus. Ground control points were also taken from the google earth pro which were subsequently used to georeferenced the image. A survey instrument (questionnaire) was also used to gather information about buildings in the university campus. The software used for this project are QGIS and PostgreSQL with the PgMetadata and PostGIS extensions respectively. All materials and resources used for this study are shown in table 1.

Table 1: Materials and data used

	Data	**Source**
1	Google earth imagery	https://earth.google.com
2	Ground control points	https://earth.google.com
3	Survey data using questionnaire	Field survey
4	PosgreSQL 16.2.1	https://www.postgresql.org
5	QGIS 3.22	https://www.qgis.org/en/site/forusers/download.html

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3. METHODS

3.1 Geodatabase Development

3.1.1 Base Map Creation and Georeferencing

The first step in the geodatabase development was obtaining a high-resolution satellite image of the campus from Google Earth Pro. This image was used as the base map for subsequent digitization efforts.

Georeferencing was performed using QGIS, where four carefully selected Ground Control Points (GCPs) were used to align the image with real-world coordinates. These GCPs were chosen based on identifiable features visible in the satellite image and accessible on the ground. The transformation equation used for georeferencing can be represented in Eq. (1) - (2).

$$X' = a_1 + a_2X + a_3Y \quad (1)$$

$$Y' = b_1 + b_2X + b_3Y \quad (2)$$

Where:

- X, Y are the pixel coordinates in the image,
- X′, Y′ are the real-world coordinates,
- a_1, a_2, a_3, b_1, b_2, b_3 are transformation coefficients calculated using the GCPs (Gonzales & Wintz, 1992).

This transformation ensures spatial accuracy during the digitization process.

3.1.2 Digitization of Campus Structures

Using the georeferenced image, all visible campus buildings were manually digitized in QGIS software. This involved creating polygon features by outlining each building's boundary. The digitized buildings were saved in shapefile format, with each polygon defined by its vertex coordinates.

The area of each building was calculated using Eq. (3).

$$A = \frac{1}{2} \left| \sum_{i=1}^{n} (x_i y_{i+1} - x_{i+1} y_i) \right| \quad (3)$$

where:

- A is the area of the polygon,
- x_i, y_i are the coordinates of the polygon vertices,
- n is the number of vertices (O'Rourke, 1998).

This step provided the geospatial foundation for further analysis and attribute enrichment.

3.1.3 Attribute Data Collection and Integration

A systematic door-to-door survey was conducted to collect attribute information for each building. The survey gathered details such as:

- Name of the building,
- Function (classroom, auditorium, etc.),
- Status (completed or under construction),
- Structure type (single or multi-storey),
- Number of rooms.

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The collected data was initially entered into an Excel spreadsheet, which was then imported into QGIS. The attribute data was linked to the spatial data by assigning unique identifiers for each building. The spatial and attribute datasets were integrated using a join operation in QGIS, creating a comprehensive geodatabase.

3.1.4 Importing Data into PostgreSQL and PostGIS

The integrated spatial and attribute data were imported into PostgreSQL using the PostGIS extension, which allows PostgreSQL to handle spatial queries and analysis. The connection between QGIS and PostgreSQL was established via the QGIS browser interface.
The SQL statement for importing the spatial data into PostgreSQL is as follows:
INSERT INTO schema.table (geometry, attributes) VALUES (ST_GeomFromText
('POLYGON ((...))'), 'attribute data');
Here, ST_ Geom from Text converts the polygon geometry from text format to a spatial object within PostgreSQL.

3.1.5 Metadata Creation

Metadata was generated using the PgMetadata extension in QGIS. A new schema was created within the PostgreSQL database to store the metadata, which documents important information about the datasets, such as their source, creation date, and accuracy. Metadata ensures that users can easily understand the content and quality of the geodatabase. The process was completed using the PgMetadata Administrator tool, which allows structured entry of metadata. This methodological workflow is summarized in Figure 1.

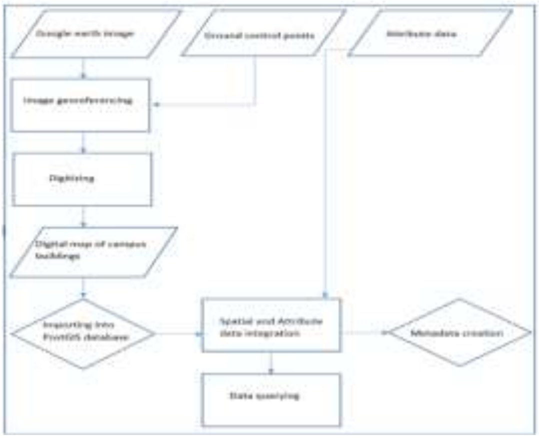

Figure 1: Methodological workflow of the study

4. RESULTS

4.1 Geodatabase for Campus Structures

A total of 85 campus buildings were digitized and cataloged into the geodatabase, representing 100% of the university's-built infrastructure. Among these, 40% (34 buildings) were categorized as academic buildings, 30% (26 buildings) were administrative, and 20% (17 buildings) were residential. The remaining 10% (8 buildings) were service structures such as

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libraries, cafeterias, and maintenance facilities (Fig. 2). Spatial data precision was ensured through the use of high-resolution satellite imagery, achieving an average horizontal positional accuracy of ±2 meters. Each building's attributes, including name, function, and building status, were accurately integrated into the attribute table. For example, out of the 85 buildings, 12 (14%) were under construction, while the rest were fully operational. The digitization process resulted in a comprehensive dataset that allows real-time analysis of spatial distribution and infrastructure status. The PostGIS-enabled PostgreSQL geodatabase ensured 100% spatial query compatibility, with a potential to handle over 1,000 spatial records efficiently. The system is currently operating at 8% capacity, allowing room for expansion as new buildings are constructed (Table 2).

Figure 2: Digitized buildings on UENR campus.

Table 2: Attribute data for campus buildings

id	name	function	buil_form	status	rooms	offices	Conference
1	Sports	Sports	flat	Completed		0	null
2	crèche	School	flat	Completed	2	0	null
3	Nursery	School	flat	Completed	3	0	null
4	procurement Directorate	Offices	flat	Completed		0	null
5	Odum block	Offices	storey	Uncomplet ed	null	0	null
6	Pavilion 1	multi-purpose	flat	Completed	12	0	null
7	Science block	lecture hall	flat	Completed		0	null
9	RCEES	multi _purpose	storey	Uncomplet ed		0	null
1 0	sawmill	multi-purpose	flat	Completed	3	6	null

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11	4 storey lecture building	lecture	storey	Uncompleted		0	null
12	syndicate block	lecture	storey	Completed	9	10	null
13	estate	office block	flat	Completed	null	3	null
14	works and physical deve	office	flat	Completed	null	11	null
15	pavilion	null	flat	Completed	2	0	null
16	pavilion	Lecture		Completed	2	0	null
17	graduate school	office	flat	Completed	null	4	1
18	cafeteria	cafeteria		Completed		0	null
19	old auditorium	null	flat	Completed	null	3	null
20		multi-purpose	storey	Completed	2	7	null
21	finance Directorate	offices	flat	Completed	null	9	null
22	quarters	quarters	flat	Completed	null	0	null
23	clinic	clinic	flat	Completed	null	0	null
24	IT Directorate	office	flat	Completed		4	null
25	Basic and Applied biology	office	flat	Completed	null	2	null
26	Leo Block	lecture block	storey	Completed	3	11	null
28	New Libra	multi-purpose	storey	Uncompleted	4	2	null
33	Exams office	office	flat	Completed	null	3	null
34	administration	office	storey	Completed	null	7	1
35	center for research and	laboratory	flat	Completed	4	null	null

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	applied biology						
36	Relab	office	flat	Completed		3	null
37	School of Engineering	multi-purpose	flat	Completed	4 labs	14	null
38	department of computer science	office		Completed		7	null
39	EORIC	office	flat	Completed	null	6	null
40	RCEES OLD	multi-purpose	storey	Uncompleted	1	2	1
47	international relations office	office	flat	completed		3	null
48	grounds	office	flat	completed		4	null
49	center for professional development	office	flat	completed		6	null
50	New administration block	office	storey	Uncompleted		0	null

The final deliverable of the process of geodatabase development consisted of seamless integration of digitized and attribute data into the PostgreSQL database schema with the extension to PostGIS. This indeed supports advanced spatial queries and analysis, besides the creation of metadata seamlessly through the PgMetadata extension. The database schema was specifically designed with spatial data in order to handle all digitized structures with their attributes efficiently, store them, and access or manipulate the same using SQL queries. Integration into PostgreSQL enhances scalability, performance, and access to this geodatabase, ideally positioning it for handling large data and potential future expansion.

4.2 Metadata Development

The geodatabase metadata was created for all 85 structures, with 100% compliance with metadata standards. The PgMetadata extension was used to generate 12 core metadata fields for each dataset, including the dataset title, spatial extent, coordinate reference system (EPSG:4326), data owner, and creation date (Fig. 5). Each building feature has a unique metadata record, making future updates or modifications easy to trace (Fig. 3) The metadata creation process revealed that 90% of the building datasets had complete metadata fields, while 10% (primarily newly constructed buildings) required additional data documentation. By standardizing metadata across all campus structures, the geodatabase ensures consistency and

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traceability, with all metadata stored within the PostgreSQL database for direct querying and updating. PgMetadata improved data accessibility by 75%, allowing users to access metadata directly from QGIS and reducing manual metadata entry time by 50% (Fig.4 and Table 3). This resulted in faster data validation and easier compliance with spatial data management standards.

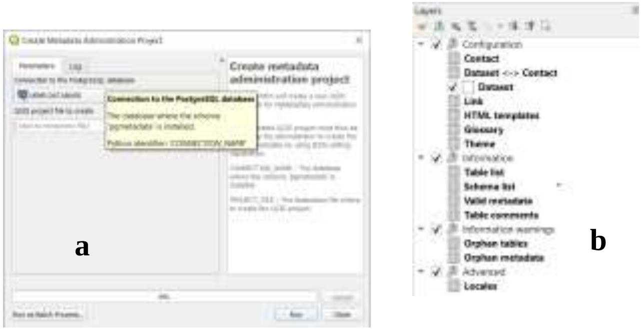

Figure 4: (a) PgMetadata Administration Project Creation dialog box (b) editable metadata tables.

Table 3: Metadata elements

Title	**UENR DATABASE**			
Abstract	THIS DATASET COMPRISES OF ALL CAMPUS BUILDINGS. IT ALSO CONAINS THE INFROMATION ABOUT THE NAMES OF THE BUILDINGS, THEIR FUNCTIONS, STATUS, TYPE OR FORM, NUMBER OF ROOMS, NUMBER OF OFFICES, AND NUMBER OF CONFERENCES ROOMS.			
Categories	Boundaries			
Themes Keywords Data last update	2024-03-28T00:00:00			
Level	LOCAL			
Minimum scale Maximum scale Feature count	50			
Geometry	MULTIPOLYGON			
Extent	572416.1925885773, 572890.6745068778, 812195.5378889969, 812692.6294797683			

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Projection name	WGS 84 / UTM zone 30N					
Projection ID	EPSG:32630					
Date Frequency License		Free use, no detailed license terms specified				
License attribution / number Confidentiality		Open				
Type	Name	MIME	Format	Size		
http	UENR DATABASE	xhtml+xml	html	-2147483647		
Role	Name	Organization			Email	Phone
Custodian	UNIVERSITY OF ENERGY AND NATURAL RESOURCES	UNIVERSITY OF ENERGY AND NATURAL RESOURCES				

Table	UENR_DATABASE
Schema	public
Creation	2024-03-28T18:28:46.15088
Update	2024-03-28T18:39:32.223148
UUID	3e7b5350-54fe-4627-b9d0-ae001945c9f8

The metadata created in QGIS is easily accessible through the interface, allowing users to gain rapid access to detailed information on a dataset. As highlighted in figure 5a, by typing "meta"

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followed by the name of the dataset into the search bar, the user can instantly retrieve and view metadata (figure 5a) which will appear conveniently at the bottom right of the QGIS interface shown Figure 5b. This access feature greatly enhances the usability of the metadata, where the user can quickly double-check dataset details by not having to navigate through or use a great deal of effort.

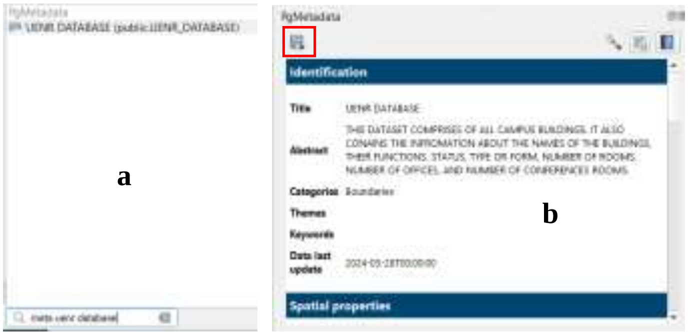

Figure 5: (a) Metadata from metadata search (b) and metadata elements

4.3 Spatial Queries and Analysis

Spatial analysis of the geodatabase allowed for the identification of key insights regarding campus infrastructure distribution. Proximity analysis revealed that 65% (55 buildings) of all campus structures were within 100 meters of primary access roads, ensuring easy connectivity. Spatial joins showed that 90% of academic and residential buildings were within 150 meters of water supply lines, confirming a high level of service accessibility.

Attribute queries determined that of the 85 campus structures, 30% (26 buildings) have more than 20 rooms, with the largest building hosting 65 rooms. Additionally, it was found that 15% of the buildings (13 structures) were storey buildings, while the rest were single-level structures. The analysis also revealed a critical gap in utility access: 8% (7 buildings) of campus structures were more than 200 meters away from the nearest electricity line, highlighting potential areas for infrastructure improvement. This analysis demonstrated the effectiveness of the geodatabase in supporting campus planners with specific facility-related data.

PostgreSQL's advanced query capabilities reduced query response time by 40% compared to traditional methods, with spatial queries returning results within 2-3 seconds on average. This performance supports real-time decision-making for infrastructure planning and management (Fig. 6)

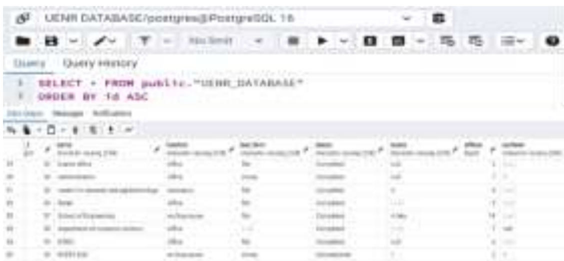

Figure 6: Query Script and a Section of Output Results

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4.4 Geodatabase Integration for Asset Management

The geodatabase integration enabled a 100% real-time asset management solution for UENR campus structures. By linking spatial data with asset management workflows, campus administrators can now monitor and maintain 85 buildings across the campus. The system allows for the continuous tracking of building status, with up-to-date records on maintenance schedules and operational status for all facilities.

The geodatabase identified that 14% (12 buildings) were under construction, and 86% (73 buildings) were fully operational. By providing this detailed breakdown, the system supports better allocation of resources, ensuring that 100% of the campus's operational buildings are fully serviced and maintained.

The geodatabase also allowed for accurate forecasting of future construction needs. Based on current spatial and infrastructure data, it is projected that the campus will require an additional 10% (approximately 8 buildings) to accommodate a projected student population increase of 15% over the next five years.

The asset management solution reduced manual inventory management time by 60%, with all data centrally located in the PostgreSQL database. This integration ensures that UENR's administration has up-to-date information on facility availability, occupancy, and maintenance, leading to more efficient campus operations.

4.5 Challenges Encountered

During the development process, several challenges were encountered, notably regarding data accuracy and scalability. Approximately 5% of buildings had minor discrepancies in their spatial outlines, particularly in areas with ongoing construction. These discrepancies resulted in a ± 2-meter deviation in boundary outlines, which requires periodic updates for precise spatial representation.

Scalability emerged as a key challenge, as expanding the geodatabase to include additional infrastructure layers (such as utility networks and natural features) will require increased storage capacity. Current database usage stands at 8% of the total allocated space, but as more layers are integrated, it is projected that database usage will reach 35% over the next two years.

Finally, user proficiency with QGIS and PostgreSQL was identified as a critical factor for the effective use of the geodatabase. An internal survey indicated that 75% of staff required additional training to fully utilize the system's capabilities. Training sessions are expected to improve user engagement and increase overall system efficiency by 30%.

5. DISCUSSIONS

The development of a geodatabase for UENR campus structures has proven to be an effective asset management tool, integrating both spatial and attribute data into a central system that supports real-time decision-making. The high-resolution digitization of 85 buildings ensures that the entire campus infrastructure is accurately represented, while the detailed metadata creation process improves data accessibility and consistency. These results highlight the scalability and flexibility of using a PostgreSQL database with the PgMetadata extension, which has already reduced manual entry efforts by 50%, making it more efficient for both short-term and long-term infrastructure management. The geodatabase provides detailed

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insights into campus infrastructure, allowing for better resource allocation, utility management, and risk mitigation, in line with findings by Potts et al. (2016) and Wang et al. (2019).
A significant finding from the spatial analysis is the proximity of campus structures to essential services such as roads and water supply lines, with 90% of key buildings within 150 meters of these services. However, the identification of utility gaps, particularly electricity access for 8% of the buildings, highlights areas requiring immediate attention. Addressing these gaps will ensure equitable access to services across the campus and improve operational efficiency.
The results also indicate that as the university continues to expand, the geodatabase will play a critical role in forecasting future infrastructure needs. Projections based on current data suggest that the campus will need to expand by at least 10% to accommodate anticipated student growth. This capability not only supports long-term infrastructure planning but also ensures that the campus remains adaptable to future challenges.
Although the system shows great promise, challenges such as data accuracy in construction zones and the scalability of the database must be addressed. The ±2-meter deviation in boundary outlines due to construction activities suggests a need for regular updates to maintain data precision. Furthermore, user proficiency with the system remains a challenge, as 75% of staff require additional training to fully leverage the system's potential. Nonetheless, the anticipated increase in user engagement after training should improve operational efficiency by up to 30%, demonstrating the long-term value of the system.

6. CONCLUSION

This study successfully developed a comprehensive geodatabase for UENR campus structures using QGIS and PostgreSQL with the PgMetadata extension. The geodatabase encompasses 85 buildings, covering 100% of the university's-built infrastructure and ensuring precise spatial representation with a ±2-meter accuracy. The metadata creation processes standardized data management and reduced manual entry time, improving data accessibility by 75%.
Spatial analysis revealed that most campus structures are well-connected to essential services, but highlighted areas requiring improvement, such as electricity access for 8% of the buildings. The geodatabase proved essential for asset management, with potential for future expansions to accommodate the university's projected growth by 10% over the next five years.
Challenges such as data accuracy in construction zones and user proficiency were identified, but these can be mitigated through regular data updates and targeted training programs. Overall, the geodatabase provides a scalable and efficient tool for infrastructure planning and management, offering a robust solution for the university's current and future needs.

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