

# Design and Implementation of Land Information System Using Spatial Database

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## Abstract

*Improving the accessibility, integration, and usability of land information is increasingly important for supporting planning, service delivery, and public transparency. This paper presents the high-level design of an Internet-based Land Information System using PostgreSQL/PostGIS spatial database technology. The proposed approach unifies spatial and non-spatial datasets within a single web-accessible environment, enabling the practical querying, visualization, and management of land ownership, rights, taxation, and parcel block maps. The system architecture emphasizes ease of use, scalability through open-source tools, and WebGIS-based deployment. The interface was developed using HTML and Tailwind CSS to ensure responsiveness and dynamic interaction. Core features include a navigation bar, search-based query tools with auto-suggestions, parcel selection with “info-on-click” attribute display, layer control, and attribute-based filtering (e.g., land-right type and owner-related attributes). Spatial visualization uses the OpenLayers JavaScript library, which fetches spatial data from the PostgreSQL/PostGIS database in GeoJSON format and overlays it on OpenStreetMap and other basemap tiles, allowing zoom, pan, and layer toggling. The dynamic display of results in GeoJSON format using JavaScript is made possible by PHP scripts that interface between the backend and frontend and fetch spatial SQL queries in response to user actions. The system was evaluated through functionality, performance, and usability testing. Transaction testing confirmed compliance with the ACID properties, while validation against official registers demonstrated consistent attribute integration and high geometric fidelity, with parcel-area differences of only 0.0096%. Performance testing showed efficient database query execution (average 51.78 ms), while web load time (Largest Contentful Paint) ranged from 2 to 4.5 seconds for approximately 2000 parcel records. Usability evaluation yielded a feasibility score of 83.57% (Very Good). The main contribution is the demonstration of permitting spatial databases unrestricted access to build agile but powerful land information systems for users, including administrators and the public, strengthening transparency and supporting digital transformation in local governance.*

**Keywords:** Digital Land Governance, Land Information System, PostgreSQL/PostGIS, Spatial Database, WebGIS

## 1. Introduction

Land management supports spatial planning, secure land tenure, and sustainability [1]. Well-defined governance structures, spatial data sharing, and Land Information Systems (LIS) require integrated, transparent systems, especially amid ongoing waves of digital transformation [2]. In many developing countries, land tenure systems remain administratively fragmented, particularly in tax management. In this context, taxation is crucial for revenue generation and controlling the economy. In Indonesia, Land and Property Tax (Pajak Bumi dan Bangunan, PBB) is a direct land and property tax, payable by landholders or persons entitled to rights to a given parcel of land. This tax supports local

government services, infrastructure development, and efficient land use.

In the administration of land tax, the ownership and jurisdiction of land, its spatial information, and property valuation must overlap [3]. A disconcerting problem arises from the divisions created by different governing bodies that manage land ownership and taxpayer systems. Most of the time, the landowners and taxpayers are the same individuals. Nevertheless, due to a lack of communication between systems, multiple systems run in parallel, generating contradictory and redundant information. This division neither facilitates the fulfilment of tax obligations nor renders the timely performance of

public service land-related functions virtually impossible. The integration of tax obligations, legal boundaries, and ownership records for a given parcel of land comprises the integration of the legal cadastre with the fiscal cadastre, which are the two essential components of the total cadastre system in land administration. The legal cadastre is the legal registration of the rights and ownership of a given parcel of land. In contrast, the fiscal cadastre is the recording of the parcels of land for tax purposes [4]. Integrating these cadastres improves governance by reducing conflicts and consolidating legal and fiscal land information. Like other countries, Indonesia faces challenges with its local land administration systems. Many areas still have land records kept on paper. Both spatial and non-spatial data are typically stored in silos, increasing fragmentation and data inconsistency [4]. The inability to integrate institutional data systems hinders efforts to develop agile, responsible land administration systems.

Affordable proprietary software and technical expertise are often in short supply. In contrast, open-source software is advantageous for creating simple, customizable, and localized LIS [5] and [6]. These solutions are particularly beneficial for rural and less developed regions, offering flexibility and relatively low scaling costs. While current land administration systems are often characterized by outdated frameworks and fragmented data silos, this study proposes a comprehensive web-based LIS to bridge the critical gap between the legal and fiscal cadastres. By leveraging a PostgreSQL/PostGIS spatial database, our system integrates disparate spatial and non-spatial datasets into a unified web interface, enabling simultaneous querying, visualization, and management of land boundaries, tax, and ownership records. Moving beyond the limitations of existing WebGIS prototypes that focus primarily on simple map visualization, this approach introduces modular, open-source analytical workflows specifically designed for long-term sustainability and scalability in rural contexts. Ultimately, this research demonstrates how the convergence of actual administrative data and open-source spatial technology can automate local governance functions, thereby enhancing efficiency, accountability, and the delivery of responsive land administration services [7].

## 2. Literature Review

The ownership of land remains a vital component of land administration systems, which are closely linked to legal frameworks, economic development, and social stability [8]. Practical, up-to-date documentation is necessary to resolve ownership disputes and to enable the Indonesian government to

enforce property taxes, including the Land and Property Tax [9]. The property tax system in Indonesia relies on land ownership information. It requires a link between land ownership and taxpayer information, posing challenges for compliance and streamlined service provision [10]. In rural Indonesia, ownership and taxation records are often fragmented and maintained in separate systems, resulting in inefficiencies and inconsistent records [11]. This division illustrates the more complex challenge of merging the legal and fiscal cadastres, the two fundamental pillars of land administration systems. The real estate cadastre captures data about ownership and rights, while the fiscal cadastre captures data about taxation. The integration of these cadastres improves coherence, reduces duplication, and increases administrative efficiency [4].

LIS, including subsystems such as Geographic Information System (GIS) and spatial databases, offers efficient solutions for the integrated management of both spatial and non-spatial data. GIS enables the capturing, storing, and manipulation of spatial data, as well as its visualization [12]. GIS spatial data processing technology aids in defining land parcels for ownership, delineating land use, and delineating legal boundaries and rights of the land [7] and [13]. The LIS also has a reliable spatial data infrastructure that supports spatial land data, even when the data are intricate. As Shashi and Chawla noted, spatial databases enhance the capabilities of traditional databases by permitting the storage of geometric data types and performing spatial operations, such as buffering, intersection, and proximity analysis [14]. Among open-source alternatives, PostgreSQL with its PostGIS spatial extension is best known for its proprietary spatial features, compliance with OGC standards, and integration with commercial GIS tools [15]. With these technologies, spatial queries can be performed for tax assessment, unpaid tax identification, and visualization of ownership patterns [2]. They also support real-time monitoring of ownership and tax status [16]. More efficient WebGIS systems have supplanted traditional GIS systems integrated with advanced spatial database technologies. Users no longer need specialized software to interact with spatial data, as WebGIS applications support standard browser interfaces [17]. With OpenLayers, interactive maps and specific layer displays can be rendered using simple JavaScript libraries. These systems form the framework of contemporary web-based LIS and are particularly beneficial in resource-limited settings [18].

The application of WebGIS for the separate management of land ownership data and tax data has been documented in various research works. In the

case of rural development, a spatially enabled information system incorporating ownership data, which, despite lacking fiscal datasets such as tax records, increased data availability and aided local decision-making [19]. In another study, a GIS application was developed for land parcel mapping, emphasizing the depiction of spatial data for land administration [20]. While the work improved the precision of land records, it did not integrate tax data or fiscal functions. In another example, the application of WebGIS was developed for supervising mining land licenses in the South Sulawesi region [21]. Although the work did not emphasize ownership or tax data, it demonstrated the capabilities of WebGIS for geospatial management of land-related permits. These studies demonstrate the fragmented application of spatial technology for managing land ownership data and related datasets, revealing the lack of an integrated system that unites the legal and fiscal cadastres. Other sectors, too, have availed of open-source geospatial technologies. WebGIS system was developed for managing emissions data in PostgreSQL/PostGIS and rendered it using MapServer [22]. This system is a clear example of spatial databases and web-based technology for the visualization and handling of spatial data.

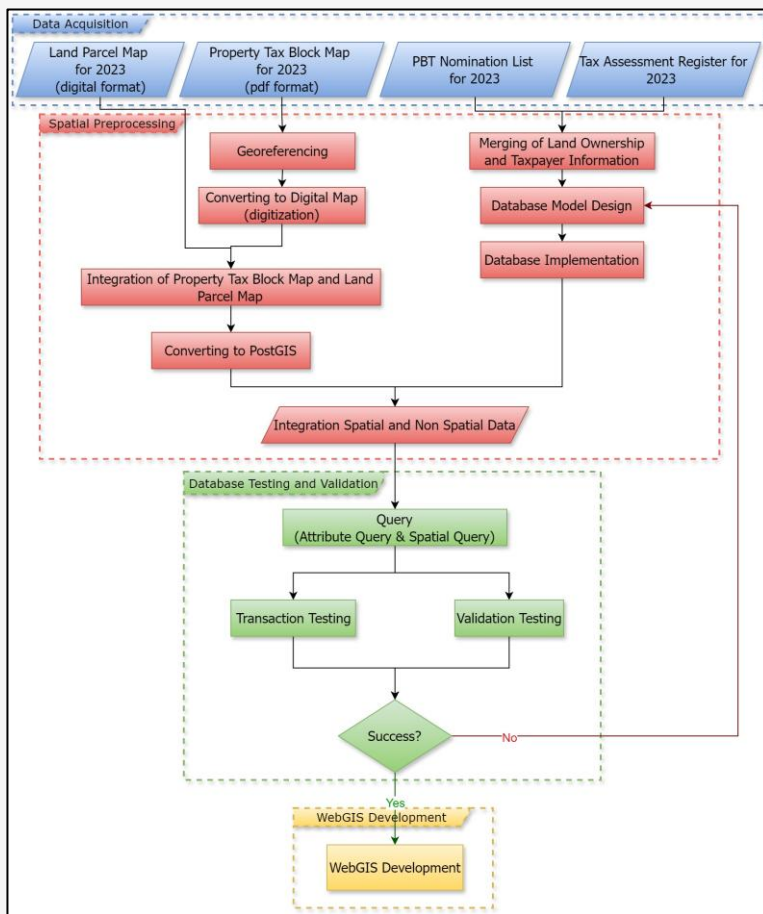
Although the focus of this study is on the environmental aspect, the central concept can be adapted for land administration to integrate spatial data in real time across other levels of governance in a multi-attribute context. Technological improvements pave the way for refining specific systems; however, some elements remain lacking. Most existing systems focus on map visualization components of geospatial data and rarely allow the integration of geospatial and attribute information into analytical workflows. Furthermore, most systems are implemented as prototypes on a small scale, ignoring critical elements such as long-term maintenance, adaptability to rural or under-resourced regions, and extensibility. The absence of rational modular design approaches, alongside spatial databases and WebGIS, integrated within practical land governance frameworks and "real-world" administrative data, represents a significant gap in the literature. This integrated, open-source, geospatially enabled LIS fills the void using a case study that illustrates the synergy of PostgreSQL/PostGIS and WebGIS in land administration for developing regions. Using actual land and tax documents from a local land office and

village administration, the system demonstrates the utility of PostgreSQL/PostGIS and WebGIS in a land administration system for developing regions. The proposed system supports scalable, transparent, and accountable land governance.

### 3. Methodology

The research site selected for this study was Kedaton Village in Kapas District, Bojonegoro Regency, in East Java Province, Indonesia, and is geographically situated at  $7^{\circ} 12' 6''$  S and  $111^{\circ} 55' 39''$  E. This village was selected because it had both spatial and non-spatial datasets, which made the development of a spatial database possible, based on a land information system. This study used spatial and non-spatial datasets. The spatial datasets comprised the 2023 Land Parcel Map obtained from the National Land Agency and the 2022 Block Map PBB of Kedaton Village obtained from the Regional Revenue, Financial Management, and Asset Agency. Non-spatial datasets included land parcel data and a document from the 2022 Tax Assessment Register (Daftar Himpunan Ketetapan Pajak, DHKP), which lists the region's land and building tax assessments obtained from the Regional Revenue, Financial Management, and Asset Agency.

This research integrated various software applications for data management, processing, and analysis. Spatial data visualization and analysis were conducted using QGIS, and spatial databases were administered using PostgreSQL with the PostGIS extension. These tools were chosen for the study because of their familiarity to the community where the study was conducted, affordability, spatial capabilities, and appropriateness for the study objective of building a low-cost land information system. The methodology for this study is presented in Figure 1. The initial phase began with the identification of data consisting of digital land maps for 2023, 2023 PBB block maps in PDF format, a 2023 PBB nomination list, and a 2022 PBB assessment master list. Spatial data without coordinate references underwent georeferencing to ensure their positions were consistent with the coordinate system used. Next, analog or semi-digital maps are converted into digital vector maps for further processing in a GIS environment. Once all spatial data were available in a digital format, land parcel maps and PBB block maps were integrated to ensure administrative boundary consistency and spatial compatibility between layers.



**Figure 1:** Overall methodology for web GIS development flowchart

The integrated spatial data were then converted and stored in a PostGIS spatial database, which served as the main repository for the geospatial data. At this stage, a database model was designed to integrate spatial and non-spatial data, including land ownership information, tax obligations, and property tax assessment attributes.

The next phase is the integration of spatial and non-spatial data, which enables relational links between geographic objects and tax attributes using shared keys. This integration supports the implementation of attribute and spatial queries, such as searching for objects by taxpayer identity and land location, and spatial analysis based on administrative areas. To ensure system reliability, data validation and database transaction testing were performed to ensure the accuracy, consistency, and integrity of the managed data. The system underwent evaluation through attribute query and spatial operation query testing on the geospatial data. Also, transaction tests were performed to evaluate the Atomic, Consistent, Isolated, and Durable (ACID) principles, which are crucial for maintaining data integrity in multi-user

environments. Furthermore, the data returned by the system and the data queried were checked against the original data to validate the data stored within the system, ensuring consistency between the data retrieval and the data returned. These evaluations, along with the compilation of results, were conducted to support analysis and reporting.

After the database was validated through transaction testing and system validation, the WebGIS interface development stage began (Figure 2). This development adopted a client-server architecture that separates the user interface (frontend) development from the server logic (backend). The overall system architecture is illustrated in Figure 3, which shows the interactions among the client (browser), the frontend layer, the backend API service, and the PostgreSQL/PostGIS spatial database. On the backend side, an API Endpoint was developed using the PHP programming language to execute queries on the PostGIS database and generate output in GeoJSON format. GeoJSON was chosen for its efficiency in web-based spatial data exchange.

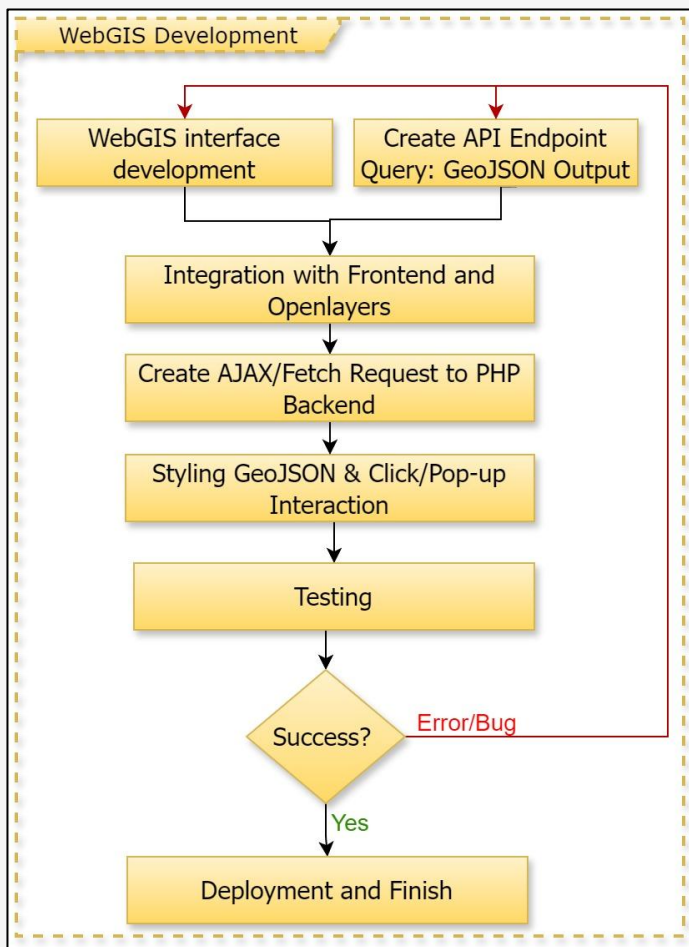


Figure 2: WebGIS development flowchart

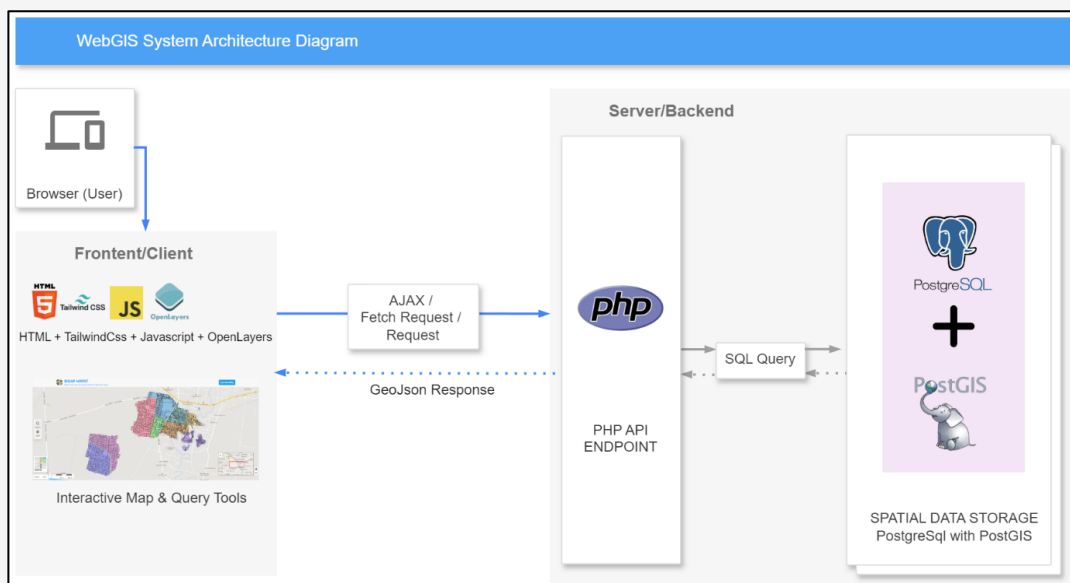


Figure 1: WebGIS system architecture illustrating the client-server structure and data flow between the frontend (OpenLayers), backend API (PHP), and PostgreSQL/PostGIS spatial database

The webGIS interface uses HTML with Tailwind CSS. This interface includes an interactive map, navigation bar, search tool via a search box, and a panel for metadata display. Tailwind CSS not only helps with visual spatial layout but also makes the work cohesive and simplifies layout design and prototyping across various screens and devices. Integration is achieved by connecting the frontend using the OpenLayers library as the main mapping engine, which is capable of dynamically rendering spatial data that is then displayed on top of the OpenStreetMap base map and other base map tiles. The ability to zoom, pan, and enable/disable layers was provided to enhance user interaction with spatial data.

Communication between the frontend and backend is handled using Asynchronous JavaScript and XML (AJAX) or the Fetch API. This mechanism allows data to be loaded without refreshing the entire page and triggers geospatial SQL queries using custom PHP scripts, returning spatial data and attributes in GeoJSON format. This data can be manipulated and displayed via JavaScript on the frontend, enabling dynamic data interaction without reloading the page. Spatial data manipulation through the map interface, including land parcel selection, attribute-based filtering (e.g., land rights or owner's name), and data refresh actions, is performed using JavaScript. This design allows users to operate all land-related information systems easily and provides significant assistance. After the system was built, it underwent functionality, usability, and performance testing to evaluate its suitability for land administration and for public access. Data visualization was enhanced by applying styling schemes to GeoJSON and by developing interactive features, such as click events and pop-ups, to display detailed attributes for each land parcel.

The final phase included functional testing of the WebGIS system to ensure that all components met the requirements and expectations. Once all functions were declared successful and met the functionality standards, the system was implemented in a production environment for public access. Furthermore, a performance test was conducted by measuring query execution time on the database side using EXPLAIN ANALYZE and web load time using the Largest Contentful Paint (LCP) metric, with each measurement repeated 10 times to ensure reliable results. To complement functional and performance evaluation, a usability test was conducted to assess the system from the end-user perspective. A structured questionnaire consisting of 19 questions was designed based on fundamental usability dimensions, including learnability, efficiency, memorability, error prevention, and user

satisfaction. Each indicator was measured using a 5-point Likert scale ranging from strongly disagree (1) to strongly agree (5). The collected responses were then quantified into a feasibility percentage using the formula presented in Equation (1), which compares the total test score to the maximum possible score. Furthermore, the resulting percentage values were interpreted into qualitative categories based on the conversion criteria provided in Table 1.

$$Feasibility [\%] = \frac{Total\ test\ score}{Maximum\ score} \times 100$$

Equation 1

**Table 1:** Conversion of eligibility percentage

Feasibility Percentage	Predicate
81% - 100%	Very Good
61% - 80%	Good
41% - 60%	Fairly Good
21% - 40%	Not Very Good
< 20%	Very Poor

## 4. Results and Discussion

### 4.1 Spatial Database Design and Implementation

The spatial database serves as the core toward which the rest of the system is oriented for data collection, querying, and analysis of land data. The Entity Relationship Diagram (ERD) presented in Figure 4 illustrates the logical structure of the spatial and non-spatial entities integrated within the database. The most crucial spatial table, "Bidang Tanah" (Land Parcel), which is the primary table, contains geometry data types and references both the Parcel Identification Number (Nomor Identifikasi Bidang, NIB) and Tax Object Number (Nomor Objek Pajak, NOP) as foreign keys, thereby linking cadastral parcels to ownership and tax records.

A normalized database structure was adopted to ensure data consistency, reduce redundancy, and support system scalability. The "Pemilik Tanah" (Landowner) table is linked through NIB, capturing the ownership details. Other demographic data are also stored in the "Orang" (Person) table and include name, date of birth, religion, and occupation, which are also stored in the "Agama" (Religion) and "Pekerjaan" (Occupation) tables. Administrative linkages are supported by references to "Wajib Pajak" (Taxpayer) and "Desa" (Village) tables. The database is implemented with PostgreSQL and PostGIS, which provide spatial indexing and advanced geospatial analysis for land administration, including, but not limited to, proximity analysis, spatial joins, and intersection queries.

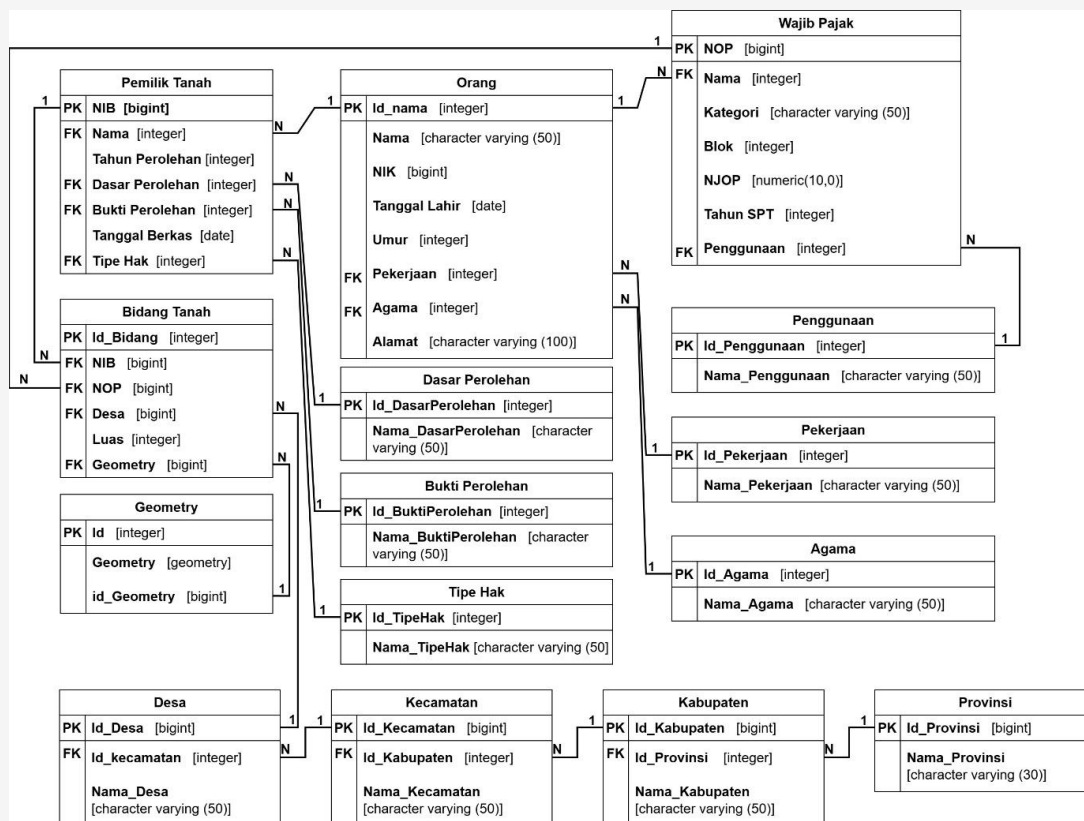


Figure 4: Logical model

## 4.2 Database Testing and Validation

### 4.2.1 Transaction testing

The test results show that the PostgreSQL database used in this study successfully meets all ACID principles. The atomicity testing demonstrates that the system can abort an entire transaction sequence when a single operation fails. This test was conducted using an SQL script scenario that attempted to update data in both the "Orang" and "Wajib Pajak" tables within a single transaction block. In this scenario, the second instruction (UPDATE "Wajib Pajak") was intentionally designed to violate a NOT NULL constraint. As shown in Figure 5, when the second command fails, the system automatically rolls back all changes within the transaction, restoring the "Orang" table to its original state. Consequently, the system prevents partial data updates that could lead to database inconsistencies. The consistency principle is tested through transactions involving relationships between tables. The consistency test results in Figure 6 were obtained by executing an INSERT operation into the "Pemilik Tanah" table that references Id\_Nama (5000), which does not exist in the parent table "Orang". This indicates that the system automatically rejects transactions that violate foreign key constraints. This rejection proves that the integrity of

the relationships between entities is maintained, and each transaction can only move the database from one valid state to another.

Isolation testing was performed to ensure that concurrent transactions did not affect each other. The testing was performed using two separate terminal sessions. The test results, shown in Figures 7(a) and 7(b), indicate that the other session cannot read uncommitted data changes in one session. This indicates that the transaction isolation mechanism works well, is able to prevent dirty reads in a multi-user environment, and satisfies the isolation principles of the default PostgreSQL isolation level. Furthermore, durability testing demonstrated that committed data remained permanently stored despite system disruptions. The test involved updating one of the "Wajib Pajak" category records to "K1," confirming the transaction, and immediately restarting the PostgreSQL server. PostgreSQL's write-ahead logging (WAL) mechanism ensures that data changes remain available after a system restart. Thus, the database system is deemed suitable for use in critical and ongoing land data management. Overall, the results of this transaction testing demonstrate that the database system has sufficient reliability to support critical and ongoing land administration operations.

```

Query Query History
1 BEGIN;
2
3 UPDATE "Orang"
4 SET "Nama" = "Faris Naufal", "Umur" = 45
5 WHERE "Id_Nama" = 101;
6
7 UPDATE "Wajib Pajak"
8 SET "Kategori" = NULL
9 WHERE "NOP" = 3522240707027777;
10
11 COMMIT;
Data Output Messages Notifications
ERROR: transaksi saat ini dibatalkan, perintah diabaikan sampai akhir blok transaksi
SQL state: 25P02

```

Figure 5: Results of the atomic principal transaction test

```

Query Query History
1 BEGIN;
2
3 INSERT INTO "Orang" ("Id_Nama", "Nama", "NIK", "Umur", "Pekerjaan", "Agama", "Alamat")
4 VALUES (5000, "Fauzan Azhar", 3503241307000007, 38, 3, 2, "Jl. Raya No. 5");
5
6 INSERT INTO "Pemilik Tanah" ("NIB", "Nama", "Tahun Perolehan", "Tipe Hak")
7 VALUES (35100100500400123, 5000, 2019, 1);
8
9 COMMIT;
10
Data Output Messages Notifications
ERROR: kolom « Fauzan Azhar » tidak ada
LINE 4: VALUES (5000, "Fauzan Azhar", 3503241307000007, 38, 3, 2, "J...
                          ^
SQL state: 42703
Character: 111

```

Figure 6: Consistency principal transaction test results

```

Query Query History
1 BEGIN;
2
3 UPDATE "Orang"
4 SET "Umur" = 78
5 WHERE "Id_Nama" = 1;
6
Data Output Messages Notifications
UPDATE 1
Query returned successfully in 57 msec.

```

(a)

```

Query Query History
1 SELECT "Umur" FROM "Orang" WHERE "Id_Nama" = 1;
Data Output Messages Notifications
Umur integer
1 77

```

(b)

Figure 2: (a) Terminal 1 view (update process not yet committed);  
(b) Terminal 2 (Concurrent Data Query) view

4.2.2 Data validation and verification

Attribute validation was conducted by comparing non-spatial data stored in the database with source documents, specifically DHKP copy book and nominative data from Kedaton Village. The validation results indicated that attributes such as NOP, taxpayer name, National Identity Number (Nomor Induk Kependudukan, NIK), age, occupation, and religion recorded in the database were consistent with the data in the reference documents. As illustrated in Figures 8 and 9, the taxpayer data for "Sumarni," with NOP (35.22.130.023.001-0008.0) recorded in the database, corresponded to the data in the DHKP copybook. Similar data validation was also conducted using village nominative data, as shown in Figures 10 and 11. The comparison results show that

attributes such as owner name, NIK, age, occupation, and religion stored in the database are consistent with the source data. These findings demonstrate that the non-spatial data integration process was conducted accurately and reliably. Spatial data validation was conducted by comparing the geometric accuracy of land parcels: the area calculated in the database was compared with the PBT and PBB. The comparison between the land area on the Nominative Land Parcel Map and the geometric calculation results from the PostGIS spatial function (ST\_AREA) is shown in Figures 12 and 13. The analysis results show a very small difference in area, which is around 0.0096% of the total land area. This small difference is still within acceptable tolerance limits and can be attributed to variations in the measurement algorithm method, map scale, and geometric calculation approach used.

5	I	35.22.130.023.001-0005.0	H.KASRUN	SWH KULON OMAH
6	I	35.22.130.023.001-0006.0	WIJI	KULON OMAH
7	II	35.22.130.023.001-0007.0	BK.KAUR PEMBANGUNAN/SUYONO	KULON OMAH
8	II	35.22.130.023.001-0008.0	SUMARNI	SWH KULON OMAH

Figure 8: A copy of the tax assessment register book (Sample Data Sumarni)

	NOP bigint	Nama Wajib Pajak character varying (50)	NIK bigint
1	352213002300100080	SUMARNI	[null]

Figure 9: Database Display (Sumarni Data Sample)

NAMA PEMILIK TANAH	N.I.K	TANGGAL LAHIR	UMUR	PEKERJAAN	AGAMA
KASRINI	3522144110650003		24016	59 Petani/Pekebun	Islam
MOH. NASYIM	3522140704630006		23108	61 Pegawai Negeri Sipil (PNS)	Islam
SOEJONO	3522141212490003		18244	75 Petani/Pekebun	Islam
AHMAD BAGUS PRASETYA	3522141708920001		33833	32 Wiraswasta	Islam
AGUS SUP'I	3522141708740005		27258	50 Wiraswasta	Islam
SUPARNO	3522141010670009		24755	57 Petani/Pekebun	Islam
FINDIANA CATUR APRILIA	3522145504950001		34804	29 Mengurus Rumah Tangga	Islam
CHOLIS SUFIYAH	3515134305770003		28248	47 Mengurus Rumah Tangga	Islam
WIWIK SOFIAH	3522146408940001		27265	50 Mengurus Rumah Tangga	Islam

Figure 10: Nominative land parcel map (Peta Bidang Tanah, PBT) data view

Nama Pemilik character varying (50)	NIK bigint	Tanggal Lahir date	Umur integer	Pekerjaan character varying (50)	Agama character varying (50)
AHMAD BAGUS PRASETYA	3522141708920001	1992-08-17	32	Wiraswasta	Islam

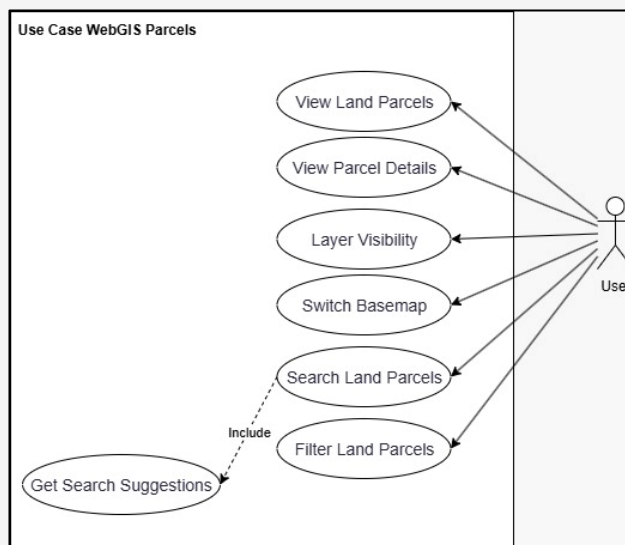
Figure 11: Database Display (Ahmad Bagus Prasetya Sample)

▼ PBT
▼ Data input TETAP
▶ (Derived)
▶ (Actions)
OBJECTID 219
Shape_L... 496,74199802100
Luas pbb 13468
CRatio p... 1
LUAS PB... 13468,374440

Figure 12: Broad results on PBT nominative land parcel map data

▼ Area_Kedaton	
▼ _uid0_ 219	
▸ (Derived)	
▸ (Actions)	
_uid0_ 219	
st_area	13467,083869804943

**Figure 13:** Broad results on the database (PostGIS)



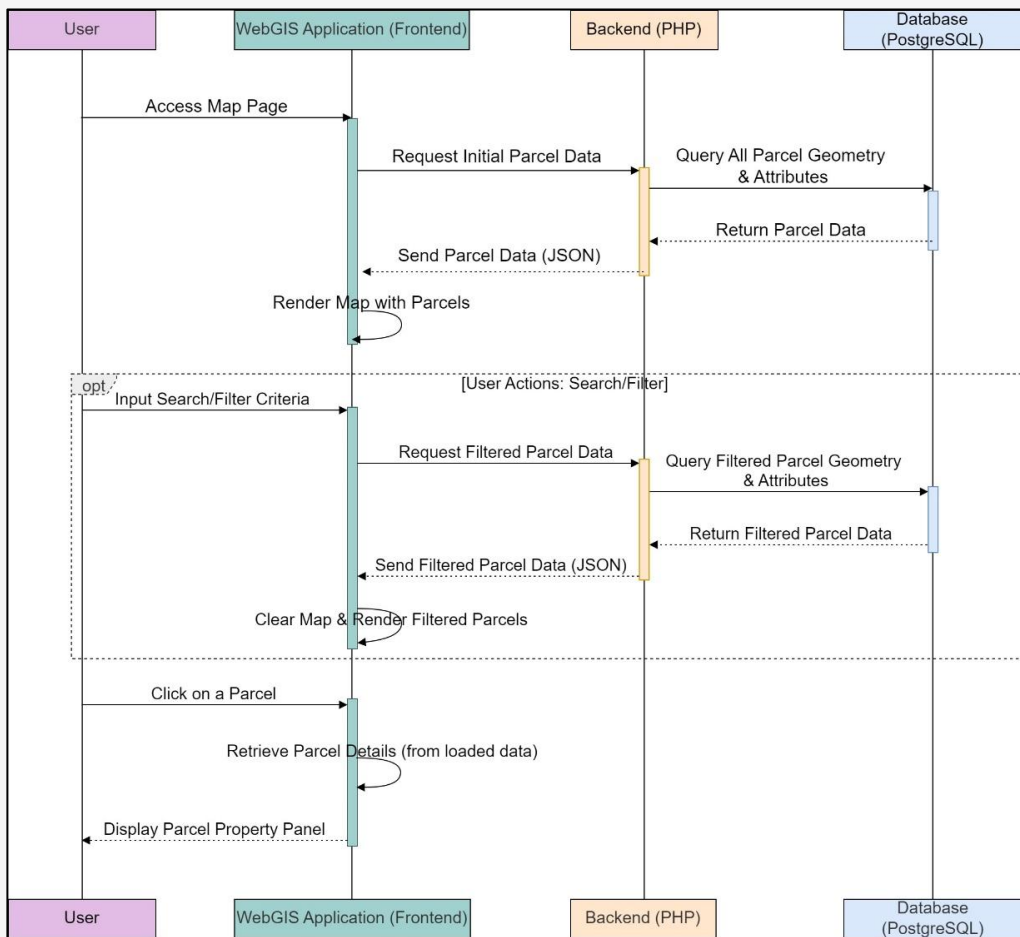
**Figure 3:** Use case diagram of the WebGIS-based Land Information System of SIGAP (Sistem Informasi Geospasial Aset Tanah dan Pajak-Geospatial Information System for Land Assets and Taxes)

#### 4.3 WebGIS Functionality, Interaction, and Interface

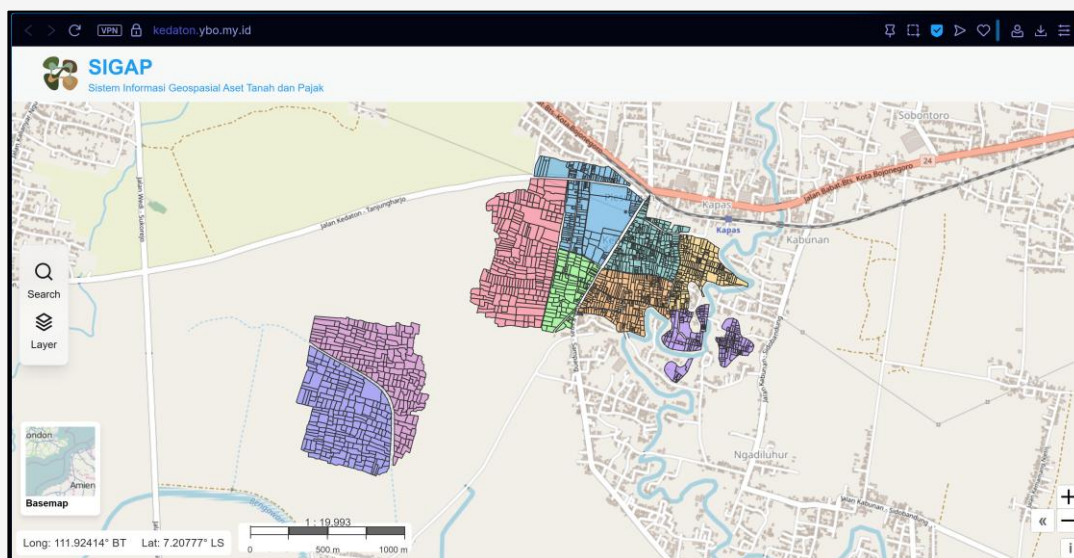
The WebGIS function developed in this study is a direct implementation of a previously validated integrated spatial database. The relationship between users and the system is summarized in the use case diagram shown in Figure 14, which illustrates the role of users in accessing, exploring, and analyzing land parcel data and related attributes through a web-based interface. The system is built using a combination of technologies such as OpenLayers, HTML, PHP, JavaScript, and Tailwind CSS. The SIGAP WebGIS application is accessible at <https://kedaton.ybo.my.id> and provides a live platform for users to interact with the system. The interface is designed to transform the complexity of spatial databases into tools for public transparency and intuitive decision-making for administrators and the general public. Unlike conventional systems that often separate map and textual data, this system integrates them into a single, dynamic, unified display.

Spatial interaction is a key feature of this system, supporting the transparency and accessibility of land and building tax data integrated into a single system. The interaction between the user and the system components is detailed in the sequence diagram in Figure 15, which illustrates how the user, the

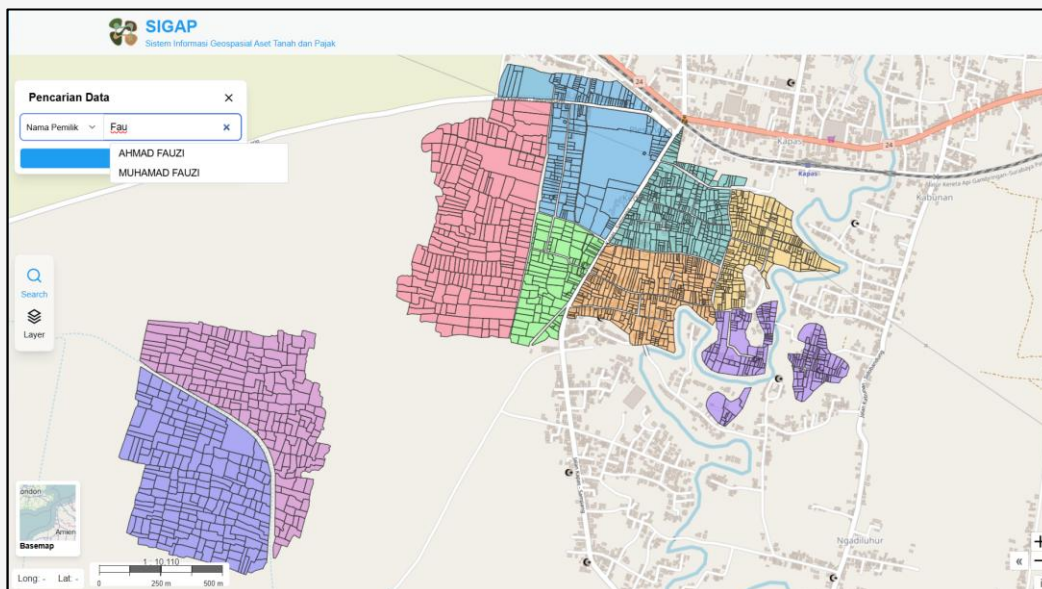
frontend, the backend, and the PostgreSQL/PostGIS database communicate during a typical WebGIS session. The implemented client-server architecture allows asynchronous data retrieval using AJAX. The request process begins when the user opens a map page, which triggers the frontend to send the user's request for processing to the backend. The backend executes a query against the database, retrieves relevant records, and returns them in JSON format. The system then resets the previous map view and populates it with new data for the filtered land parcels. The results are returned in an efficient data format for display on the map without reloading the page. This provides a responsive user experience, where land parcel visualizations (Figure 16) can be accessed with minimal latency. The use of the OpenLayers library allows for rapid rendering of thousands of parcel polygons on top of a variety of basemap options (satellite or street maps) to provide accurate geographic context. As shown in Figure 16, the WebGIS system can dynamically display all land parcels by retrieving their geometries directly from a PostgreSQL/PostGIS database. This visualization enables users to understand the comprehensive spatial distribution of land parcels, a key function that supports land data transparency and accessibility.



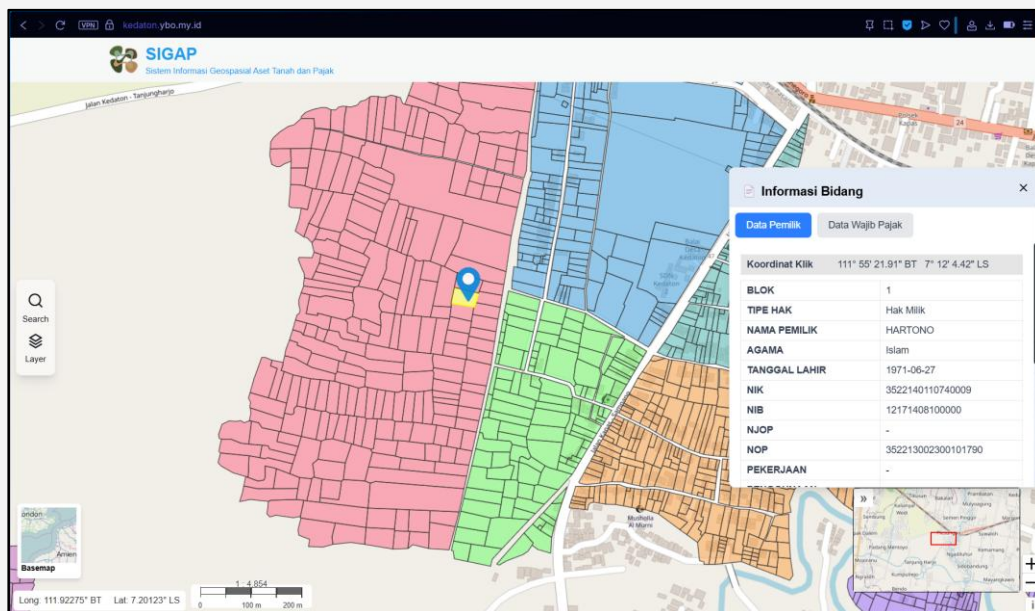
**Figure 4:** Sequence diagram illustrating the system interaction flow of SIGAP, illustrating the asynchronous data retrieval flow between the User, Frontend, and Backend



**Figure 16:** Main Visualization of cadastral land parcels rendered dynamically from the PostgreSQL/PostGIS database within the WebGIS interface



**Figure 17:** Auto-suggestion mechanism for parcel search queries



**Figure 18:** Accessing parcel attribute information through spatial selection (Info-on-Click)

Data search and filtering capabilities are crucial to supporting the transparency of attribute-based analysis information. The system allows users to search for land parcels by keywords such as owner name or parcel number, and to apply data filters to narrow the displayed data. The system also includes an auto-suggestion mechanism to improve search efficiency. The system automatically navigates to the location of relevant land parcels on the map. This feature is demonstrated in Figure 17, which shows how the system dynamically suggests relevant entries based on stored data. Another important

feature is the "Info-on-Click" feature (Figure 18), which bridges the gap between legal and fiscal cadastres by instantly displaying ownership data, land area, and tax status when a parcel is selected. This feature significantly reduces asset identification time compared to conventional search methods on analog maps and digital documents.

In addition to searching, users can also perform thematic filtering of land parcels based on specific attributes, such as the owner's religion or land title type. The filtering results are visualized directly on the map, supporting intuitive attribute-based spatial

analysis. The implementation of this feature is shown in Figure 19. Overall, the WebGIS interface, shown in Figure 20, demonstrates the integration of spatial visualization, search functionality, attribute filtering, and metadata presentation in a single, responsive work environment. This integration allows users, both administrators and the general public, to quickly and transparently access and understand land information without specialized GIS software. To conclude, the WebGIS system integrates geographic and alphanumeric land data with a responsive human-machine interface. It enables hierarchy-free,

transparent, real-time access to data and information from the structured backend system to the frontend engineering team, using interactive mapping libraries and a responsive, intuitive user interface. It also enables better comprehensive land management for the users. It helps stakeholders identify land ownership patterns, compute intersections, and determine compliance with zoning regulations. As such, the platform enhances transparency, effectiveness, and access, particularly in rural areas with limited digital infrastructure.

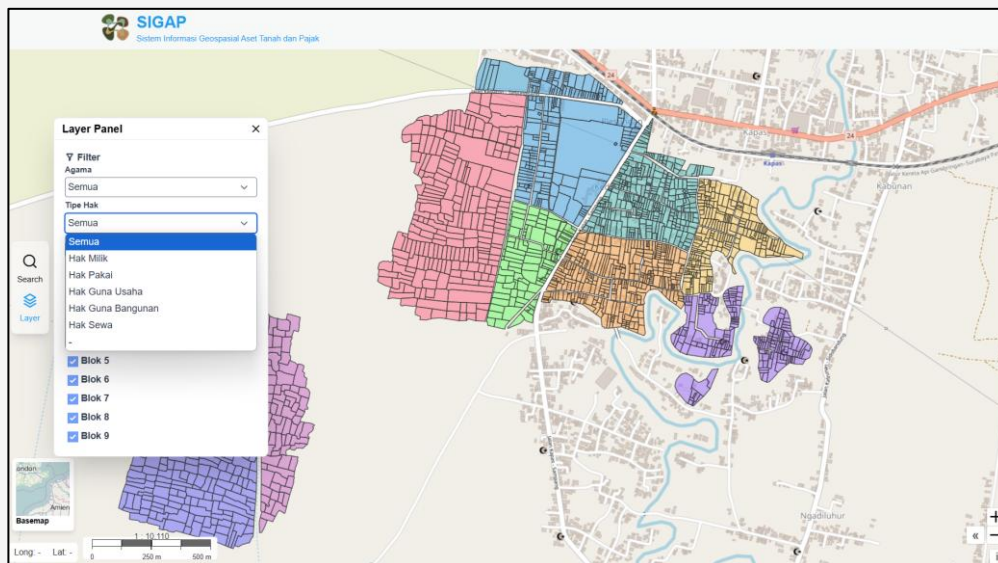


Figure 19: Attribute-based filtering of land parcels

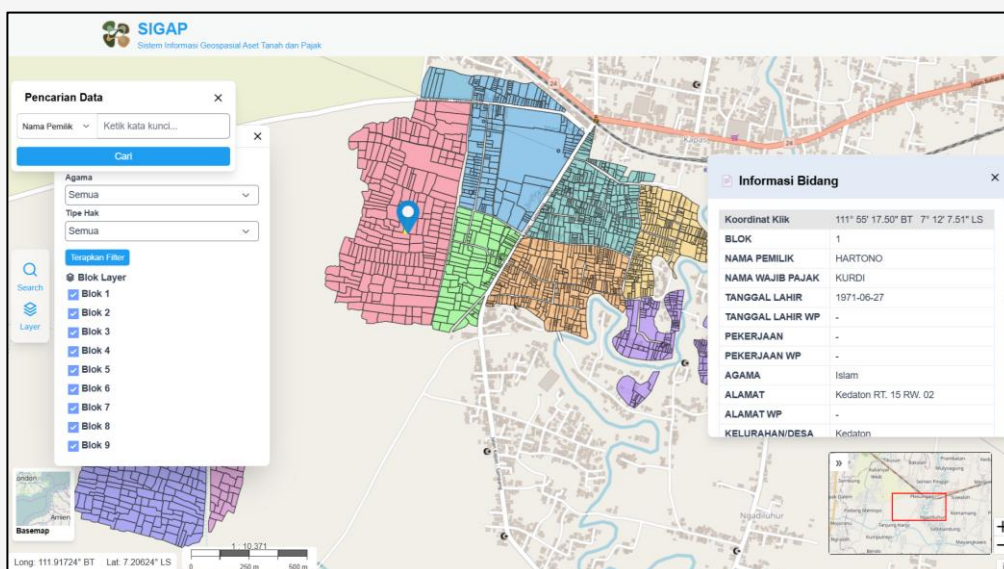


Figure 20: GUI Prototype for SIGAP application

#### 4.4 System Performance and Usability Analysis

To ensure the reliability and responsiveness of the system for end users, performance testing was conducted to evaluate the performance of the PostgreSQL/PostGIS-based WebGIS system in a database query scenario with a join operation between the spatial table of land parcels and attribute tables (ownership and taxes), with a data amount of  $\pm 2000$  land parcels. The testing focused on two main metrics: the pure query execution time on the database side (using EXPLAIN ANALYZE) and the web page load time, represented by Largest Contentful Paint. Each scenario was tested 10 times to obtain a more stable performance overview. The test results shown in Table 2 show that the execution time for pure database queries ranges from 44.36 ms to 72.80 ms, with an average of around 51-55 ms.

**Table 2:** Performance result for Database Query and Web Loading Time (10 Iterations)

RUN	DB Query (ms)	Load Time Web LCP (ms)
1	44.36	2078.719
2	45.06	2355.746
3	46.22	4529.288
4	47.31	4463.704
5	49.07	4588.341
6	51.17	4367.728
7	52.11	2720.503
8	53.73	4455.048
9	55.92	3475.291
10	72.80	3499.506
<b>Average</b>	51.78	3653.3874

This value indicates that PostgreSQL can efficiently execute the join mechanism between tables, including attribute and geometry processing. Meanwhile, the results of the web load time (LCP) test show more varied values, ranging from  $\pm 2078$  ms to  $\pm 4588$  ms. This variation reflects that client-side performance is influenced not only by the speed of database queries but also by the GeoJSON data transfer process, vector map rendering in the browser, and network conditions and frontend processing load. Nevertheless, all LCP values remain within the 2-4.5 second range, which is generally acceptable for WebGIS applications with complex spatial visualizations and a relatively large number of polygon objects.

Beyond technical performance, system quality must also be evaluated from the user perspective. Therefore, usability testing was conducted to assess ease of use, learnability, efficiency, errors, and user satisfaction. The evaluation involved 33 respondents who assessed the system using 19 indicators (Q1–Q19) on a 5-point Likert scale (Strongly Disagree

(STD)-Strongly Agree (SA)). The detailed distribution of respondents' assessments is presented in Table 3, which summarizes the frequency of responses across the five Likert categories. These indicators were designed to represent various dimensions of usability, including ease of navigation, clarity and consistency of the interface, efficiency of interaction, and overall user comfort and satisfaction. This approach allows for a comprehensive quantitative assessment of the user experience when interacting with the system. Based on the assessment results, the feasibility value was calculated using the feasibility percentage formula as shown in Equation (1). The percentage value was then converted from a quantitative value to a qualitative value using the criteria in Table 1. The analysis results showed that the system obtained a feasibility percentage of 83.57%, which falls into the "Very Good" category based on the eligibility percentage conversion. This score indicates that the system has met the fundamental principles of usability, namely learnability, efficiency of use, memorability, error minimization, and user satisfaction. This achievement shows that users can understand and operate the system effectively. More deeply, this high level of usability indicates that the interface design and interaction flow applied are in line with user needs and expectations.

#### 4.5 Discussion and Implications for Land Administration

The results of the development and implementation of a land information system based on a spatial database in this study indicate that an integrated approach combining spatial and non-spatial data using PostgreSQL/PostGIS and WebGIS is effective in supporting land administration at the local level, particularly in addressing the fragmentation between land ownership data and taxation-related information. By integrating legal and fiscal cadastres within a single WebGIS-based system, the proposed framework provides comprehensive, accessible, and transparent land information. The main findings from the database testing phase demonstrate that PostgreSQL/PostGIS ensures transactional data integrity by adhering to ACID principles, while maintaining high geometric accuracy of land parcels with minimal deviation (0.0096%) compared to the official cadastral map.

From a system performance perspective, the results indicate that the spatial database can efficiently support the execution of integrated queries at the local administrative scale and does not become a major system bottleneck.

**Table 3:** Summary of usability evaluation results and feasibility calculation

Questions	Assessment					Total
	STD	D	N	A	SA	
Q1	2	1	6	3	21	139
Q2	2	0	6	11	14	134
Q3	4	0	6	7	16	130
Q4	2	0	6	7	18	138
Q5	2	0	6	6	19	139
Q6	2	0	4	8	19	141
Q7	1	2	5	5	20	140
Q8	2	0	7	5	19	138
Q9	1	1	6	4	21	142
Q10	2	0	7	5	19	138
Q11	2	0	6	5	20	140
Q12	1	1	5	12	14	136
Q13	2	0	11	7	13	128
Q14	2	2	5	5	19	136
Q15	2	1	5	7	18	137
Q16	2	0	4	8	19	141
Q17	2	1	4	4	22	142
Q18	2	0	4	9	18	140
Q19	2	0	4	8	19	141
<b>Total Test Score</b>						2,620
<b>Maximum Value</b>						3,135
<b>Usability Test Feasibility Percentage</b>						83.573

To further demonstrate the quantitative improvement over conventional manual systems, previous studies report that digital land information systems generally provide faster processing time, higher data accuracy, and clearer administrative services [23] and [24]. Conversely, WebGIS performance is more influenced by the visualization and presentation of spatial data on the frontend, so future optimizations need to focus on this aspect to support scalability and user experience. This is further supported by the usability evaluation results “Very Good”, indicating that users generally perceive the system as responsive and easy to use despite variations in load time.

Despite the system's significant potential, this study acknowledges several limitations that warrant careful consideration. Given the system's entirely web-based architecture, its reliance on network connectivity significantly impacts system performance, contingent on the state of the information technology infrastructure in remote rural areas. Furthermore, the system's scalability has not been tested at larger scales, such as the district or provincial level, and requires further evaluation to handle significantly larger user numbers and data volumes. Data quality also relies heavily on the accuracy and consistency of the source data, particularly analog or semi-digital data that requires georeferencing and digitization, potentially

introducing errors. Without strict data maintenance protocols and standardized data management procedures, the risk of “garbage in, garbage out” remains a potential threat to the long-term validity of the system. The implementation process indicates that system sustainability depends not only on technological integration but also on consistent data governance and institutional capacity. The experience underscores the importance of standardized data management procedures and careful frontend optimization, particularly in environments with limited digital infrastructure.

In the context of national land reform, this system has practical relevance as a model for implementing geospatial technology at the local level. This system aligns with the spirit of village digitalization and the “One Map” policy. The system's ability to map ownership and tax status can be a vital tool for local governments to identify unregistered land or unpaid taxes, thereby supporting increased regional original income. The system is not intended as a universal solution or a replacement for existing national systems, but rather as a contextual approach that can complement land digitization efforts. By leveraging open-source software and administrative data available at the village and regional levels, this system demonstrates how digitization can be implemented incrementally and realistically, in accordance with local capacity.

The future work development roadmap could focus on several aspects to increase user adoption. First, optimizations need to focus on frontend performance, scalability at broader administrative levels, and user experience. Second, the development of mobile apps is highly recommended to facilitate village officials in the field by updating data and providing residents with direct access to information. Third, to ensure broader data interoperability with national and global systems, the database structure should be adapted to comply with the ISO 19152 Land Administration Domain Model (LADM) standard. This step would transform the system from a local administrative tool into a standardized data node within the national geospatial information infrastructure. Therefore, the system developed in this research is not intended as a final solution but rather as an initial platform that can be developed incrementally to meet institutional needs and capacity.

## 5. Conclusion

This research successfully demonstrates the design and implementation of a WebGIS-based LIS using a spatial database within a client-server architecture. The system was developed using PostgreSQL with the PostGIS extension as the spatial database, a PHP based API for backend processing, and the OpenLayers JavaScript library for frontend spatial visualization and interaction. Through this system, data concerning land ownership, rights, taxes, parcels, and boundaries can be queried, visualized, and managed via the web. An important innovation is the integration of ownership information into a spatially enabled database, which incorporates land and building tax records. This merger integrates the legal cadastre (ownership records) and fiscal cadastre (taxation records), enhancing administrative accuracy, transparency, and efficiency.

Validation results confirm high geometric reliability with a deviation of only 0.0096% and full adherence to ACID properties in database transactions. Performance testing shows that the database layer operates efficiently. At the same time, usability evaluation results (83.57% – "Very Good") indicate that the system is well accepted by users and meets core usability principles, including learnability, efficiency, memorability, error minimization, and user satisfaction. These benefits underscore the system's potential as a scalable and adaptable tool for regional digital transformation.

However, the system's effectiveness remains highly dependent on the availability and quality of the initial data, and its accessibility is influenced by internet connectivity in rural areas, as the application is entirely web-based. System integration challenges

may also arise when aligning the platform with existing national infrastructure, necessitating rigorous data management and strengthening interoperability through ISO 19152 (LADM) standardization. Overall, this research provides a replicable and context-sensitive framework for leveraging spatial databases and WebGIS technologies to improve land governance, enhance transparency, and support evidence-based public service delivery, particularly in developing and rural regions.

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