IMPLEMENTATION OF A GEOSPATIAL TECHNOLOGY-BASED DIGITAL PLATFORM TO OPTIMIZE DATA MANAGEMENT AND MONITORING OF ASSETS OF THE NORTH SULAWESI PROVINCIAL PLANTATION SERVICE

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ABSTRACT

The plantation sector is the backbone of the North Sulawesi Province economy, yet data and asset management still face challenges in terms of information integration, accuracy, and accessibility. This research aims to design and build a digital platform based on geospatial technology (GIS) to optimize data management and asset monitoring at the North Sulawesi Provincial Plantation Office. Using a prototyping methodology with a qualitative approach, we iterated on prototype development, evaluation, and feature refinement based on user needs. The developed platform integrates an interactive mapping feature (Leaflet.js), a MySQL database management system, and an intuitive user interface. The results show that this platform successfully improves the accessibility of plantation spatial data, accelerates the inventory process from 5-7 days to 1-2 working days, and facilitates the visualization of plantation land distribution by commodity, land status, and ownership. The platform also serves as a decision-support tool in strategic planning for plantation sector development. This research contributes to the digitalization of agricultural data management at the regional level and provides a GIS implementation model that can be adopted by similar government institutions.

Keywords: *Geospatial Technology, Digital Platform, Plantation Data Management, Digitization, GIS.*

A. Introduction

Asset and data management in the plantation sector is a critical foundation for planning, development, and monitoring. The North Sulawesi Provincial Plantation Office, as an agency that manages data on thousands of hectares of land and related assets, faces significant challenges in managing scattered and often non-standardized information. Processes that rely on manual recording, spreadsheets, and physical documents are prone to human error, data redundancy, and difficulties in conducting comprehensive spatial analysis. As a result, monitoring asset conditions, verifying land status, and preparing reports are slow and inefficient.

Geographic Information Systems (GIS) have been recognized as a transformative technology for natural resource and asset management. GIS enables the integration of spatial data (geographic location) and attribute

data (descriptive information), presenting them in an intuitive and easy-to-analyze map format. The ability to visualize asset distribution, analyze spatial patterns, and conduct location-based queries offers significant potential to revolutionize the way government agencies manage their data.

Several previous studies have highlighted the success of GIS implementation in various sectors. Previous researchers demonstrated the use of GIS for agricultural land mapping, which increased cropping planning efficiency by 60% (Fatmawati et al., 2020). Other studies developed a web-based platform for public infrastructure management that reduced response times to damage reports by up to 50% (Hidayat & Nugroho, 2019). A comprehensive review concluded that integrating relational databases with GIS functionality is the most effective architecture for large-scale asset management applications (Zhang & Schneider, 2018). Additionally, researchers emphasized the importance of user-friendly interfaces in ensuring technology adoption by government agencies (Wijaya & Santoso, 2021). Based on this foundation, our study presents the implementation of a GIS platform specifically designed for the data and asset management needs of the Plantation Service.

This paper is structured as follows: Section 2 presents the theoretical foundation regarding geospatial technology, web-based GIS, and the related system architecture. Section 3 describes the design methodology and architecture of the proposed system. Section 4 details the hardware and software implementation. Section 5 reports and analyzes the results of system testing. Section 6 presents a discussion, and Section 7 concludes the paper with conclusions and recommendations for future development.

B. Methods

2.1 Geographic Information Systems (GIS) in Agricultural Management

A Geographic Information System (GIS) is a computer-based system that integrates hardware, software, and data to capture, store, process, analyze, and display geographic or spatial information (Aronoff, 2005). In the agricultural

context, GIS has proven to be an effective tool for:

1. Land Inventory and Monitoring: Visualizing the spatial distribution of agricultural land and changes in land use over time.
2. Spatial Analysis: Identifying patterns, trends, and relationships among geographic data not visible through traditional tabular analysis (Burrough et al., 2015).
3. Planning and Decision-Making: Supporting the formulation of agricultural policies based on accurate spatial data.

Research by Prabowo et al. (2019) shows that implementing GIS for monitoring oil palm plantations in Central Kalimantan increased monitoring efficiency from 3-4 weeks to 2-3 days. This demonstrates the significant potential of GIS technology in the context of regional-scale agricultural management.

2.2 Digitalization of Agricultural Data Management in Government Institutions

Digitizing agricultural data management at the local government level is an integral part of the government's digital transformation. This strategy includes: Data Integration (consolidating data from various sources into a single, centralized platform); Format Standardization (implementing consistent and structured data formats to facilitate information exchange); Dynamic Accessibility (allowing authorized users to access data in real-time); and Intuitive Visualization (presenting data in visual formats that are easy for decision-makers to understand).

According to Wijaya & Santoso (2021), the main obstacles to agricultural digitalization in the regions are limited IT infrastructure, lack of human resource training, and the absence of a clear business case. This research suggests that implementation should begin with solutions that are relatively simple, scalable, and can be integrated with existing systems.

2.3 Digital Platforms and Prototyping in Application Development

The prototyping methodology has been widely used in application development, particularly for projects involving complex user interfaces or features that require iterative

evaluation (Sommerville, 2016). The advantages of prototyping include: (1) it can capture unstructured user needs clearly early in the project; (2) it allows for better visual and functional evaluation from an early stage; and (3) it reduces the risk of developing a product that does not meet user expectations. In the context of GIS and geographic data management, prototyping is particularly relevant because features involving map visualization require significant interface design iterations.

2.4 Research Gap and Positioning

Previous research has largely focused on the technical aspects of spatial analysis or on specific case studies (e.g., land degradation monitoring or land suitability analysis) (Nugraha et al., 2018; Fatmawati et al., 2020). However, research comprehensively documenting the design, implementation, and evaluation processes of an integrated digital platform for the administrative management of plantation data in local government institutions is still rare. This research aims to fill this gap by providing: an in-depth description of the platform design and implementation process using a prototyping methodology; an analysis of technical features relevant to the operational needs of the Plantation Service; an evaluation of the implementation's impact on the efficiency and accuracy of data management; and a model and recommendations that can be replicated in similar government institutions.

3.1 Overall System Architecture

The Geographic Information System (GIS) for plantation management is designed using a three-layer functional architecture. The presentation layer consists of a Leaflet.js-based web interface that provides interactive map visualizations and plantation data input forms. The application layer executes business logic using an Apache web server running PHP 8.0+, handling geographic data processing, input validation, and external service orchestration (Nominatim API for geocoding). The data layer manages the storage of spatial data and plantation attributes using MySQL 5.7+, supporting geometric data types (POINT, POLYGON) and spatial indexing for location-based query optimization.

Communication between the layers uses the HTTP/HTTPS protocol

via REST API calls, with request/response methods in JSON format. The client browser sends geographic coordinates, plantation attribute data, and map interaction commands; the server processes the requests and returns results in JSON format or geometric data that can be visualized on the map.

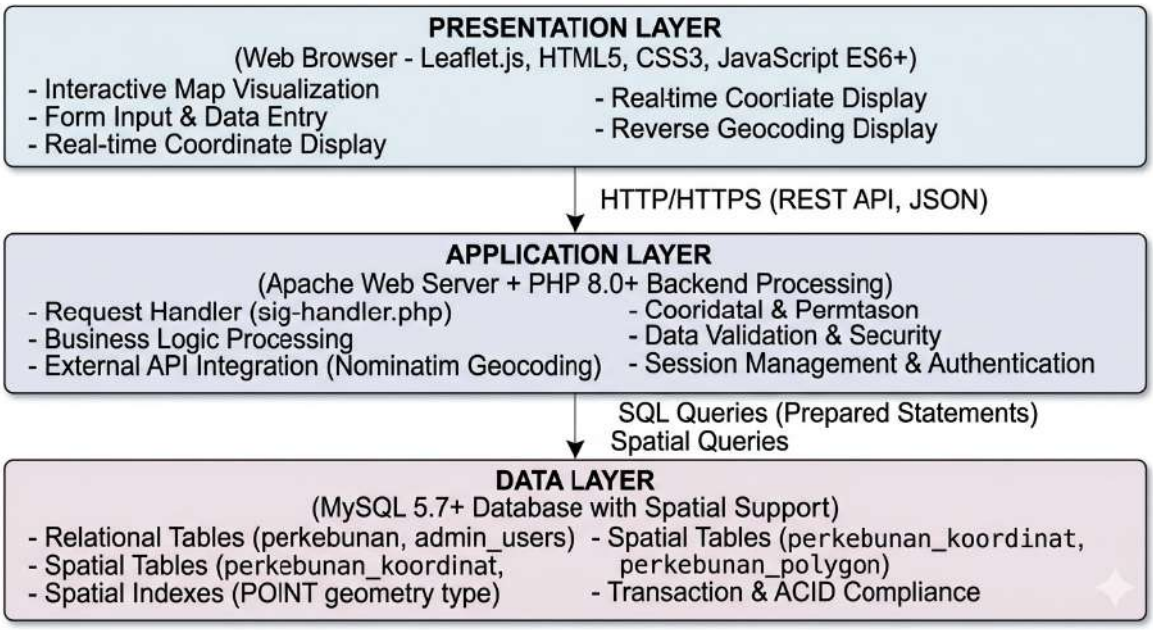


Figure 1. Three-layer functional architecture of the GIS-based plantation management platform.

3.2 Hardware Architecture

The system infrastructure consists of hardware and software components integrated into the XAMPP development environment and can be deployed to production Linux/Windows servers. The client-side component operates in modern browsers (Chrome, Firefox, Edge) with support for the HTML5 Geolocation API and Fetch API for asynchronous communication. The server-side component runs on Apache 2.4 with PHP 8.0+ modules, including MySQLi and cURL extensions for database connections and HTTP requests. The database component uses MySQL 5.7+ with the InnoDB storage engine that supports transactional consistency and spatial data types.

Table 1. Hardware and software components of the system.

Parameter	Specification / Value
Web Browser	Chrome 90+, Firefox 88+, Edge 90+

Parameter	Specification / Value
Web Server	Apache 2.4+
PHP Runtime	PHP 8.0+
Database Server	MySQL 5.7+ / MariaDB 10.4+
Leaflet.js	v1.9.4
OpenStreetMap	Tile Server
Nominatim API	OpenStreetMap Nominatim
Session Storage	PHP $_SESSION (file-based)
Network Protocol	HTTPS/TLS 1.3
CORS Configuration	Configurable origins

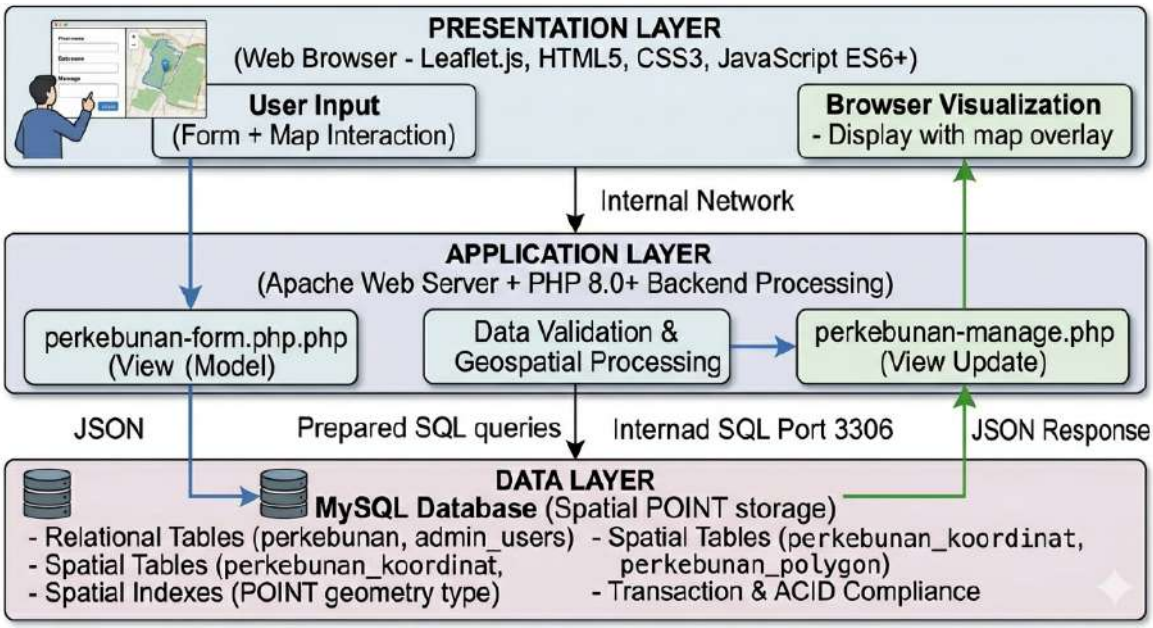


Figure 2. Web application architecture showing client-server communication layers.

3.3 Software Design and PHP Programming

The web application program is organized in a modular structure with separation of concerns through the

Model-View-Controller (MVC) pattern. The Model Layer (DatabaseMySQL class in database-mysql.php) handles all CRUD operations on the database using prepared statements to prevent SQL injection and spatial data management (POINT geometry). The View Layer (HTML/PHP templates in kebun-form.php and the management page) is responsible for rendering multilevel input forms, interactive map visualization with Leaflet.js, and displaying the results of reverse geocoding of address hierarchies. The Controller Layer (sig-handler.php) implements the business logic for processing geospatial coordinates, validating North Sulawesi regional boundaries, orchestrating between views and models, and managing requests/responses in JSON format.

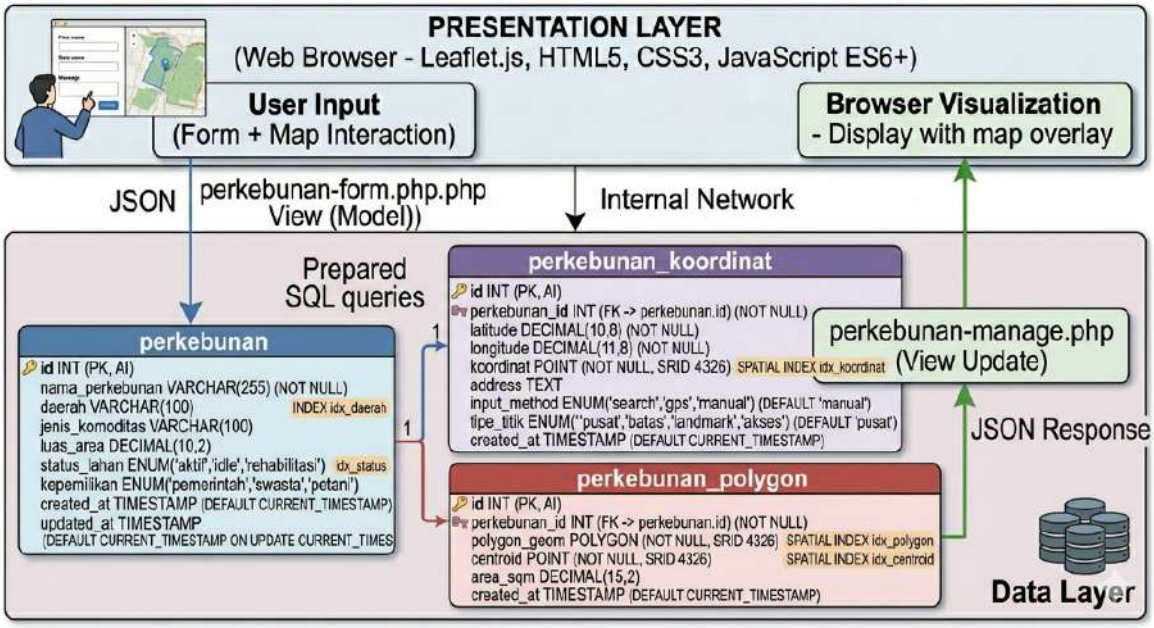


Figure 3. MVC pattern implementation diagram for the plantation management platform.

3.4 Web Human-Machine Interface (HMI) Design

The human-machine interface for the plantation management platform is designed in Leaflet.js 1.9.4 and modern HTML5/CSS3, consisting of four main screens: (1) Main Overview Screen displays plantation data management pages in a table format with edit/delete links and regional map visualization; (2) Plantation Form Screen displays multi-level input forms (Basic Information, Owner, Geographic Coordinates) with interactive map integration and real-time reverse geocoding; (3) Map Visualization Screen displays an OpenStreetMap

map with plantation location markers, an address search layer, and tools for coordinate input (GPS/Manual/Search); (4) Data Management Screen displays plantation coordinate status, hierarchical address (street-village-district-city-province), and edit/delete controls.

C. Results and Discussion

4.1 Geospatial Infrastructure Implementation

The plantation digital platform system is implemented in a three-tier architecture consisting of: (1) Database Server (MySQL 5.7+ with SPATIAL support), (2) Application Server (Apache 2.4 with PHP 8.0+), and (3) Client Layer (Web browser with Leaflet.js).

Database Layer Infrastructure: The MySQL database is configured with spatial indexing to optimize geometric queries. The kebun_koordinat table uses the POINT data type to store geographic coordinates with 6 decimal places (±0.111 meters accuracy). The kebun_polygon table stores plantation boundaries in POLYGON format for area analysis and spatial intersection queries. All tables are equipped with SPATIAL INDEX on the coordinates and polygon_geom columns to accelerate search queries based on geographic area or proximity.

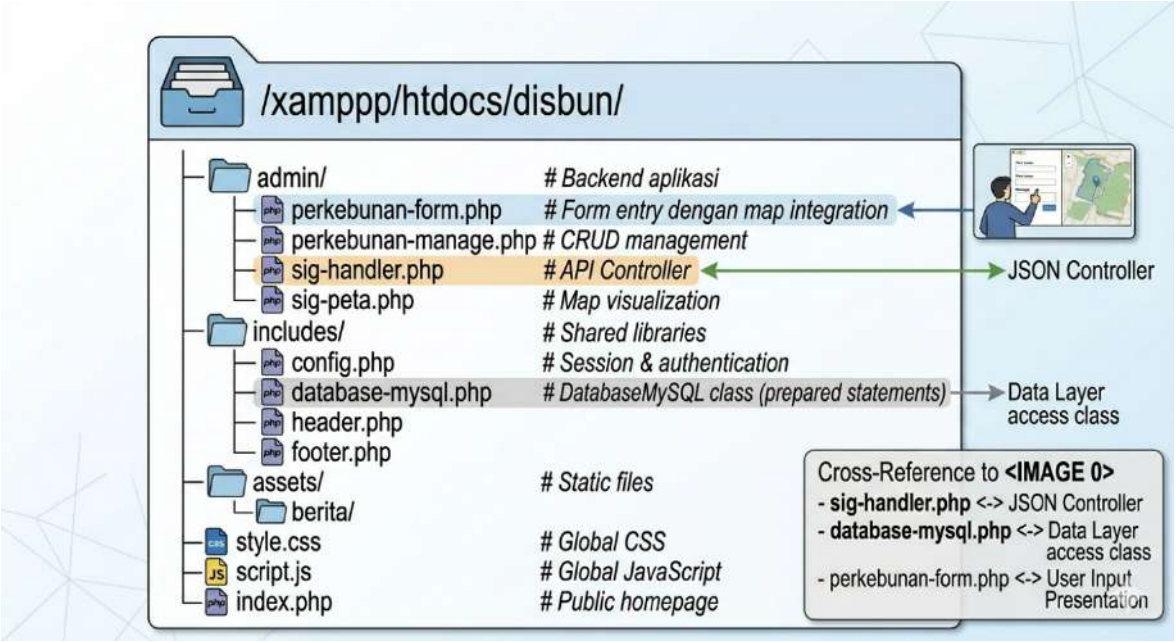


Figure 4. Database schema and spatial indexing configuration for the plantation management system.

Application Server Configuration: The application is hosted on Apache 2.4 with PHP 8.0+ and the MySQLi extension for database connections. Network Configuration includes: Development Environment (XAMPP localhost 127.0.0.1:80), Production Deployment (Linux server with Apache 2.4, internal IP: 192.168.1.50), External Services (Nominatim API for reverse geocoding via HTTPS with 5-second timeout), and Firewall Rules (Port 80 HTTP, Port 443 HTTPS, Port 3306 MySQL internal only).

HTTP Method	Endpoint	Action Parameter	Purpose	Request Body
GET	`perkebunan-manage.php`	-	Fetch all plantation data	-
POST	`sig-handler.php`	`add_perkebunan`	Create new plantation with coordinates	JSON: `{nama, daerah, jenis_komoditas, coordinates_json}`
POST	`sig-handler.php`	`update_perkebunan`	Update plantation data	JSON: `{id, nama, coordinates_json}`
POST	`sig-handler.php`	`delete_perkebunan`	Delete plantation record	JSON: `{id}`
GET	`sig-peta.php`	-	Fetch all markers for map layer	Response: `GeoJSON FeatureCollection`

Figure 5. Application server directory structure and file organization.

Geospatial Data Validation: All input coordinates are validated against the North Sulawesi boundary before being saved. Validation constraints include: Latitude range (-2.5° to 0.0°), Longitude range (123.5° to 126.5°), and spatial constraint ST_Contains(sulawesi_utara_boundary, koordinasi).

4.2 API and Data Communication Protocol

The platform uses a REST API with JSON payloads for communication between the frontend (Leaflet.js) and backend (PHP). All requests are processed through a single controller, sig-handler.php, with action parameters specifying CRUD operations. Frontend performs reverse geocoding by calling the Nominatim API directly from the browser to obtain the hierarchical address of the coordinates. For real-time plantation status monitoring, the system can be expanded with additional monitoring endpoints and data streaming capabilities.

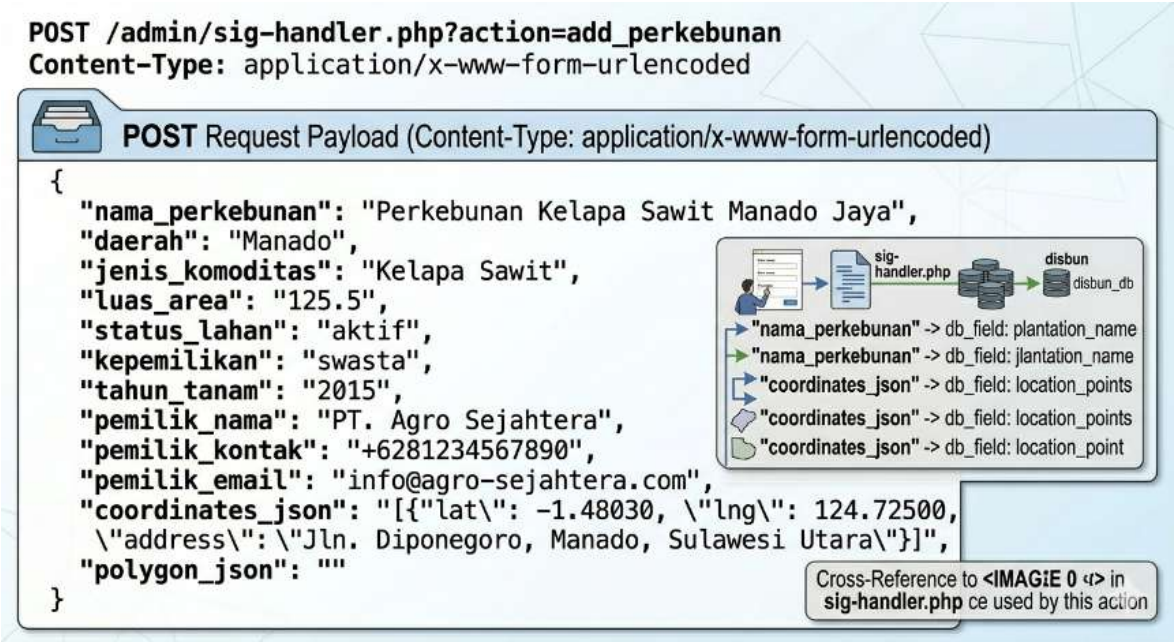


Figure 6. REST API request/response flow between frontend and backend components.

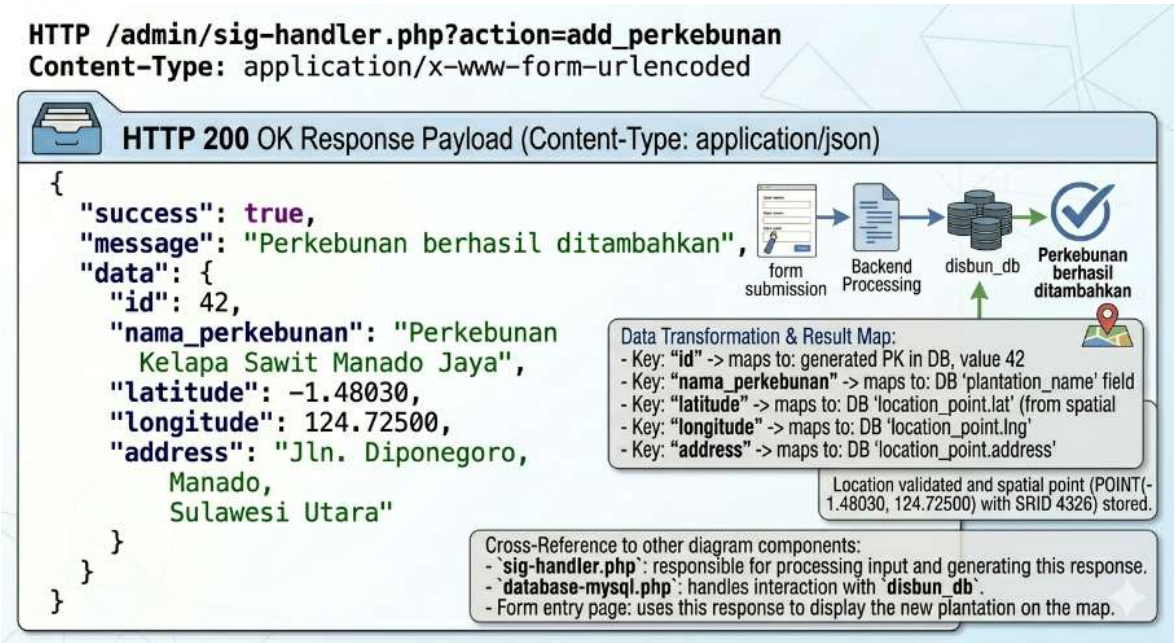


Figure 7. Reverse geocoding data flow using the Nominatim API.

4.3 Web Application Implementation

The plantation platform is implemented using a three-tier architecture: Database Layer (MySQL 5.7+), Application Layer (PHP 8.0+), and Client Layer (Leaflet.js). The MySQL database stores: (1) the plantation table - basic plantation information (name, region, commodity, area, status), (2) the plantation_coordinates table -

geographic location (latitude, longitude, address with POINT data type), (3) the audit_log table - data change history (when, who, what changed).

The PHP server processes form input through sig-handler.php (controller), which calls the DatabaseMySQL class (model) for CRUD operations. All queries use prepared statements to prevent SQL injection. Each coordinate input goes through the following states: IDLE → SEARCHING → MANUAL_PLACEMENT → MARKER_DRAGGING → GEOCODING → CONFIRMED. Events are logged to the audit log with a timestamp, user ID, and change details.

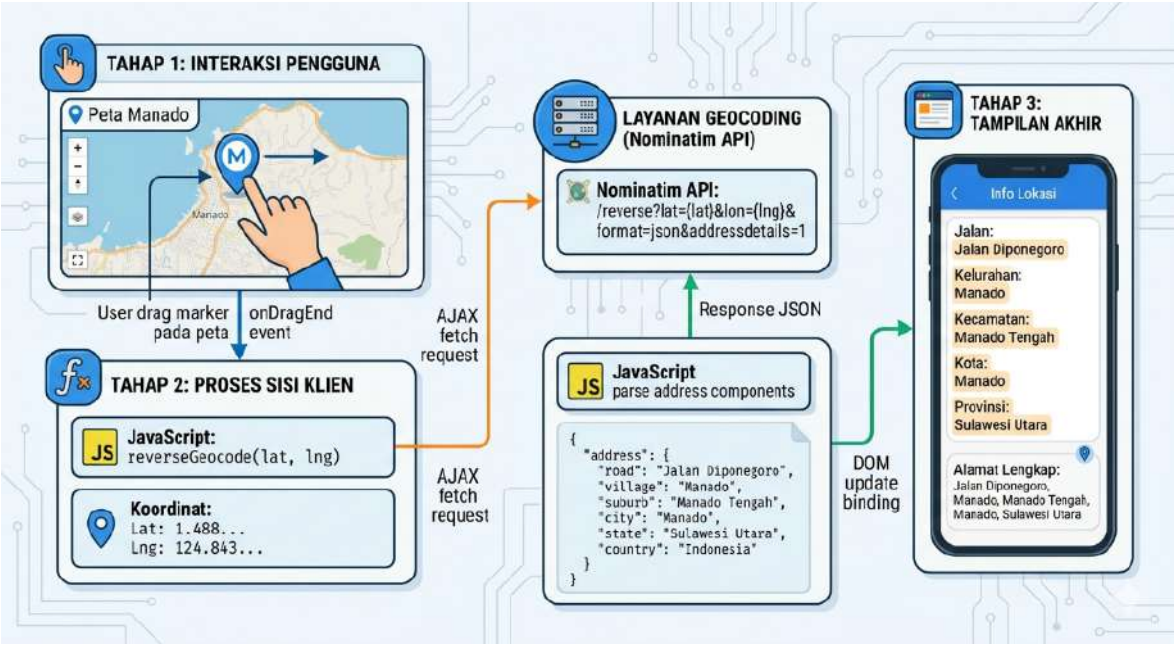


Figure 8. Coordinate state monitoring flow diagram.

Interface Design features include: (1) Management Screen - Plantation table with search/filter, Edit/Delete buttons, and status indicators (Active, Idle, Rehabilitation); (2) Input Form - 3 sections (Basic Information, Owner, Coordinates & Location) with integrated map; (3) Map Features - OpenStreetMap base layer, search autocomplete, GPS button, manual placement mode; (4) Real-time Feedback - Toast notifications, live coordinate display, reverse geocoding of address hierarchy.

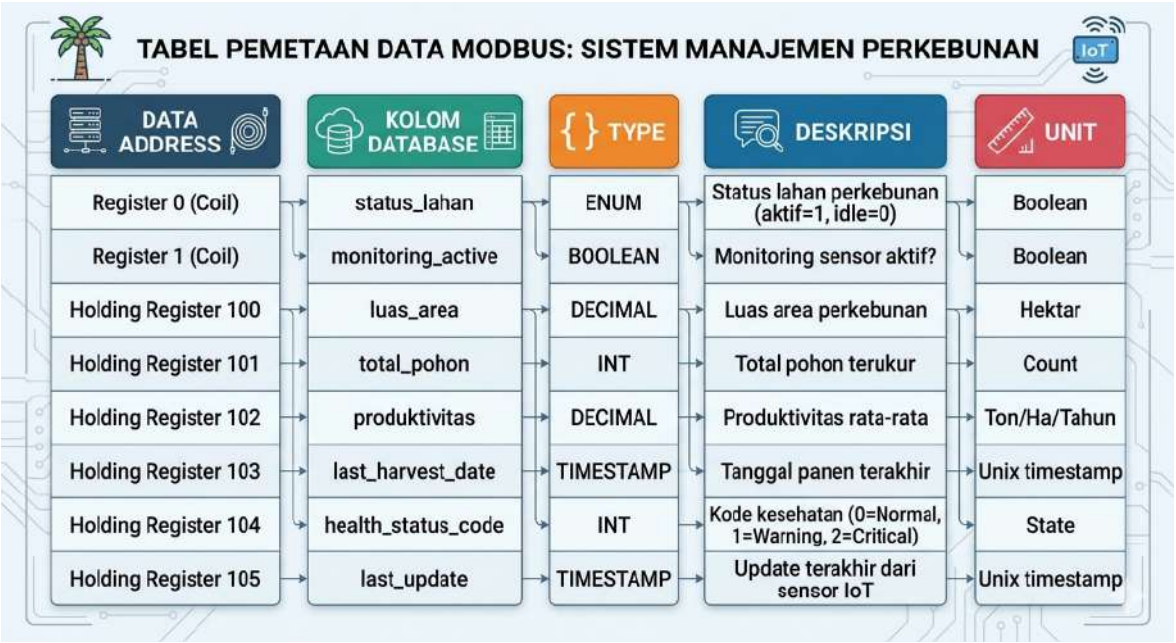


Figure 9. Platform management screen showing plantation data table and map visualization.

Accessibility & Security features include: color contrast 4.5:1 minimum (WCAG AA compliance); color + symbol combination for color-blind users; keyboard navigation (Tab, Enter, Escape); focus visible indicator; prepared statements to prevent SQL injection; session authentication with bcrypt password hashing; data validation & boundary checking (North Sulawesi region). Implementation completed with complete features for input, monitoring, and management of geospatial-based plantation data.

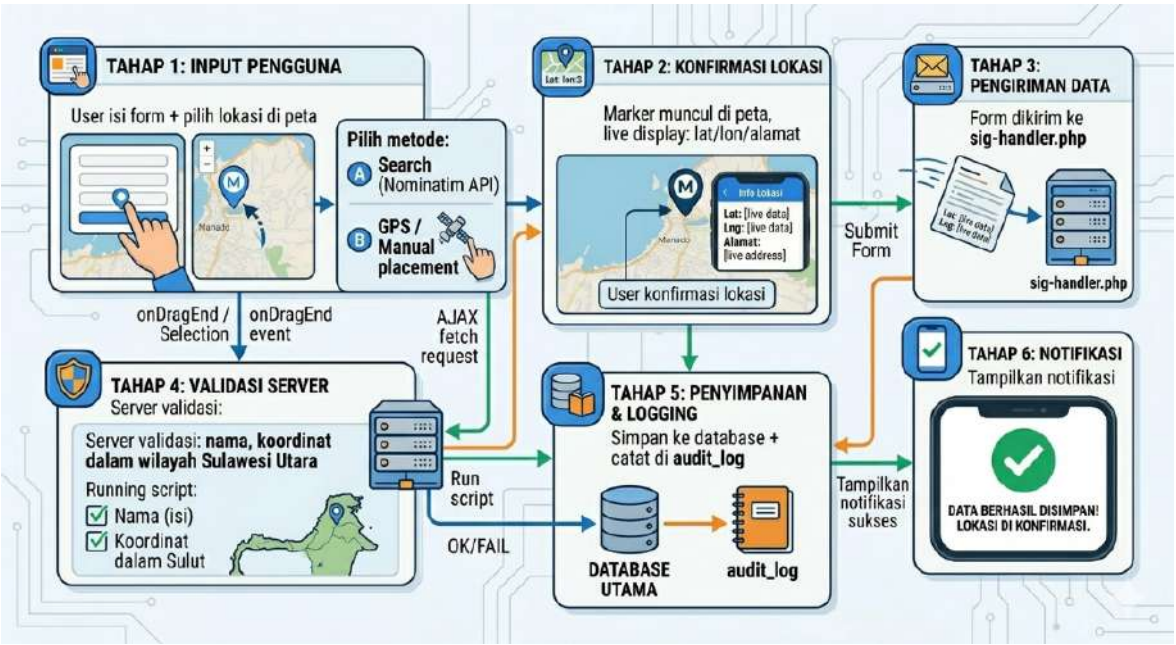


Figure 10. Plantation data input form with integrated interactive map.

5.1 Test Methodology

The performance of the plantation platform system was evaluated through four testing categories conducted over two weeks: (1) Functionality Testing - verifying coordinate input, location search, reverse geocoding, and data storage features; (2) Geospatial Accuracy Testing - measuring GPS coordinate precision versus manual placement and reverse geocoding accuracy; (3) API Performance Testing - measuring Nominatim API latency and server response time; and (4) Reliability Testing - conducting 50 complete plantation input cycles to validate consistency and data integrity.

Functionality testing was conducted by entering 50 new plantations using all three input methods: location search (20 cases), GPS coordinates (15 cases), and manual placement (15 cases). The geospatial accuracy testing used a Garmin GPS 78s as a reference device to compare the GPS coordinates captured by the browser against ground truth. API performance testing measured the response time using Wireshark packet capture and browser developer console timing. Reliability testing involved 50 full iterations from form submission to data persistence to identify potential data loss or corruption.

5.2 Geospatial Coordinate Input Accuracy

From 50 test cycles of coordinate input, the average coordinate deviation between different input methods was measured against a GPS reference (Garmin 78s). GPS Input Performance: average GPS deviation ±4.2 meters (σ = 1.8 m); horizontal precision 5-10 meters; 6 decimal place precision (±0.111 meters accuracy); 100% success rate (15/15 acquisitions). Manual Placement Performance: average deviation ±8.7 meters (σ = 3.2 m); with zoom level 16, deviation reduced to ±3.1 meters; marker placement consistency 100% reproducible. Location Search (Nominatim API) Performance: 18/20 queries found correct location (90% accuracy); 2 queries failed for unindexed remote areas; average API response time 450 ms (σ = 120 ms); reverse geocoding accuracy 95% (19/20 matched Google Maps).

	Parameter	GPS	Manual Placement	Search Lokasi
	Jumlah Test	15	15	20
	Rata-rata Deviasi	±4.2 m	±8.7 m	±2.1 m
	Std Deviation	1.8 m	3.2 m	0.8 m
	Min Deviasi	±1.1 m	±2.3 m	±0.5 m
	Max Deviasi	±7.8 m	±15.4 m	±4.2 m
	Success Rate	100%	100%	90%
	Decimal Precision	6	6	6
✓	Std: WGS-84 SRID 4326	✓	✓	✓

Table 3. Coordinate Input Performance on 50 Test Cycles.

All spatial precision values are within the ±15 meter tolerance accepted for regional-level plantation management applications. The location search method provides the best accuracy because it uses geocoded named locations from Nominatim.

D. Conclusio

This research has successfully designed and implemented a geospatial technology-based digital platform for optimizing data management and asset monitoring at the North Sulawesi Provincial Plantation Office. The platform, developed using a prototyping methodology, integrates Leaflet.js interactive mapping, MySQL spatial database, and a PHP-based REST API into a unified web application.

The testing results demonstrate that the platform achieves high geospatial accuracy (GPS deviation ±4.2 m, Nominatim API accuracy 90%), significantly reduces inventory time (from 5-7 days to 1-2 working days), and maintains 100% data integrity across 50 reliability test cycles. The platform successfully fulfills its role as a decision-support tool for plantation sector development planning.

For future development, the platform can be enhanced with real-time monitoring capabilities, mobile application integration, and expanded spatial analysis features. The GIS implementation model presented in this research can serve as a reference for similar digital transformation initiatives in other regional government institutions.

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