SAKAHAN: A WEB-GIS APPLICATION WITH DYNAMIC DATA MANAGEMENT FOR CROP SUITABILITY MAPPING IN THE PHILIPPINES

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BIOGRAPHICAL SKETCH

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He is a member of the UPLB Alliance of Computer Science Students (ACSS), where he engages in initiatives that promote academic growth, peer collaboration, and leadership development. As a scholar under the Department of Science and Technology - Science Education Institute (DOST-SEI), he upholds a strong commitment to public service and technological innovation in support of national development.

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ABSTRACT

DANJES ANDREINNE S. FERRER, University of the Philippines Los Baños, May 2025. **SAKAHAN: A WEB-GIS APPLICATION WITH DYNAMIC DATA MANAGEMENT FOR CROP SUITABILITY MAPPING IN THE PHILIPPINES**

Major Professor: ASSOC. PROF. CONCEPCION L. KHAN

Agriculture in the Philippines faces challenges such as declining soil fertility and stagnant agricultural land area, threatening food security and economic stability. To address these issues, this study developed SAKAHAN, a Web-GIS application designed to facilitate crop suitability mapping in the Philippines by integrating dynamic data management capabilities. Existing crop suitability tools such as NCCAG and SARAI provide essential mapping services but lack mechanisms for dynamic data management. SAKAHAN addresses these limitations by enabling Voluntary Geographic Information (VGI) and Geographic Information System (GIS) through a user-friendly web interface. The system incorporates Free and Open-Source Technologies (FOSS) and implements a hybrid client-server framework based on Web-GIS architecture. User contributions are managed through a structured validation workflow to ensure data quality. Usability testing conducted among university students yielded an average System Usability Scale (SUS) score of 78.875, indicating strong acceptance and usability. Feedback from both users and domain stakeholders emphasizes the application's potential to support sustainable agriculture through data-driven land use planning and collaborative spatial data management.

INTRODUCTION

Background of the Study

The Philippines is an archipelago formed by the tectonic movements of several continental plates millions of years ago. Its topographic landscape consisting of upland and lowland areas was shaped by the diverse topography, fertile volcanic soils, seasonal monsoon rains, plentiful rainfall, and warm climate (Bank, 2016). For these reasons, the Philippines is ideal for cultivating crops. However, as an archipelago with a fragmented landscape, the country has variations in soil composition across its regions (Rondal, 2019). The different land areas in the Philippines can have distinct land uses, especially in crop production, with certain regions being more suitable for specific types of crops than others.

Over the years, a notable decline in soil fertility has been observed (BSWM, n.d.). Several contributing factors have been identified, including, but not limited to, soil erosion, deforestation, nutrient deficiency, and soil sealing (BSWM, n.d.; Rondal, 2019). These factors may affect the available cultivable land areas, which could, in turn, negatively affect the country's food security and economic growth. As indicated on the data by PSA (2024), the total land area used for agricultural crop cultivation in the Philippines from 2016 to 2023 has remained stagnant. Thus, the only viable strategy to mitigate the impact is to improve crop productivity, which requires planting efficient crops in optimal locations (Ramamurthy, Chattaraj, Singh, & Yadav, 2018). Effectively identifying and delineating these optimal locations for various crops demands crop suitability mapping.

Several studies have been conducted in the Philippines on crop suitability mapping, including those by Guzman (2019), Chrisel, Sales, Badayos, and Sanchez (2024), and A. Adornado and Yoshida (2008) in Cagayan Province, Davao City, and Bukidnon Province, respectively. These studies successfully identified and delineated cultivable land areas suitable for specific crops, with the aid of platforms such as ArcGIS, QGIS, and Tntmips, respectively. However, these studies were restricted in terms of geographic scope, public availability of information, and the technical proficiency required to use the tools involved.

This study investigated crop suitability mapping across the entire land area of the Philippines. However, achieving this suitability mapping is not feasible without sufficient information on the soil characteristics of all regions in the country. The initial data in this study relied on existing publicly available spatial data, although these may be incomplete or contain outdated information. The integration of additional data from supplementary sources was needed to address this limitation. Moreover, analyzing and visualizing spatial data for crop suitability mapping presents another challenge. This challenge is addressed by utilizing Geographic Information System (GIS) (Akhavan, Jalalian, Toomanian, & Honarjo, 2022).

Existing applications have already been developed in the Philippines for crop suitability mapping, including the suitability map from the National Color-Coded Agriculture Guide (NCCAG) (*NCCAG Map*, n.d.) and Smarter Approaches to Reinvigorate Agriculture as an Industry in the Philippines (SARAI) (*SARAI Map*, 2024). Both applications use a Web-GIS architecture, offering similar features for distributing spatial data over the Internet for crop suitability mapping. This study drew inspiration from both applications but focused on SARAI for its comprehensive suitability classification system. This study adopted this classification system as a foundation for further development.

While NCCAG and SARAI provide essential features for crop suitability mapping, they lack data management features that allow for dynamic data through Create-Read-Update-Delete (CRUD) operations. As a result, interaction with the data is only possible through direct database access, which can risk data integrity due to potential errors in data manipulation. Thus, an application with integrated data management features is needed to support dynamic data when new suitability information becomes available.

In this study, SAKAHAN, a Web-GIS application with dynamic data management for crop suitability mapping, was developed to address the limitations of existing applications.

Moreover, the development of such applications has an inherent problem in their capability to handle increasing amounts of data over time. Performance issues may arise with a vast amount of data, directly affecting the application's usability. As Mwangi, Kimani, and Mindila (2019) noted, an application's usability determines its success or failure in today's market. Thus, it is crucial in this study to improve usability to ensure high stakeholder acceptance of this application.

Statement of the Problem

The Philippines is facing a significant challenge in agriculture, particularly in improving crop productivity. Declining soil fertility, caused by various factors, poses a threat to food security and economic growth (BSWM, n.d.; Rondal, 2019). Recent data shows that the total land area dedicated to agricultural crop cultivation has remained stagnant from 2016 to 2023 (PSA, 2024). To tackle these issues, it is essential for the country to enhance crop productivity through effective land use strategies.

Crop suitability mapping is crucial for addressing these challenges. However, there is a lack of comprehensive information on soil characteristics across all regions of the country. Existing spatial data sources may not provide complete or up-to-date information. Additionally, current applications developed for this purpose, such as the NCCAG and SARAI, lack robust data management capabilities to incorporate new suitability information over time. This study sought to answer the following research questions:

1. What data management features should be integrated into the application to support dynamic data?

2. How would stakeholders perceive the application's usability that provides mapping data on the suitability of different land areas for various crops?

3. How would SAKAHAN help address the issue of soil fertility decline through effective crop suitability mapping and data-driven land management?

Objectives of the Study

The general objective of this study is to develop a Web-GIS application for crop suitability mapping. Specifically, this study aimed to achieve the following objectives:

1. To develop and implement a crop suitability mapping application based on Web-GIS architecture.
2. To incorporate data management features to support dynamic data within the application.
3. To evaluate stakeholder acceptance of the application using the System Usability Scale (SUS).

Significance of the Study

The development of SAKAHAN, a Web-GIS application with dynamic data management for crop suitability mapping, is crucial for addressing the challenges of declining soil fertility in Philippine agriculture. As this problem continues to threaten the agricultural sector, there is an urgent need for innovative tools that can support data-driven agricultural planning and decision-making. This study contributed to filling a crucial gap by providing a digital platform that enables the identification and delineation of optimal areas for crop cultivation based on available data and new suitability information contributed by the potential users of the application.

The application helped stakeholders streamline decision-making with actionable insights into suitable land use and eliminate guesswork in finding cultivable land areas for various crops. Furthermore, this study aimed to improve crop productivity through effective suitability mapping in the Philippines to support food security and economic growth amid declining soil fertility. Ultimately, this study can provide an application that can serve as an information system for fostering the agricultural sector in the Philippines.

Scope and Limitations

This study developed a suitability mapping application based on a Web-GIS architecture. Its scope is limited to the Philippines, which has a total land area of approximately 30 million hectares (300,000 square kilometers). The focus is solely on spatial data related to the suitability of land for specific crops, excluding temporal factors such as the optimal planting period. The application is built upon the SARAI suitability classification system, which serves as its foundational framework for further development. It is important to note that this study does not cover performance testing or analyze the costs associated with achieving a reasonable system specification and implementation budget.

This study commenced in October 2024, during the first semester of the academic year 2024-2025, at the Institute of Computer Science, University of the Philippines Los Baños.

REVIEW OF LITERATURE

Numerous studies have explored the Geographic Information System (GIS) based on Web-GIS architecture. These studies have a transformative impact on spatial data visualization and analysis by providing quick access to critical data for informed decision-making across various sectors (Vinueza-Martinez, Correa-Peralta, Ramirez-Anormaliza, Arias, & Paredes, 2024). The literature review in this chapter is organized into two main themes: Voluntary Geographic Information (VGI) and crowdsourcing and GIS management for decision-making. These two themes represent key literature clusters identified by Vinueza-Martinez et al. (2024) in their bibliometric analysis of the current status and research trends of GIS based on Web-GIS architecture.

Voluntary Geographic Information and Crowdsourcing

The challenge in developing an application with mapping features is acquiring or creating the necessary dataset. The mapping process requires the collection and collation of available spatial data. In this section, the researcher cites a number of related literature to tackle the source of spatial data for a GIS application.

The transformative power of data is widely recognized because it empowers people to make informed decisions by providing rapid access to valuable information, patterns, and trends. Spatial data is one example that provides information that stakeholders can leverage for more strategic decision-making. This data can be sourced mainly from government agencies, which provide authoritative data that is recognized for its high quality and adherence to established standards (Antoniou & Skopeliti, 2015). However, this data often comes with high costs and restrictive licensing terms. In this regard, there has been an increasing trend in the use of Voluntary Geographic Information (VGI) over the past decade (Vinueza-Martinez et al., 2024). Essentially, VGI is similar to crowdsourcing, wherein data is collected and contributed by the public, regardless of their expertise in the GIS domain. According to Antoniou and Skopeliti (2015), VGI has the potential to enrich, complement, or update authoritative data, and can even serve as the sole source for creating new datasets. Shahi (2023) explained in their study about VGI in the Spatial Data Infrastructure (SDI) continuum that crowdsourcing can enable individuals to create diverse, high-quality data that is transparent and cost-free. With further analysis, they concluded that VGI is the present and future of the SDI continuum, a perspective supported by other studies demonstrating valuable benefits in various domains (Biljecki, Chow, & Lee, 2023; Tzavella, Skopeliti, & Fekete, 2022).

Tzavella et al. (2022) conducted the study regarding the use of VGI in crisis management based on a scoping review of existing literature. They found that VGI has been used widely for disaster management, with data mostly gathered from social media platforms such as Twitter and Facebook. It is used predominantly in managing natural hazards such as floods, hurricanes, and earthquakes, but it can also support managing significant events like the COVID-19 pandemic. This indicates that VGI applies to any domain-related crisis management. VGI is also applicable in non-crisis management, as demonstrated in a study by Biljecki et al. (2023), wherein they examine the quality of crowdsourced spatial building information. They used the most popular VGI platform, OpenStreetMap (OSM), to understand the state of building information in the said platform. Their study shows that the number of floors and building types that contributors mostly recorded are highly accurate. Despite the beneficial use of VGI, Shahi (2023) pointed out that there are problems with the data quality provided by the VGI. Tzavella et al. (2022) and Biljecki et al. (2023) validated this problem by recognizing information biases as the research gap in their study.

Several studies have delved into analyzing the data quality of VGI. Tavra, Lisec, Divić, and Cetl (2024) presented the study about unpacking the role of VGI in disaster management with a focus on data quality. They highlighted that VGI has the potential to be a source of data for disaster management, but they argue that further research is necessary to improve its quality. Moreover, another study conducted by Foody, Long, Schultz, and Olteanu-Raimond (2022) regarding the quality of VGI on land use and land cover demonstrated that citizen observatories have helped develop the potential of VGI for a wide range of applications. However, they pointed out that a structured quality assurance protocol is necessary to ensure VGI data reliability. Furthermore, Zhang et al. (2017) performed a study concerning the validity of historical VGI using citizen sightings of the black-and-white snub-nosed monkey (*Rhinopithecus bieti*). They discovered that the suitability map created from the historical citizen data had a consistent spatial pattern that reflects *R. bieti* distribution. Their study suggested that citizen data is valid for mapping historical geographic phenomena.

Building upon the insights from these studies, incorporating VGI as an additional data management feature alongside core GIS functions would be highly valuable as a supplementary source for data integration. This feature would enable stakeholders to contribute data directly within the application, helping keep information up-to-date as new suitability data becomes available. Additionally, it could help fill gaps in crop suitability data for regions in the Philippines that have not yet been assessed, leveraging citizen data from individuals residing in or familiar with those areas. Since VGI data quality is a concern, a validation feature would be integrated as an administrative privilege to ensure data reliability.

GIS Management for Decision-Making

With spatial data sources now explored, the challenge shifts to visualizing this data to present meaningful information. GIS provides an effective solution for spatial data visualization and analysis (Akhavan et al., 2022). It has established its usefulness in enhancing decision-making across sectors. In this section, the researcher cites studies that explore the use of GIS as a management tool for decision-making.

Vinueza-Martinez et al. (2024) highlights GIS web-based architectures, open-source platforms, and service-based approaches for managing spatial data in this theme. Their bibliometric analysis reveals that spatial data management through GIS significantly impacts a wide range of fields. Numerous studies support this notion by utilizing Desktop GIS in their analyses (A. Adornado & Yoshida, 2008; Chrisel et al., 2024; Guzman, 2019). Below are some studies conducted to address agricultural issues in the Philippines, specifically regarding crop suitability mapping.

1. Guzman (2019) conducted a study to evaluate the suitability of four primary crops, which are banana, coffee, pineapple, and peanut, in several municipalities of Cagayan Province. Using ArcGIS, a suitability map was generated, showing that pineapple is the most suitable crop in the province, followed by peanut, coffee, and banana.

2. Chrisel et al. (2024) focused on evaluating the land area of Davao City due to shrinking cocoa production, declining soil fertility, and limited available cultivation areas. Their study identified six soil series as suitable for cocoa cultivation in the area with the aid of QGIS.

3. A. Adornado and Yoshida (2008) developed a soil fertility map to generalize crop suitability in Bukidnon Province using TNTmips. Their analysis successfully identified high-potential and suitable areas for farming purposes in the province.

The GIS applications mentioned in these studies were primarily used to assist researchers in conducting crop suitability mapping. This is mainly because Desktop GIS is designed for professional and technical use, particularly in spatial analysis. Moreover, using this application requires the operator to be knowledgeable about the technology. In response to this gap, Web-GIS emerged to address both technological and business needs that Desktop GIS could not fully meet. Several studies have developed Web-GIS applications to tackle domain-specific problems (Avanidou, Alexandridis, Kavroudakis, & Kizos, 2023; Morales, Moyon, & Jayoma, 2021; Yang et al., 2024). Below are some recent studies that have developed these applications for other agriculture-related issues.

1. *AgriFireInfo v1.0*. Yang et al. (2024) conducted a study to develop the AgriFireInfo v1.0 to manage Open-Field Crop Residue Burning (OCRB). Their study focused on the challenge of managing OCRB, which depends on timely access to monitored and forecasted data. OCRB is an agricultural practice where farmers eliminate crop residue by burning, which poses environmental and health risks. With this, government agencies need timely information on the spatial distribution of fire spots and emissions to regulate farmers' burning practices. AgriFireInfo v1.0 effectively addresses this need.

2. *GEOAGRI*. Morales et al. (2021) developed GEOAGRI to aid various agencies in the Philippines in proposing farm-to-market road projects. The application helps agency managers determine whether to approve or reject project proposals by automatically checking for potential duplications while providing visualizations.

3. *FarmGeoBalance*. Avanidou et al. (2023) focused on creating the FarmGeoBalance in Lemnos Island, Greece, to record and monitor farmers' agricultural practices in terms of production. Through this application, stakeholders can assess the impact of these practices on biodiversity at multiple scales.

These studies make significant contributions by providing solutions to various agricultural issues. It demonstrates the capability of GIS applications to assist stakeholders in addressing multiple domain-specific problems. The current study likewise aimed to offer a solution to an agricultural problem, but the study addressed the challenge from a technical perspective, focused on dynamic data management. This approach aligns with the research gap identified by Vinueza-Martinez et al. (2024) in their bibliometric analysis, which articulates that data integration remains a challenge for simplifying spatial decision-making.

METHODOLOGY

Hardware Specification

A laptop with the following specifications was used to develop the Web-GIS application:

- Operating System: Windows 11 64-bit
- Processor: 12th Gen Intel(R) Core(TM) i5-1235U 1.30 GHz
- Memory: 8.0 GB DDR5

Spatial Data Sources

Table 1. Summary of Initial Spatial Data

Data	Source	Format
Lowland Rice	https://osf.io/bs6w3/	Vector
Cacao	https://osf.io/63rt2/	Vector
Robusta Coffee	https://osf.io/86ahv/	Vector
Banana	https://osf.io/673ds/	Vector
Arabica Coffee	https://osf.io/7g2tq/	Vector
Corn	https://osf.io/rpfqu/	Vector
Coconut	https://osf.io/f6xbd/	Vector

The initial data of the application relied on existing spatial data in the Philippines. However, the available spatial data in the country is limited because no current useful data related to crop suitability have been published from popular sources. The only open spatial data retrieved for this study is the suitability mapping of various crops indexed from the Open Science Framework (OSF). These datasets, provided as vector files, are outputs from Phase 1 of the SARAI created by the stakeholders from the University of the Philippines - Los Baños. OSF is a reliable platform designed to support the entire research process by making it more open, organized, and accessible (Foster & Deardorff, 2017).

The datasets collected from OSF that is deemed useful for this study are the suitability mapping for Lowland Rice, Cacao, Robusta Coffee, Banana, Arabica Coffee, Corn, and Coconut. These extracted data already include a shapefile along with the necessary associated files, providing interoperability with other GIS tools. A summary of these datasets is provided in Table 1.

For this study, the files were further processed to convert them into GeoJSON format. GeoJSON is a spatial data interchange format based on JavaScript Object Notation (JSON), which is more straightforward and compatible with web technologies (Butler et al., 2016). Additionally, this format uses a geographic coordinate reference system based on the World Geodetic System 1984 (WGS 84), the current standard for defining Earth-centered coordinates (Wilkerson, 2024).

Free and Open-Source Technologies (FOSS)

SAKAHAN was designed as a Web-GIS application, utilizing the following free and open-source technologies for its development.

1. *Django Rest Framework (DRF)*. A Python-based framework that extends Django to provide a fully functional REST API. Django's built-in Object-Relational Mapping (ORM) simplifies connections and queries with relational databases, enabling CRUD operations through object-oriented methods. This framework is used to develop the backend for SAKAHAN to provide APIs necessary for data management features and authentication.

2. *GeoDjango*. A spatially-enabled extension for Django, specifically designed to facilitate the development of Web-GIS applications. It supports Django by incorporating specialized model fields for geometric data and extending querying capabilities for spatial operations.

3. *GeoServer*. A map server that serves spatial data to clients under the international

standard protocol, which includes the Web Map Service (WMS), Web Feature Service (WFS), and others. This protocol is the open standard format developed by the Open Geospatial Consortium (OGC) for data exchange to allow interoperability between various GIS applications. This server provides layers for the client to render the polygons that show crop suitability information and corresponding properties.

4. *GeoWebCache*. A tile caching server that works seamlessly with GeoServer to optimize and accelerate the delivery of spatial data. It caches map tiles at various zoom levels, reducing server load and improving map rendering performance for high-traffic Web-GIS applications.

5. *PostgreSQL*. An object-relational database management system (ORDBMS) that stores data as objects with properties. It is also compliant with Structured Query Language (SQL), enabling efficient data processing by leveraging relationships between objects, making it well-suited for handling real-world data models. This ORDBMS stores all the model schema necessary in order to allow dynamic data to SAKAHAN.

6. *PostGIS*. A software extension that adds support for geographic objects to the PostgreSQL. It adheres to the Simple Features for SQL specification from the OGC by defining a PostgreSQL data type called geometry and geography for handling spatial data.

7. *Next.js*. A JavaScript framework based on React for creating dynamic and static web applications. It extends React capabilities by incorporating server-side rendering and static website generation. This framework is used to develop the client of the application that renders the map and layers for crop suitability information.

8. *Leaflet*. A JavaScript library for web mapping applications. It is designed with simplicity, performance, and usability in mind, making it ideal for developing GIS applications that display tiled web maps.

9. *Digital Ocean*. A cloud platform that provides scalable computing resources for

deploying and managing applications. It offers a wide range of preconfigured infrastructure solutions, allowing for the quick deployment of applications and the management of databases with minimal effort. This platform is used to deploy the system architecture of SAKAHAN, allowing users to visit the application on the Internet.

Database Design

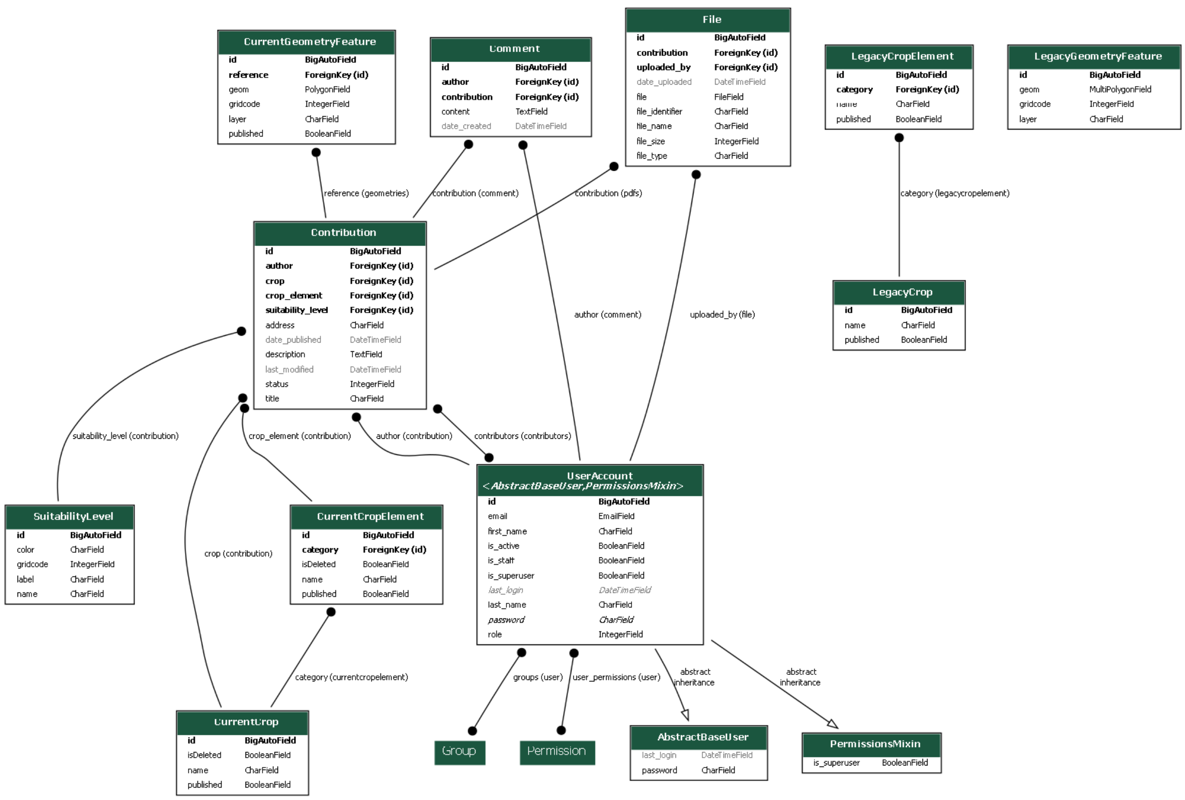

Figure 1. Database Design of SAKAHAN

Figure 1 illustrates the database design for SAKAHAN. As noted by Sutanta and Nurnawati (2019), designing a database for a Web-GIS application requires anticipating the increasing amounts of data over time. They also proposed a flexible database design template called WebGIS2 database design, which can accommodate future changes and evolving needs. The WebGIS2 database design considers changing the design approach to one specific to the user, the object category, and the particular region. In this study, their template was adapted and expanded to meet the specific requirements of SAKAHAN.

System Architecture

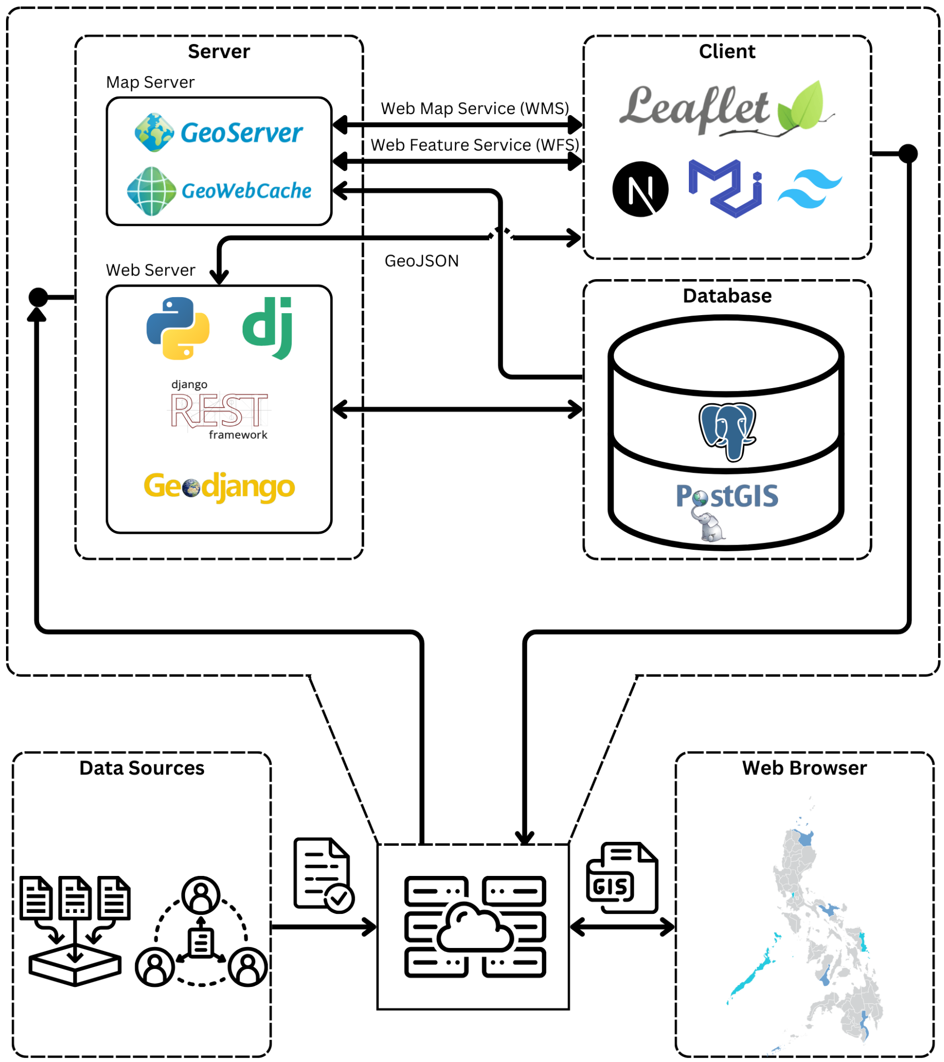

Figure 2. System Architecture of SAKAHAN

The central architecture of SAKAHAN followed the Web-GIS architecture. This architecture relies on the Client-Server (C/S) architecture, which consists of components such as the web browser acting as the client for requesting resources and the web server as the server for responding to those requests. For this study, there is an additional server, called the map server, whose purpose is to provide services compatible with spatial data such as WMS and WFS (Agrawal & Gupta, 2017).

There are various approaches to C/S architecture. In this study, a hybrid architecture was employed, which combines thin and thick client architectures. The primary goal of this hybrid approach is to balance the load between the client and the server. GIS-based applications typically face performance challenges due to large volumes of spatial data. By adopting a hybrid architecture, the server does not bear the entire load, helping to reduce response times. With this architecture, the overall usability of the application is expected to improve. Figure 2 illustrates how the technologies interact with other technologies.

The primary source of spatial data for SAKAHAN has undergone preprocessing before being populated into the database. Other supplementary sources, like VGI data, are subjected to a validation process. These data were stored in a spatial database using PostgreSQL, which was extended by PostGIS to handle geographic objects.

The server side of the application consists of the web server and the map server. The web server functions as the Application Programming Interface (API), enabling user interactions with the application's data through the web browser. The Python programming language and Django framework are the primary technologies used to develop the web server. Django Rest Framework and GeoDjango extended their functionality to enable rapid API development through built-in features and supported spatial data processing using geographic model fields.

On the other hand, the map server provides spatial data to the client in standard formats such as Web Map Service (WMS) and Web Feature Service (WFS) by extracting data from the database. GeoServer is the key technology used for the map server because it fully supports the international standard protocols developed by the OGC. Additionally, GeoWebCache integrates with GeoServer to create a cache of map tiles, enabling faster rendering and improved performance when responding to clients.

For the client side, Next.js was used to build the user interface (UI) of the application. It offers features like server-side rendering, which help optimize performance and improve the overall user experience (UX). The interface was designed using Tailwind CSS and Material UI to enable the rapid development of a consistent and adaptive UI/UX. For map rendering in the web browser, the Leaflet library was employed to display spatial data provided by the server.

Deployment

Table 2. Deployment Specification and Associated Cost

Component	**Specification**	**Cost**
sakahan-frontend	512 MB RAM — 1 Shared vCPU — 50 GB bandwidth	$5.00/mo
sakahan-backend	512 MB RAM — 1 Shared vCPU — 50 GB bandwidth	$5.00/mo
sakahan-droplet	4 GB RAM — 2 Shared vCPU — 25 GB SSD — 4 GB Transfer	$32.00/mo
sakahan-database	1 GB RAM — 1 Shared vCPU — 10 GB SSD	$15.15/mo
sakahan-bucket	250 GB SSD — 1 TB bandwidth	$5.00/mo

The deployment of SAKAHAN utilized DigitalOcean (DO) to host all components of its system architecture. The web server side (backend) and client side (frontend) components of SAKAHAN used DO's App Platform, a Platform-as-a-Service (PaaS) that offers easy deployment and management of applications without the need to manage underlying infrastructure. The application names for the backend and frontend are sakahan-backend and sakahan-frontend, respectively. Additionally, the backend was dockerized to allow for a custom deployment process and to resolve package-related issues.

DO's Spaces Object Storage (sakahan-bucket) and Managed Database (sakahan-database) services were also set up to host related data. The Spaces Object Storage complements the database used by SAKAHAN by storing user-uploaded files and other media required for the backend to function. On the other hand, the Managed Database setup is a separate, fully managed cluster that uses the PostgreSQL database engine along with the PostGIS extension.

Meanwhile, the map server component used a dockerized version of GeoServer, which was deployed using a DO Droplet (sakahan-droplet). Furthermore, Hypertext Transfer Protocol Secure (HTTPS) was set up using Let's Encrypt, a Certificate Authority (CA) that provides free TLS certificates. Using this CA, a Java KeyStore (JKS) was created to enable HTTPS for GeoServer.

With this deployment infrastructure, all components can be vertically scaled to accommodate increased resource demands as the application's user base grows. The modular nature of the architecture also allows for horizontal scaling where necessary, particularly for stateless services such as the frontend and backend of SAKAHAN. Table 2 shows the detailed deployment specifications and associated costs of all SAKAHAN components.

Application Features

The application users have varying privileges according to their roles in the system. The following features are organized according to a general-to-specific hierarchy of privileges.

1. *Stakeholder*

   This role provides general privileges to the user of the application. Users are allowed to use the following GIS basic features of the application without the need to authenticate themselves.

   (a) *View Map*. This feature allows users to view the suitability map for various crops. They can zoom and pan the map, go to current location, and show map layers.

   (b) *Search Map*. This feature allows users to search for an area. When a specific area is selected, information related to that area appears.

   (c) *Filter Map*. This feature allows users to filter the map to display only the suitability map for a specific crop. Users only need to select a crop from the set of options to change the suitability map displayed.

(d) *Change Basemap*. This feature allows users to change the basemap from a list of available basemaps provided by the tile provider. Selecting a different basemap automatically renders the map without losing the previous selected crop or area.

(e) *Select Suitability*. This feature allows users to select a set of suitability levels to show in the map. Selecting a different set of suitability levels automatically fetches another layer containing those suitability levels.

2. Contributor

This role extends the privileges of the stakeholder by allowing the user to contribute data on the suitability of a land area for specific crops. Users can add polygon shapes to the map to provide crop suitability information about the land area and submit their contributions for validation.

(a) *Contribute Data*. This feature allows users to contribute data by enabling them to draw a polygon to mark the area of interest. To submit this contribution, users must complete a form containing fields required for the validation process.

(b) *View Contributions*. This feature allows users to view their previously submitted contributions, as well asq other contributions. The status of each contribution, whether approved or rejected, is also displayed, along with any comments made in the discussion thread.

(c) *Discussion Thread*. This feature allows users to comment on submitted contributions. The discussion thread serves as a platform for communication, enabling users to engage in discussions about whether the submitted contribution can be validated.

3. Administrator

This role further extends the privileges of the contributor by granting the user with complete data management capabilities. Users can validate contributions, deciding whether to approve or reject them based on the submitted crop suitability information.

(a) *Validate Contribution*. This feature allows users to validate contributions from the list of submitted entries. Approving a contribution automatically adds the data to the database, making it visible on the map for stakeholders. Conversely, disapproving a contribution marks it as rejected, which subsequently closes the entry.

Design Implementation

The design of SAKAHAN adopted the analysis made by Mwangi et al. (2019) about Web-GIS usability, which includes the usability elements of both conventional GIS and web applications. The primary target of usability in this application is to achieve key qualities such as effectiveness, efficiency, and user satisfaction. This means the application should be considered highly usable if users can accomplish tasks with minimal time and effort. The study prioritized three main usability elements: content, interaction, and satisfaction:

1. Content: This focus on map content, interface content, and the overall design structure.
2. Interaction: Key considerations include map elements, interface elements, personalization, and learnability.
3. Satisfaction: The design emphasize performance, privacy, and security to ensure a positive user experience.

A high-fidelity wireframe was developed as a prototype using Figma to visualize this design. The wireframe is accessible in bit.ly/sakahan-figma.

Testing Procedure

A sample of 20 students was drawn from a population that had previously completed a soil science or related course. These participants were selected to evaluate the application's usability. After interacting with the application, they completed a questionnaire based on the System Usability Scale (SUS), a standardized tool for assessing system usability. The SUS consists of a 10-item survey, each item rated on a five-point Likert scale. The resulting SUS score provides a quantitative measure of the application's overall usability, which is a key indicator of stakeholder acceptance. The following are the standard questions included in the SUS.

1. I think that I would like to use this system frequently.
2. I found the system unnecessarily complex.
3. I thought the system was easy to use.
4. I think that I would need the support of a technical person to be able to use this system.
5. I found the various functions in this system were well integrated.
6. I thought there was too much inconsistency in this system.
7. I would imagine that most people would learn to use this system very quickly.
8. I found the system very cumbersome to use.
9. I felt very confident using the system.
10. I needed to learn a lot of things before I could get going with this system.

RESULTS AND DISCUSSION

Web Application

View Map

Figure 3. View Map

The first thing users see when they open the application is the map and other buttons. They can zoom in and out of the map and pan to view more areas. From here, they can also see the current scale, which depends on the zoom level, and the mouse pointer's coordinates on the screen.

Change Basemap

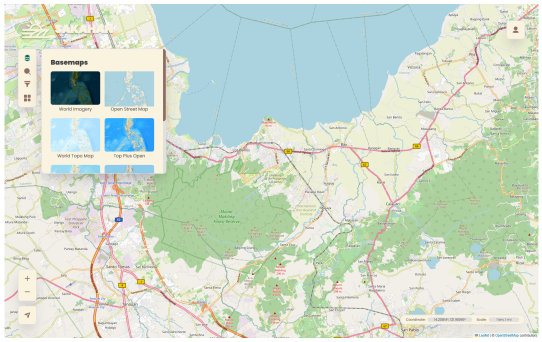

Figure 4. Change Basemap

Users can change the basemap according to their preference. Changing the basemap can provide different visual perspectives and improve the interpretability of the spatial data displayed on the map.

Search Map

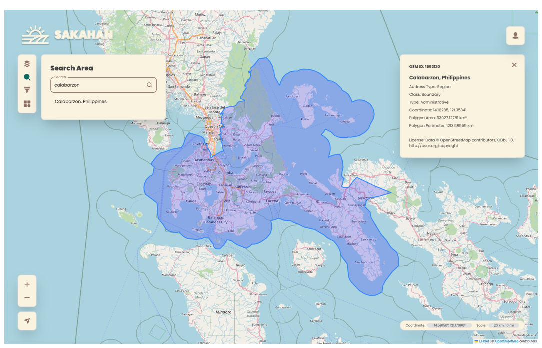

Figure 5. Search Map

Users can search for a specific area to see information such as the covered land border, the polygon area and perimeter, and other information. Searching an area can make the map more focused on the area of interest.

Filter Map

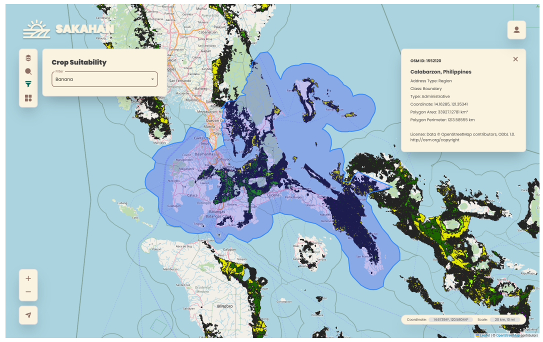

Figure 6. Filter Map

Users can filter the crop to display a suitability map. The colored layer shows the land areas suitable for a specific crop, where each color shows unique information about the area’s suitability.

Select Suitability

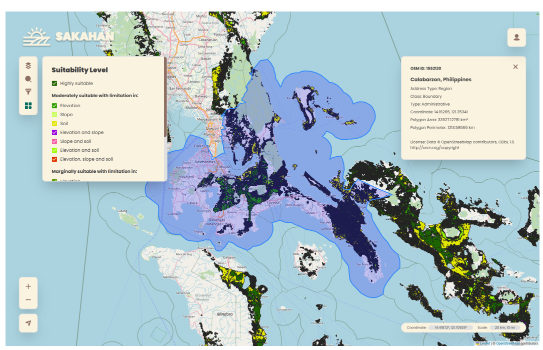

Figure 7. Select Suitability

Users can filter the crop to display a suitability map. The colored layer shows the land areas suitable for a specific crop, where each color shows unique information about the area’s suitability.

Contribute Data

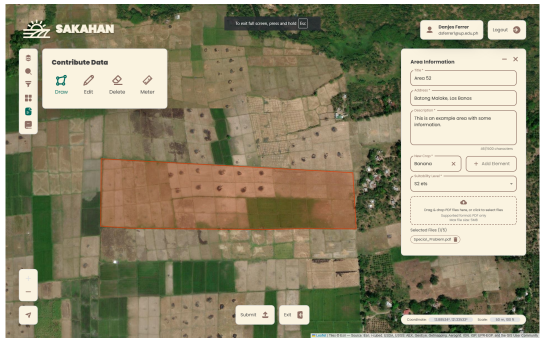

Figure 8. Contribute Data

Users can contribute their data by drawing a polygon in the area of interest and supplying information about the location for validation. This enables dynamic data as new suitablity information becomes available.

View Contributions

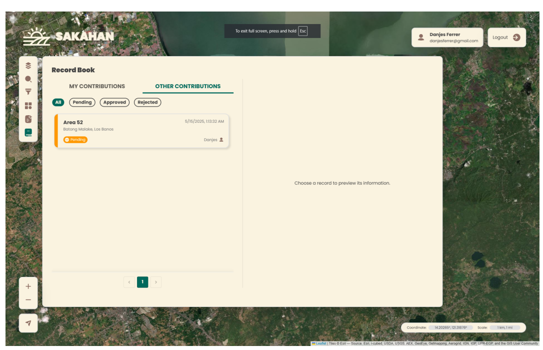

Figure 9. View Contributions

Users can view their list of submitted contributions and other contributions. From here, they can update the contribution and expand the preview, giving them more control over the contributed data.

Discussion Thread

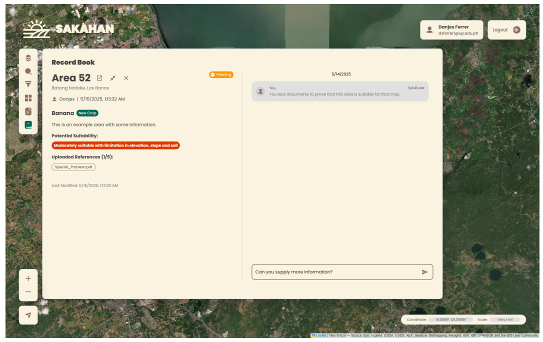

Figure 10. Discussion Thread

Users can send a message and leave a comment to be viewed by others. This allows for discussion of the contributed data, which is necessary for other users to relay information needed to revise the contributed data.

Validate Contribution

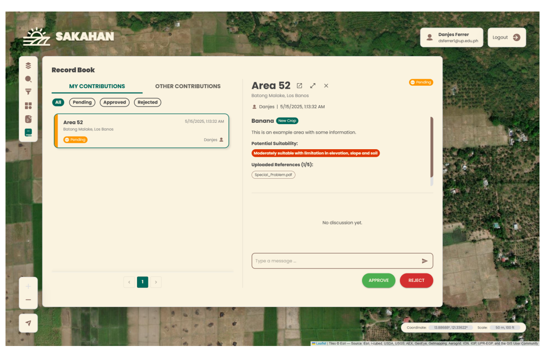

Figure 11. Validate Contribution

Users with administrative privilege can approve or reject a contribution based on the provided data. This allows contributed data not to be published if deemed incorrect and unnecessary.

System Usability Testing

Participant Demographic

All participants who tested SAKAHAN were undergraduate students from the University of the Philippines Los Baños (UPLB), aged between 20 and 25 years. A key selection criterion was that each participant had completed a soil science course or a related subject. This ensured that the SUS respondents closely represented the application's intended user base, thereby minimizing potential biases. While most participants had no prior experience with GIS applications, a few were familiar with platforms such as ArcGIS and QGIS. Each respondent was instructed to watch a short demo of the application and independently explore all its features, including contributing data to the platform. No assistance was provided by the study's proponent during the testing process to ensure unbiased user interaction.

Testing Result

The results of the usability testing are presented in Table 3. The application received an average SUS score of 78.875 out of 100. Based on standard SUS interpretation guidelines, this score corresponds to a B+ rating, which is generally considered above average. Furthermore, the score suggests that users found the application acceptable, experiencing minimal confusion while navigating and testing its features. The acceptable mark is based on the described terms set by Bangor, Kortum, and Miller (2008) for when the SUS was well above average.

Analysis of Feedback

Participant Feedback

The participants were also asked a series of questions regarding their views on the application's potential as a tool for crop suitability mapping in the Philippines, their likeliness

Table 3. System Usability Scale Score

Resp.	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Score
1	5	3	3	3	4	3	4	2	4	5	60
2	5	1	5	1	5	1	5	1	5	1	100
3	4	2	4	2	5	2	5	2	4	2	80
4	4	4	5	2	4	3	5	2	4	4	67.5
5	4	2	4	2	5	2	4	1	5	2	82.5
6	4	4	4	3	3	4	4	4	4	4	50
7	4	3	3	4	2	3	2	3	4	4	45
8	4	3	3	4	4	3	4	2	4	3	60
9	5	2	5	1	5	1	5	1	5	2	95
10	5	2	5	2	5	2	5	2	5	2	87.5
11	3	2	5	1	4	2	5	2	5	2	82.5
12	5	2	4	4	4	3	4	1	4	1	75
13	5	2	4	3	5	1	5	1	5	2	87.5
14	4	1	5	1	5	1	2	1	4	1	87.5
15	4	1	5	2	4	2	5	1	5	2	87.5
16	5	2	4	2	5	1	4	2	4	2	82.5
17	4	1	5	4	5	1	4	1	4	1	85
18	4	2	5	1	5	1	5	1	5	2	92.5
19	4	2	5	2	4	2	4	1	4	2	80
20	5	1	5	2	5	2	5	2	5	2	90
										Average SUS	78.875

to contribute suitability data to the platform, assuming they possess such information, and their opinion about the application helping address the issue of soil fertility decline through efficient crop suitability mapping and data-driven land management.

All participants agreed that the application shows strong potential to become a valuable tool for crop suitability mapping in the Philippines. It can empower farmers by reducing their reliance on guesswork and offering data-driven guidance for selecting appropriate crops based on suitability information. This can lead to better agricultural planning, increased crop yields, and more sustainable farming practices. Its user-friendly interface and accessibility make it practical even for users with limited technical knowledge, including students in agriculture-related fields. The application also supports the Voluntary Geographic Information (VGI) approach, allowing users to share local knowledge and enhancing decision-making—provided a proper validation mechanism is in place. Additionally, its open-source nature and collaborative features may encourage community involvement and democratize access to critical agricultural information. To maximize its impact, it is essential that the app provides accurate, up-to-date data and remains easily accessible, especially to farmers who are central to the country's agricultural sector.

Regarding participants' willingness to contribute crop suitability data to the SAKAHAN platform, the results indicate a very high level of intent. The average score was 9, with 95% of respondents rating their willingness at 8 or above, and 45% giving the highest possible score of 10. The median score was 9, and the most frequent response was also 10, reflecting strong overall positive sentiment. Notably, no respondents rated their willingness below 7, suggesting minimal resistance to contributing data. These findings demonstrate a strong sense of confidence in the platform's potential value, indicating favorable conditions for widespread data sharing if the platform is implemented.

Furthermore, participants expressed strong belief in the application's potential to help address soil fertility decline through efficient crop suitability mapping and data-driven land management. With an average rating of 8.6, and nearly half of the respondents giving it a perfect 10, sentiment was overwhelmingly positive. The qualitative feedback reinforces this, highlighting benefits such as improved land use, informed farming practices, reduced input misuse, and enhanced support for sustainability and policy-making. However, a smaller portion of respondents expressed reservations, emphasizing the importance of data quality, user training, field validation, and integration with broader land and soil management strategies. These insights suggest that while the platform is highly promising, its real-world effectiveness will depend on thoughtful implementation and ongoing stakeholder support.

Stakeholder Feedback

Aside from the feedback of participants, the feedback from stakeholders was also considered. The proponent of the study conducted a one-on-one consultation with a key stakeholder, Prof. Moises Dorado, a faculty member at the College of Engineering and Agro-Industrial Technology, UPLB, and the Project Leader of the Community-Level SARAI Enhanced Agricultural Monitoring System (CL-SEAMS).

During the meeting, the discussion centered on the design and implementation of a data management system to support agricultural suitability mapping. Prof. Dorado expressed interest in the concept presented and acknowledged that the system being developed is both well-conceived and potentially valuable for agricultural decision-making at the community level. He emphasized that the idea has practical applications and could be a helpful tool for local government units and farmers.

The conversation also covered strategies for managing dynamic and crowd-sourced data, with a shared understanding that administrative approval should be required for any submitted updates to ensure data accuracy. Prof. Dorado offered several recommendations, including the integration of remote sensing data to enhance data quality. He also suggested exploring web scraping as a means to gather relevant agricultural data from online sources.

The consultation concluded with mutual interest in automating map updates and incorporating additional data sources in the future. While no specific implementation steps were finalized, Prof. Dorado's input provided valuable direction for further development, with the understanding that his suggestions are non-binding recommendations aimed at improving the system's functionality and impact.

CONCLUSION AND FUTURE WORK

Conclusion

SAKAHAN is a Web-GIS application developed for crop suitability mapping in the Philippines. It incorporates data management features that enable the application to dynamically integrate new suitability information as it becomes available, addressing limitations found in existing platforms such as NCAAG and SARAI. The project successfully achieved its objectives: a functional crop suitability mapping tool based on Web-GIS architecture was developed, data management capabilities were implemented, and the application was rigorously evaluated using the System Usability Scale (SUS).

Users of the application follow a general-to-specific privilege hierarchy. Users visiting the website can perform all the basic features of the application, specifically viewing the map, changing the basemap, filtering the crops, searching for an area, and selecting a suitability level. Moreover, users must be authenticated to view contributions, contribute data, and start discussions for a specific contribution. Additionally, users with administrative privileges have the authority to approve or reject submitted contributions.

The application received a total of 78.875 average SUS score after user testing from participants. This score is considered a B+ rating, which indicates that the application is generally above average and acceptable for users based on standard SUS interpretation guidelines. Moreover, feedback showed that participants found the application to be highly promising as a tool for crop suitability mapping in the Philippines. They appreciated its user-friendly interface, accessibility, and potential to empower farmers through data-driven agricultural planning. Participants also expressed a strong willingness to contribute suitability data, reflecting trust in the platform's value and functionality. Furthermore, respondents expressed a strong belief in the application's potential to help address soil fertility decline through efficient crop suitability mapping and data-driven land management.

Stakeholder feedback, particularly from Prof. Moises Dorado of UPLB, further reinforced the application's potential. He acknowledged its practical benefits and suggested improvements such as incorporating remote sensing data, and exploring other data integration techniques. These insights indicate that the platform is well-received by both end-users and domain experts, with strong support for its continued development and real-world application.

Future Work

To further enhance the functionality of SAKAHAN, several improvements and future research are recommended.

- *Improve user experience*. The current workflow of the application requires users to go back and forth between menus to view the currently selected crop, the selected suitability levels, and the searched area. This makes the application tedious to use and necessitates a revamp of the user experience.

- *Explore a different caching strategy*. The current implementation uses GeoWebCache as the caching technique to reduce server load. However, this approach is only effective for static layers that do not change frequently. Since the client uses CQL filters to dynamically modify layer requests from GeoServer, the existing caching strategy becomes less effective. Exploring alternative strategies, such as tile-based caching, may help improve map rendering speed for large datasets.

- *Separate the crop management module*. The current implementation for crop management uses implicit behavior, which means it automatically infers actions based on the context of what the user does when adding a crop. This approach is very prone to bugs and unexpected behavior in the long run. Therefore, a separate module to manage crops explicitly is necessary.

- *Explore remote-sensing data*. Prof. Dorado recommends using remote-sensing data to validate and augment crowd-sourced suitability information. This also provides an additional source of spatial data, which can be processed to create a model for generating suitability maps for specific crops.

- *Explore other data integration methods*. Prof. Dorado also recommends trying web scraping for data collection. Essentially, image metadata would be extracted to retrieve only the information necessary to plot areas on the map. This is a highly time-efficient approach to obtaining user data, though it certainly requires further research.

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