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Development of an Agricultural Geographical Information System

Alinani Simukanga
University of Zambia
Department of Computer Science
Lusaka, Zambia
alinani.simukanga@cs.unza.zm

Madaliso Patrick Muhone
University of Zambia
Department of Computer Science
Lusaka, Zambia
madalisomuhone@gmail.com

Joseph Mulenga
University of Zambia
Department of Computer Science
Lusaka, Zambia
mulengajoseph25@gmail.com

Jackson Phiri
Lecturer: University of Zambia
Department of Computer Science
Lusaka, Zambia
jackson.phiri@cs.unza.zm

Mayumbo Nyirenda
Lecturer: University of Zambia
Department of Computer Science
Lusaka, Zambia
mayumbo@gmail.com

Abstract—An information system is proposed to monitor grain storage facilities and small-scale farmer land parcels. The proposed module would assist in improving food security by providing a real-time record of stock levels in the various strategic grain reserves. It would also help the Government, through the Farmer Input Support Program, adequately target small scale farmers. Knowing where farmers are located is vital information for the planning process.

Index Terms—agriculture; geography information systems; storage facilities; small-scale farmer; land parcels; android application.

I. Introduction

Food security and insecurity and terms used to describe whether or not people have access to sufficient quality and quantity food [1]. They are affected by factors such as poverty, health, food production, political stability, infrastructure, access to markets, and natural hazards. Improved food is important for global reduction of hunger and poverty, and for economic development countries and numbers are not falling quickly enough to achieve the goal, particularly in Africa and Southern Asia [2]. Food insecurity is the absence of food security and applies to a wide range of phenomena, from famine to periodic hunger to uncertain food supply [1]. Hunger can be experienced temporarily by people who are not food insecure, as well as those who are. Hunger is a major constraint to a country's immediate and long term economic development. Loses in labor productivity due to malnutrition causes an 11% reduction in the world's gross domestic production (GDP) according to a study by the Food and Agriculture Organization (FAO) [3] [2]. Higher agricultural production can improve food security by decreasing food prices for consumers, increasing rural incomes and contributing to economic development [2]. Studies show that a 1% rise in per capita agricultural output led to a 1.6% rise in incomes of the poorest 20% of people [4].

This study aims to display locations of FRA Storage Facilities, Small Scale Farmers' land parcels and track the crops grown on the land parcels as well as develop a mobile application for the collection of location data.

This work builds on the work done in [5] and [6].

II. Literature Review

This section describes key concepts in the problem domain. It also includes a list of related works.

A. Web Technologies in Agriculture

With the unlimited growth of the Internet and ever expansion of information on the web, this has brought the world and agriculture to a new information era. The Web offers a new medium for storage, presenting, assembling, allocation, processing and consuming information. Web technologies [7] are frequently used to give access to knowledge and information, for example, to offer immediate solutions to practical problems. Digital technologies may provide the chance for new relations within the farming community and along the value chains. When used on a shared basis, farm machinery can become a negotiation tool that benefits collective skill development.

Data collection and sharing provide farmers with the chance to develop their networking, sharing data is easy and cheap and it leads to better management on the farm (for example, by sharing information on diseases and weather) and within a community (sharing information on practices). Sharing data makes it possible to further develop good practices as collective knowledge increases. Creative applications to increase knowledge and information sharing have yet to be developed. The benefits of the web technology have been over the years.

The web offers disseminated substructure for information processing. It is used as a network to debate on one of the most popular support systems. The web [8] can provide appropriate, secure information and tools with user friendly interfaces. The web has no time limitations and also no geographic constraints. Farmers can access the system at any time, any place. Users (farmers) can control and retrieve results remotely and instantly. With the rapid development of web technology, computerized support systems are evolving more diverse groups, such as learning support system, education support system and also research support system.

B. Geographical Information Systems

Geographical Information Systems (GIS) are computer based information systems used to digitally represent and analyze the geographical features presented on the earth's surface and the events that taking place on it. GIS technology integrates common database operations such as query and statistical analysis with the unique visualization and geographic analysis, making it valuable to a wide range of public and private enterprises for explaining events, predicting outcomes and planning and visual data representation is worth a thousand words.

GIS can provide up-to-date and reliable information for managerial purposes to efficient planning decisions. Researchers and policy makers may integrate spatial, temporal, and socio economic data in order to get better manageability, higher and quality productivity [9]. By understanding geography and people's relationship to location, we can make informed decisions about the way we live on our planet. A Geographic Information System (GIS) is a technological tool for comprehending geography and making intelligent decisions. GIS organizes geographic data so that a person reading a map can select data necessary for a specific project or task.

Providing the current population and future generations with an indefinite food supply is an economic, environmental, and social concern. GIS technology enables community planners, economists, agronomists, and farmers to research and devise practices that will enable the sustainability of food production to ensure the survival of the human race. Whether implementing organic farming methods, finding the most profitable and healthy places to plant new crops, or allocating farmland for preservation to secure future food production, GIS has the capabilities to collect, manage, analyze report, and share vast amounts of agricultural data to aid in discovering and establishing sustainable agriculture practices [10]. GIS has massive potential in agriculture as it can help provide agricultural planning, attractive implications for future of managing our crop production and increasing yields in line with other technologies. Agricultural scientists are always looking at ways to best produce our crops, manage soils while respecting the environment and protect them from disease and pests. There is an ongoing challenge to cope with the changing climate and needs of today. GIS can play a vital part in tackling these challenges.

GIS take the guesswork out of the crop planning management with effective collection of soil data and seasonality of topography in line with changing conditions. It allows for precision farming.

Using GIS is essential in mapping areas, especially food sources that are vulnerable to natural disasters such as drought and flood. The World Food Program (WFP), the division of the United Nations concerned with food security, is one of the biggest users of GIS data for this purpose. They are involved in protecting food supplies by effectively building simple civil engineering projects such as damns, levies and irrigation to protect food supplies [11].

C. Related Work

1. Social Tenure Domain Model (STDM)

The Social Tenure Domain Model (STDM) is a pro poor land information tool. The concept of the STDM is to bridge this gap by providing a standard for representing the people-land relationship independent of the level of formality, legality and technical accuracy. The software, instead of reinventing the wheel, leverages existing packages by using the desktop GIS QGIS, object-related database PostgreSQL, spatial data extension PostGIS, Geraldo Reports and SQLAlchemy.

STDM provides tools for Vector and Raster data import, Data Management, Record Household Information, Mapping and digitizing, Building Reports and Analysis, Linking Spatial and Administrative data [12].

Pamoja Trust (PT) was tasked to pilot the use of STDM in Kenya in collaboration with UN HABITAT/GLTN. In implementing the pilot project, PT also collaborated with the Teaching University of Kenya (TU-K).

STDM emerged to be an adequate land information management tool to capture both enumeration and map-ping data for informal settlements which have not been captured. It has the capability to record the informality and complexity of the various tenure situation exhibited in the many information settlements in Kenya towns/cities. STDM bridges the gap between communities and land professionals. It addresses slum questions with pragmatic and realistic solutions in a participatory and sustainable manner [13].

2. Design, implementation and Evaluation of a Mobile GIS solution for a Land Registration Project in Lesotho

The GIS was developed as an application for the Android platform, primarily with the tablet computer format in mind, to be used for land registration field work. The application was developed and tested on site in Lesotho on two tablet computers. In the land registration project, all the data is collected by hand by a Claimant Support Officer (CSO) from every potential claimant in Maseru in the field. The CSOs visit every concerned claimant and collect data on a printed form, the parcel plan. This form involves some general data regarding the claimant's name and telephone number, as well as some general data concerning the parcel. These are GPS coordinated and demarcations, in this embodiment, the CSOs are required to bring a binder of printed Parcel Plan forms, an A3 overview map, and a hand held GPS device to every parcel that they visit in order to carry out their task.

The GIS application was developed in the Java programming language. The Software Development Kits (SDK) from Android: Google Android SDK (API 11) and ESRI: ESRI Android SDK v10.1.1 were used. In addition to the SDKs, the standard database system for Android: SQLite was also used as well as the open source spatial SQL extension SpatialLite (v3.0.1). Except for some SQL development in a simple Graphical User Interface (GUI) for Spatialite, all of the development took place in the widespread Eclipse Software Development Environment [14].

3. Better Crop Estimates in South Africa Integrating GIS with other Business Systems

Reliable crop information is vital to the functioning of grain markets. It is used to inform decision on planting, marketing and policy. Applying GIS to the process of preparing crop estimates has improved accuracy while lowering costs. The South African Department of Agriculture Crop Estimated Committee was tasked with producing crop estimated for South Africa on a monthly basis. To perform this task, the committee received data from various input suppliers. SiQ, a member of the National Crop Statistical Consortium (NCSC), uses statistical methods to provide inputs to the committee. Since 2002, crop information provided by producers has been used for statistical analysis. However, problems caused by producers who don't provide complete information, combined with a great emphasis on improving statistical accuracy and efficiency, led to the development on an alternative system. The Producer Independent Crop Estimate System (PICES) was developed in 2005, implemented after a successful pilot study conducted in the Gauteng province, PICES uses crop field boundaries digitized from satellite imagery with a point frame sampling system to objectively estimate the area planted with grain crops. The PICES process consists of the following steps:

- Obtain satellite imagery.
- Digitize crop field boundaries from satellite imagery.
- Design the point frame and select random sample point.
- Use aerial survey sample points to capture crop data.
- Perform statistical analysis

Satellite imagery for the project is made available by the South African government through the Department of Agriculture. Spot Image Spot 5 satellite imagery with a 2,5-meter resolution is obtained from the department and is used as the base layer for digitizing. This is done in ArcMap at a scale of 1:10,000. Comprehensive quality control measures are part of the digitizing process to ensure clean, accurate data of high quality. Detailed metadata is captured in ArcCatalog as soon as the dataset for a province has been finalized. This metadata is updated whenever changes are made to the dataset. All nine provinces of South Africa have been digitized-a lot of approximately 12,965,000 hectares. The updating schedule and procedures ensure that the dataset remains current.in the next steps, sample points are randomly selected to represent cropped fields. These points will be surveyed in the field. A point grid of 45 meters by 45 meters is set up for the total provincial area. Grid points located outside field boundaries are removed from the sample population because these points are unlikely to locate crops Digitized fields are stratified based on the probability of finding a crop. The crop strata used are high, medium, and low cultivation. High, medium, and low refer to the densities of fields within any given area as well as the presence of pivot irrigation and small scale farming. Stratification is done to increase sampling efficiency. More sample points are used in strata where there is a higher likelihood of finding crops of interest. This will obtain the most useful data within budget. The grid points are selected per stratum and exported to a Microsoft SQL Server database. These points are sorted systematically from west to east and north to south. This is done to ensure an optimal geographic distribution of sample points. A random starting point is chosen and points selected at regular intervals according to the number of points needed in the specific stratum. The selected points are inserted into a new table in the database, and the process is repeated for each stratum. Finally, the SQL Server tables are added in ArcMap and converted to shapefiles containing the sample points for each stratum. An aerial survey of the sample points is conducted. This aerial survey determines which crop is planted in the field represented by each sample point. These survey are conducted by a field observation team that consists of a pilot and an observer in a very light aircraft. The observer is from the agricultural community and is very experienced at distinguishing between different crops and differentiating between dry land and irrigated cultivation. Typically, the number of sample points verified for each survey requires the use of more than one field observation team. This system of capturing field information for crop estimated purposes is believed to be unique in the world [15].

III. Methodology

This section describes the techniques used toward the development of the information system. Details pertaining to the detailed requirements and various conceptual models are provided.

A. Development Methodology

An Agile Incremental Development approach was taken during the development of the map view component of the system. This process involves creating multiple prototypes of the required system. Each prototype is analyzed, allowing for any errors or omissions in the requirements to be revealed long before system handover [16]. Prototyping also brings up new requirements which is useful when time is in short supply or the development team lacks familiarity with the system's problem domain.

B. Requirements

This subsection describes the system requirements that were identified for this system. A Mixed Methods methodology was employed for this process. This involves relying on multiple techniques for data gathering such as inter-views and document sampling. The requirements are split between the functional and non-functional requirements. And for clarity, the functional requirements are listed per component.

1) Functional Requirements: Map View

- User must be able to view map displaying small scale farmer land parcels [17].
- User must be able to view map displaying storage facilities [17].
- User must be able to search for a farmer's land parcel on map [17].
- User must be able to search for a storage facility on map [17].
- User must be able to print maps [17].
- User must be able to view details of farmer's land parcel upon clicking on parcel [17].
- User must be able to view details of storage facility upon clicking on facility [17].

2) Functional Requirements: Mobile Application

- User must be able to log in [18].
- User must be able to specify their location [18].
- User must be able to register a farmer [18].

- User must be able to search for a farmer [18].
- User must be able to change their password [18].
- User must be able to review farmers [18].
- User must be notified when alteration of details needed [18].
- User must be able to add a farmer onto the farmer table [18].

3) Non-functional Requirements:

- The system must be easy to use [17].
- The system must be able to handle a large number of user requests [17].
- The system must be able to deal with hardware re-sources needed to perform all functions of the software system in conformance to all other requirements [17].
- The system must deal with failures to keep providing the service [18].
- Should user requirements evolve, the web portal and the mobile application should be easy to modify [18].
- Sensitive data should only be viewable by authorized users [18].
- The system should carry out the required functionality [18].

C. Development Tools

This subsection describes the development tools used in the creation of each component.

1) Map View:

Google Maps Platform - Maps JavaScript Application Programming Interface (API)
Through the Google Maps Platform, the Maps JavaScript API [19] allows for the creation of custom maps to be displayed on web pages.

JavaScript
This is a programming language that allows for the manipulation of content on web pages.

Hypertext Mark-up Language (HTML) and Cascading Style Sheets (CSS)
HTML is a mark-up language used for the purpose of defining the elements on a web page [20]. CSS defines how the elements defined in HTML are displayed on the web page [20].

Hypertext Processor - PHP
PHP is a server-side scripting language [21] that is often used in web development. It is predominantly used to create dynamic websites by populating a template with data derived from a database. This produces valid HTML which can then be displayed within a web browser.

PostgreSQL
PostgreSQL is an object-relational database management system. Like other database management systems, its main role is to hold data and provide interfaces through which data can be added, removed and manipulated [22] [23]. It is preferred to other database systems because of its built-in tools that manage location data.

2) Mobile Application:

Java
This programming language was used to implement all the mobile application functionality.

Hypertext Processor - PHP
JavaScript

D. Entity-Relation Model

The image below displays the key entities from the designed database.

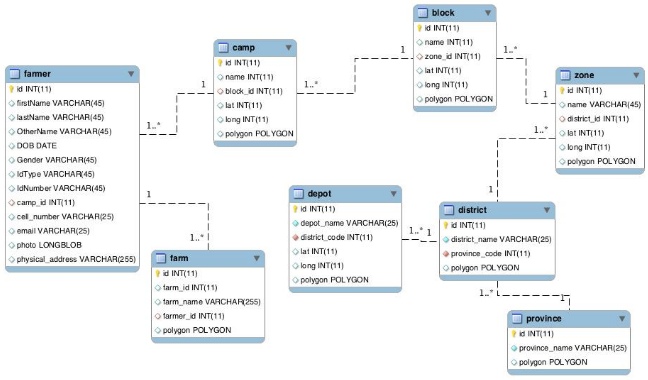

Fig. 1. Key entities

E. Use Case Models

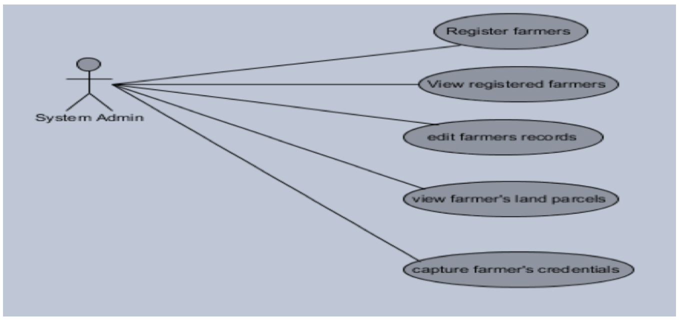

Fig. 2. System Admin Use Case Diagram

Figure 2 displays the functionality available to the system administrator within the system. Key to this study is the "view farmer's land parcels" use case. This use case delves into the process of retrieving and displaying a farmer's land parcel on a map.

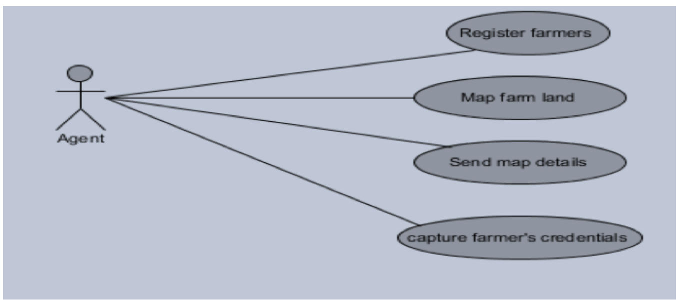

Fig. 3. Agent Use Case Diagram

Functionality availed to the agents are displayed in Figure 3. The "Send map details" use case is the most vital use case. This use case covers the means by which the mobile application sends the land parcel coordinates to the backend system.

F. Sequence Diagrams

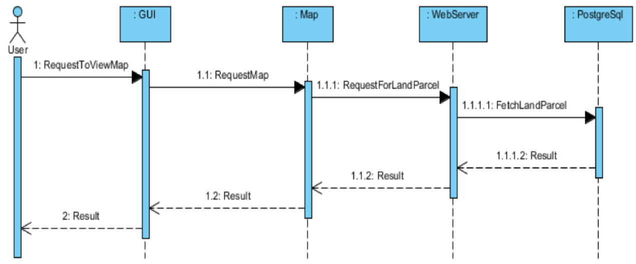

Fig. 4. View small scale farmer's land parcel on a map

Figure 4 is a sequence diagram representing the "view farmer's land parcel" use case from Figure 2. Upon receiving a request to display a map, the graphical user interface (GUI) polls the web application for a land parcel. Upon receipt, the GUI is refreshed with the updated map.

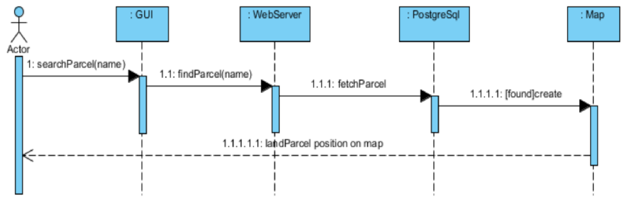

Fig. 5. View storage facilities on a map

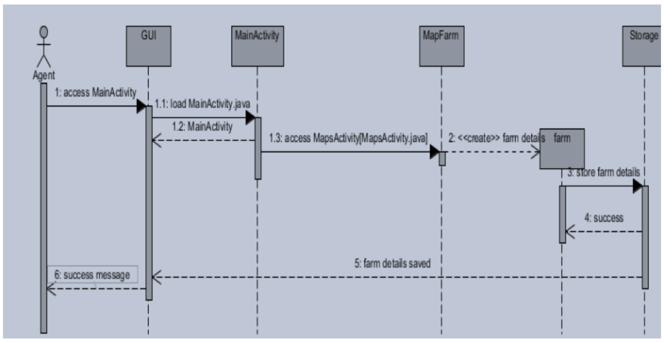

Fig. 6. Storage of coordinates

Figure 6 is a sequence diagram representing the "Send map details" use case in Figure 3. This represents the series of events occurring on both the mobile application as well as the backend system while accomplishing this task. Action 3 represents the API call from the mobile application to the backend system.

G. System Architecture

Figure 7 depicts the system architecture. The database storage and web application (PHP) are housed on the web server. Upon receiving a request, the JavaScript on the rendered page fetches the location data from the PHP and represents the data on the view through the Google Maps API.

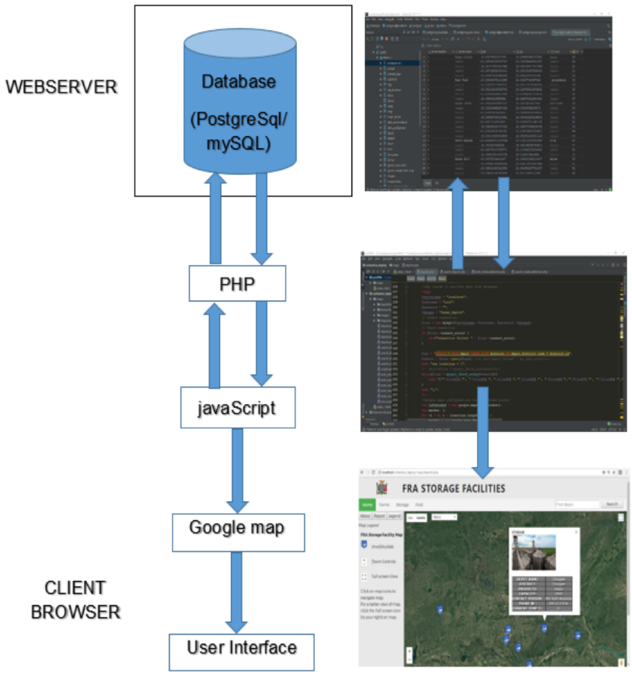

Fig. 7. System Architecture

IV. Results

A. Mobile Application

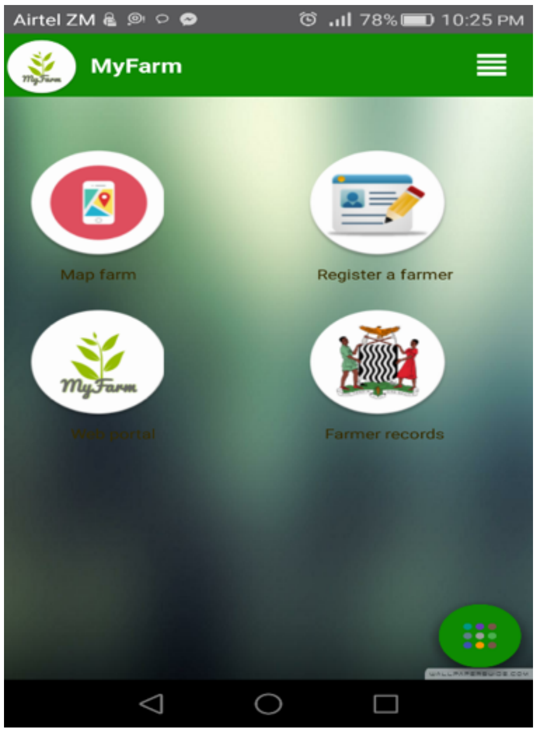

Fig. 8. Home Page

Figure 8 depicts the mobile application home page. The user is presented with all the available system functionality. Before mapping of the land parcel can begin, the farmer's particulars need to be taken. This ensures that the farmer is linked to their land parcel. The prompt for these details is displayed in Figure 9.

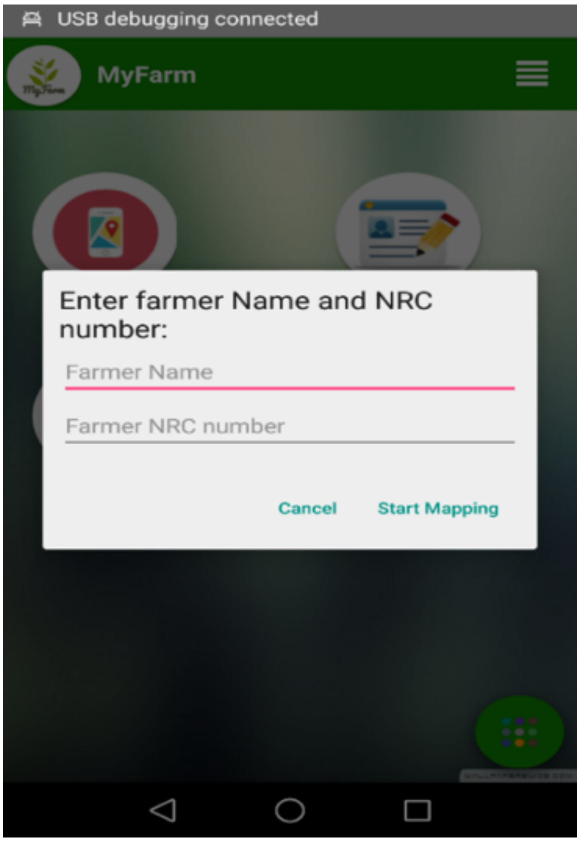

Fig. 9. Prompt dialog

During the mapping process, a map of the current location is displayed within the application. Each time the "+" button is clicked, a marker is placed onto the map. The coordinates of the location are also displayed in a pop-up at the bottom of the screen. The agent proceeds to click the "+" button as he/she reaches each vertex of the land parcel. The map view is displayed in Figure 10.

Figure 11 depicts the confirmation dialog displayed upon attempting to save the collected coordinates.

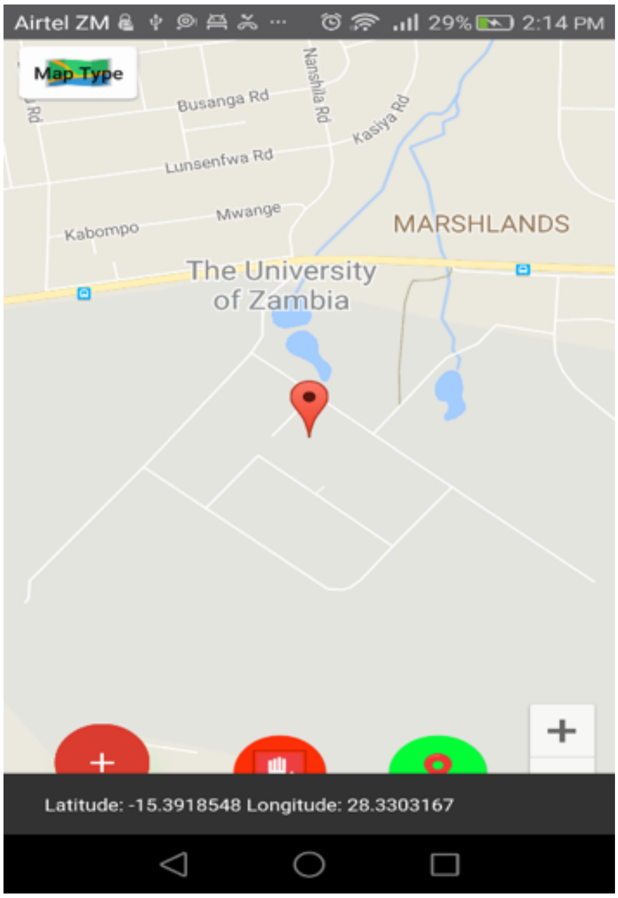

Fig. 10. Maps Activity

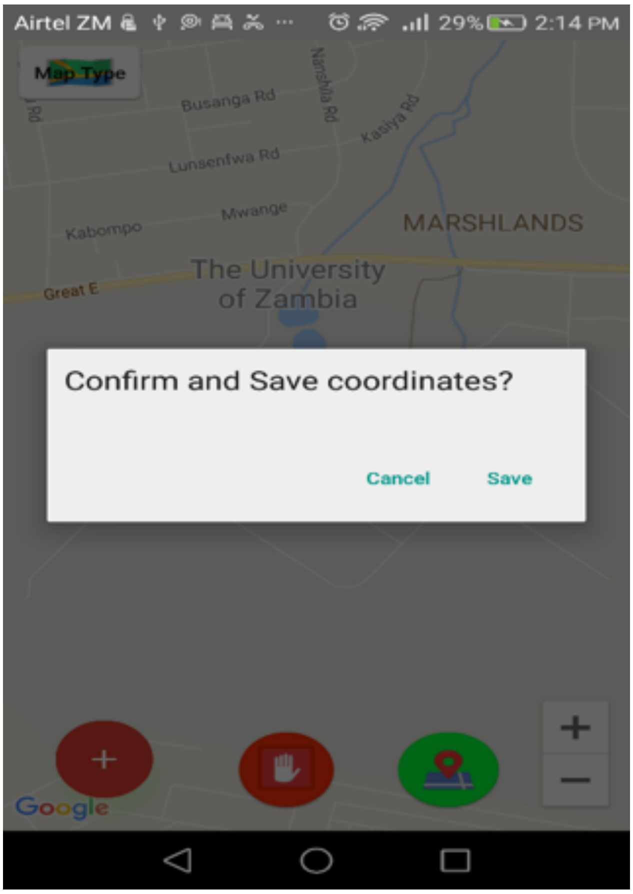

Fig. 11. Confirmation dialog

B. Map View

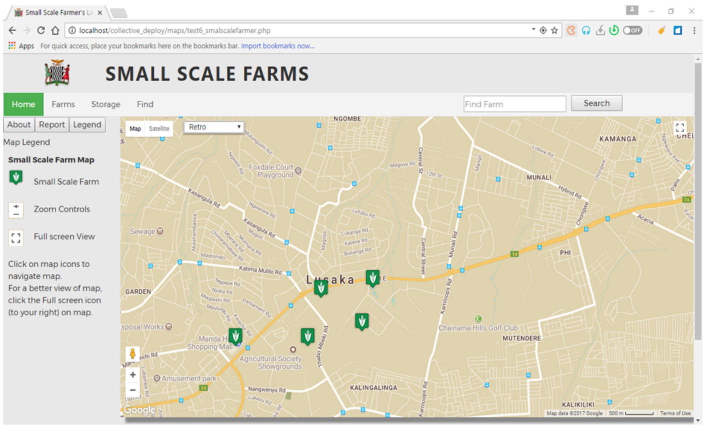

Fig. 12. View of small-scale farms as markers on map

A view of small-scale farms displayed on a map is represented in Figure 12. Land parcels are depicted as markers while zoomed out. Upon zooming in the land parcels are then visible, as shown in Figure 13.

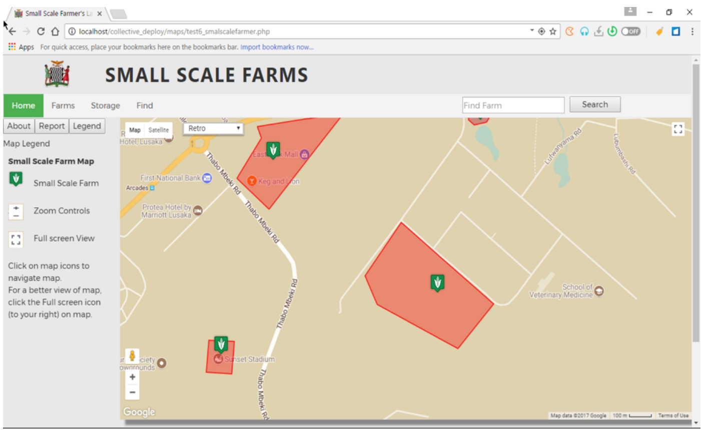

Fig. 13. Zoomed-in view of Small Scale Farms Land Parcels on map

Fig. 14. Detailed info window of a Small Scale farm on map

Clicking the marker within a land parcel brings up an info window that displays information pertaining to the farmer as well as the land parcel. This window is displayed in Figure 14.

Storage facilities displayed on a map is shown in Figure 15. As is the case with the land parcels in Figure 14, clicking a storage location marker displays a detailed information window. This is depicted in Figure 16.

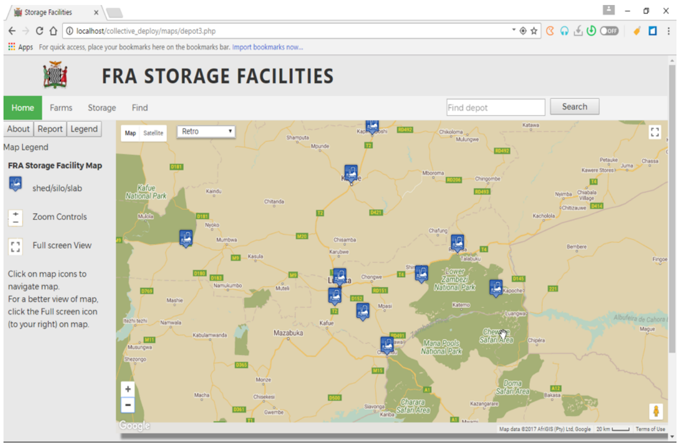

Fig. 15. View of storage facilities as markers on map

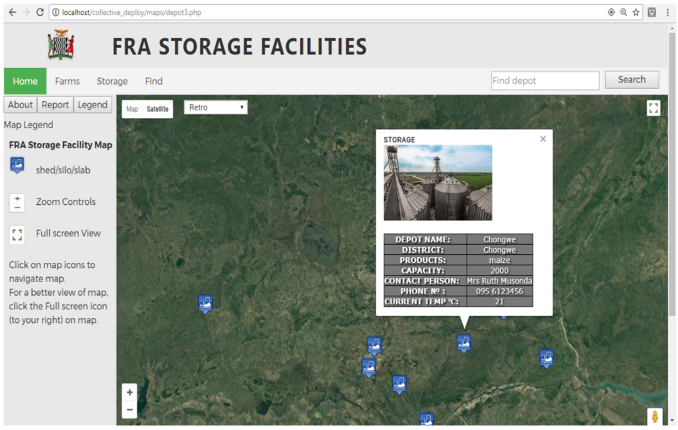

Fig. 16. Detailed info window of a storage facility

V. Conclusion and Future Work

Requirements of both modules have been met. The following modules have been developed:

- Backend system - the main web application has been developed using the PHP scripting language. This is the main module that interfaces with the database. This module also contains the application programming interfaces (APIs) through which the mapping module and mobile application communicate with the system.

- Mapping module - this mainly comprised of JavaScript and HTML. The required data is fetched through one of the backend system APIs and format- ted as required.

- Mobile application - A simple implementation of this was created. The application keeps track of all the points selected and sends the entire collection of points upon completion. The series of points is displayed on the application view.

Future works could consider the following recommendations:

- Addition of displaying most relevant routes to storage facilities and farms such as road networks.
- Incorporate a tracking systems that can track delivery trucks to the storage facilities and display the movements as GPS on a map.
- Addition of a financial module that monitors the finances relevant to the agriculture loan schemes offered by the FISP program.
- Drawing parcels from the mobile application upon fetching coordinates.
- Creation of reporting module.

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