Development and Evaluation of GIS- Based Soil Characterization Equipment

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Abstract

Soil Characterization is a key indicator of soil functional capacity. It is needed for soil and crop management functions specifically in determining crop yields, yields variability and farming activities. However, there are few available information specially from local institutions. Soil characteristics available in national institute are very general and was determined decades ago. Some of the soil characteristics change over time due to climate changes and other factors associated with the activities undertaken by the farmers. Hence, a constant soil analysis must always be undertaken which is very time-consuming and laborious. This study addresses the said constraints since it aims to develop equipment that will automatically determine quantitative soil mineral composition relevant to agricultural undertaking. This data will automatically transmit to a central server with the location of the agricultural land where the soil is being analyzed. This information will generate geo-map references necessary in Agricultural Land Geographic Information Management, Control and Monitoring processes and activities.

Keywords: geographic information, agricultural sustainability, technology integration, agricultural monitoring, soil profiling

I. INTRODUCTION

Assessment of the ecosystem service functions of soil and their importance for global sustainability underscore the importance of sustainable management of the soil resource for present and future societal welfare (Millenium Ecosystem Assessment, 2005). However, in the Philippines, the basic data on agricultural land resources and soil quality are scarce since its islands landform and soils, extent of soil degradation brought about by climate change and farmers activities. In fact, local government unit and even the national government offices do not have an updated profile of its land use more so an updated profile of soil characteristics cultivated by farmers.

Soil, water and plant are important elements in agricultural undertaking. And that, an effective and efficient analytical services and system for these is an important means for increasing and sustaining land productivity that will lead to a sustainable crops and food production. Unfortunately, Philippine government is faced with the problem of agricultural sustainability. The fundamental challenge lies in managing agricultural land resources, and its failure is attributed to the lack of appropriate approaches and tools in understanding soil characteristics that would permit diagnostic screening relevant to agricultural and agriculture-related activities.

Therefore, a major investment in improving soil and crop management is necessary in order to improve soil and crop management with the main objective to raise agricultural productivity. Moreover, soil analysis anchored in land geographic information management system is important. Crop growth depends on certain locations determined by genotype, soil characteristics, and climate. On the other hand, actual crops yield results from the interactions of local-growth-limiting and growth reducing factors (De Wit, 1992). The variability of crops growth performance within the individual farms reflects the effects, interactions and spatial distribution of these factors, many of which are directly influenced by management decision. Both long term and current soil management decision influence the prevailing soil quality, spatio-temporal patterns of resource allocation and the timing and effectiveness of agronomics practices (De Wit, 1992).

Note that crop growth variability has been attributed to: soil properties, agronomic practices and farmers' resource allocation decisions (Mutsaer et al., 1992). Conversely, information out of these crop growths' variability are of paramount importance in any agronomic management decision in order to maximize agricultural productivity that will thereby increase crop production. All of these require understanding of soil characteristics so that an appropriate agricultural undertaking is implemented.

Unfortunately, basic data on land resources and soil quality in the Philippines are obsolete, not detailed and in most instances not available. This is due to its land diversity, lack of personnel to assess and the non-availability of technology needed in the assessment. In other words, Philippine concerned government offices lack scientifically based information needed in understanding the present soil characteristics which are very important in agriculture and agro-related activities.

In light of these constraints, development of equipment and techniques for soil analysis are critical for farmers, land managers, concerned private and government institutions and even researchers. This is in order to maximize the full potentials of every agricultural land. There is a recognized need to develop rapid and inexpensive techniques for soil characterization to support the agricultural sustainability program of the government. This program includes the development of equipment and devices that will fasten the appreciation of the current conditions of the Philippines' agricultural land – specifically the Samar Island. One way to achieve this goal is to develop a mapping and expert systems for soil types based on its characteristics in terms of mineral composition relevant to crop production.

Further, climate change, time, over time, farmers activity and other factors bring significant changes to the soil quality. In fact, Schalenger (1985) observed that the agricultural land continues to loose carbon at successively lower rates with time, approximating a low steady state after 30 to 50 years. Johnson (1995) also observe changes in ecosystem carbon stocks after disturbance of degradation. Along with this, it can be concluded that indeed soil quality changes over time and that all available data that farmers and concerned government agencies may have today are already subject for re-evaluation and need to be updated.

Rapid soil characterization appraisal should be undertaken to guide both the farmers and concerned agencies on what activities and program to implement to carry over the task, and this is where the study becomes relevant.

Soil characterization equipment with GPS and GIS technology is a device capable of automatically calculating the mineral composition of the soil and also determine the exact coordinates of its location with the use of GPS technology. The data gathered is automatically sent to a centralized server for GIS mapping – for effective agricultural land use monitoring and control.

II. MATERIALS AND METHODS

Development and Evaluation of GIS-based Soil Characterization Equipment is a developmental research undertaking concerned on technology integration and application. It encompasses both software and hardware development hence the Dynamic System Development Model (DSDM) was utilized in the actualization of the project. DSDM is a project development concept that describes the stages/phases of information system development as – (1) conceptualization requirement and specification, (2) System Analysis (3) System Design (hardware and software), (4) testing and Implementation, (4) Evaluation (Smith and Thelen, 1993).

A. Conceptualization Requirement and Specification

Conceptualization requirement and Specification served as a benchmark to measure the overall acceptability of the finished system. In a nutshell, the system requirements gathered were through a certain data-gathering document and became the system specifications of the finished product – the Developed GIS-based soil characterization equipment.

In this study, document and information analysis have been undertaken through a process called requirement analysis document (RAD). Data and Information on Soil Composition and Characteristics that include but not limited to maps, agriculture-based activities and programs and other information relevant to the study are being considered.

Review of technological innovation in agriculture, focusing on the application and use of Geographic Information System (GIS) software, microprocessor technology design and integration as well as expert views and consultation has been sought relative to this aspect.

Some specific data and information taken are from Government Units that provided information about the local development programs and records about farmers and farming activities and crops in their local community. The department of agriculture, provided agricultural maps, soil characteristics information and other pertinent data. Other agencies – National Irrigation Administration (NIA), Department of Environment and Natural Resources (DENR), Department of Agriculture (DAR), National Statistics Board Commission (NSBC) – also provided information on land use and other land resources of the different municipalities under study.

Data contains quantitative and qualitative information that concerns the characteristics and activities related to agriculture undertaken by the farmers and the government. Field work is also undertaken to find out detailed information about agriculture-based socio-economic aspect of the re-using techniques of participatory and rapids rural appraisal.

Figure 1 shows the conceptual model of the system. The figure indicates the necessary Information technology Infrastructure and/or components needed

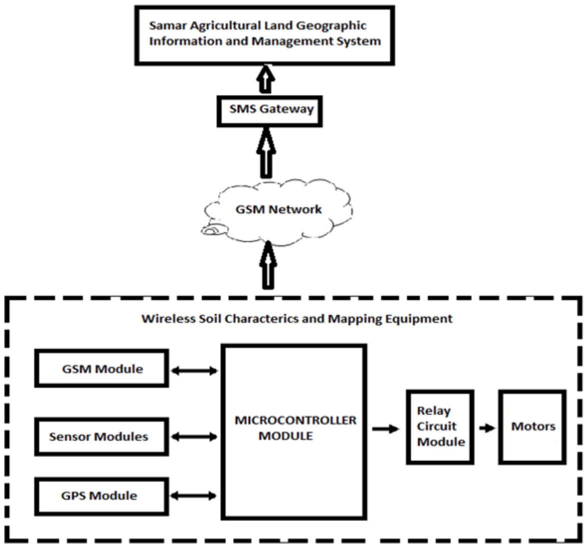

Figure 1. System Block Diagram

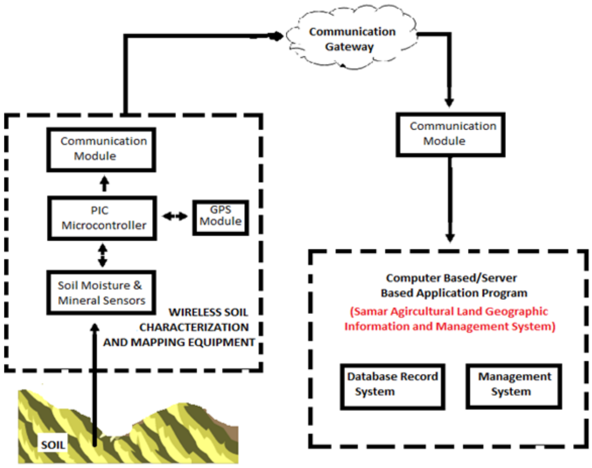

Figure 2. System Process Operation Diagram

in system development.

As indicated in the figure, the system is concerned with the development of wireless soil characterization equipment that is to be utilized in determining the soil composition and determining its exact coordinate location. The diagram also depicts the required Information Technology (IT) infrastructure such as Global System Communication (GSM), Short Messaging System (SMS), GPS Technology and Computer System Infrastructure (for Agricultural Geographic Information, Control and Monitoring). The Computer System Infrastructure include the database systems, control system and monitoring system.

B. System Analysis

From the vast information gathered in project conceptualization and anchored to the laid down concept block diagram shown in figure 1, the system has been further analyzed, and a detailed system operation is shown in figure 2. Figure 2 shows the entire process of the system which starts the moment that the device is activated/used. The WSCME determines first the soil moisture and its corresponding mineral composition through the use of soil moisture and mineral sensors, and the results would then be forwarded to the microcontroller circuit. The microcontroller circuit will then activate GPS module in order to determine the coordinates of the location to where the readings are taken. Results from these two modules would then be forwarded to the communication module for data transmission to the Server based Application.

C. System Design

Designing the system requires multidisciplinary expertise since the discipline involved from electronics sensor technology, computers, software development, materials and manufacturing. In general system, development was divided into two general categories: (a) Hardware Design and (b) Software Design

Another aspect of the system involves geographic information system processing which include the use of maps and GIS software. This project utilizes the available information existing in a range of formats, and some maps are already digitized but most are in the form of paper from different agencies. All of these require a transformation to a digital format and standardization to the same cartographic system before it can be integrated into a Geographical Information System (GIS). The following

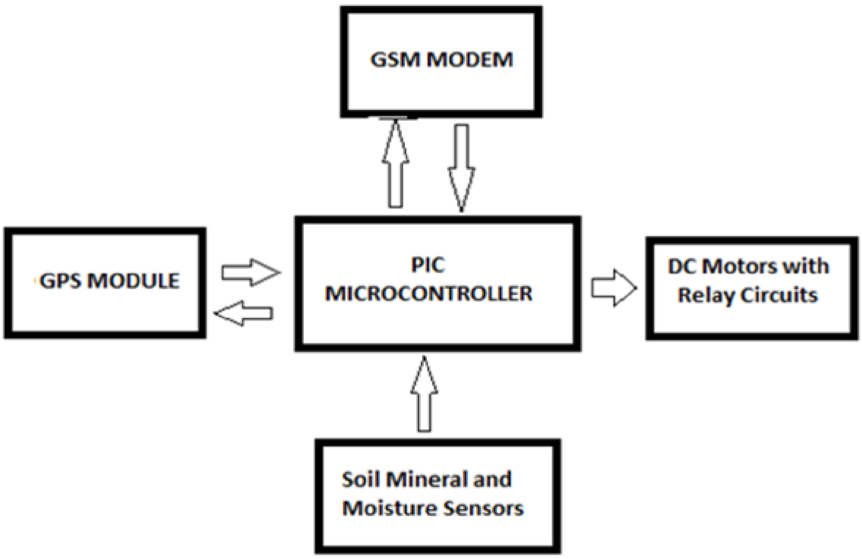

Figure 3. Hardware Architectural Design

procedure will be carried out for the inputting and integration of information in the GIS: maps of the Province, Municipal boundary maps, Barangay boundary maps, soil, vegetation and land use maps will be digitized and the digital information about satellite images and the digital elevation model will be out into GIS. With the transformation of maps and digital data into the same cartographic system and the mapping and overlay procedures of GIS the inventory, availability and location of agricultural land and other information achieved was at the municipal level. This information can then be used for a number of purposes e.g. the location of agricultural areas, its soil characteristics, crops suitable to be planted, crops yields, government program undertaken in an specified area and other agriculture-based geographic information. All of these are very significant information in agricultural land management and decision making.

Hardware Design

Hardware design involves the actual creation and integration of the project hardware requirement which include the following: soil moisture sensors; GSM module; DC motor; soil mineral composition sensors; microcontroller and other electronic and electrical components.

The hardware was designed based on the WSCME device internal structure as shown in figure 3. The Programmable Integrated Chip (PIC) microcontroller was programmed as a controller of all other subcomponents of WSCME. It will continuously receive data from the soil moisture and mineral sensor and compute for its corresponding amount at the same time it will activate the GPS system to determine its location. The result would be forwarded to GSM modem for transmission to the Application Program, which is the Samar Agricultural land Geographic Information and management System. The PIC microcontroller will also activate the DC motor so that the soil and moisture sensor will eventually perform soil sensing.

Software Design

Software design includes both embedded system program development and application system program development with database and GIS software integration. The embedded system program designed is in accordance to the functions of the hardware system which primarily focused on hardware control. The program is to be loaded into the Programmable Integrated Chip (PIC) which is the microcontroller. The microcontroller is to be coded and to be compiled in MikroC Programming

Table 1.
System Functionality Criteria

NO	CRITERION
1	Transmission of Data between the developed Soil Composition Mapping Equipment to the developed software based application program
2	Auto determination and calculation of the 5 types of soil mineral under study
3	Provision of SMS control as alternative control mechanism for device operations
4	Reception of SMS message (specific control command) for specific control mechanism.
5	Automatic database record updates for received data which includes Agricultural Land specific location and soil mineral composition
6	Updates of GIS maps and Information based on received information
7	Automatic Soil Moisture detection
8	Automatic location coordinates determination and calculation
9	Automatic map geo-referencing formulation

language as well as to be loaded using PIC Kit version 2 software applications.

On the other hand, the application program is to be designed using Visual basic.Net Programming language. The different control and monitoring function of the application program for Samar Agricultural land Geographic Information, Control and Monitoring System. The program also receives data from WSCME and processes the same in consonance to the operation and function of the system.

D. Testing and Implementation

The actual project development used the iterative approach. This approach involved project module development both hardware and software. Functionality test is likewise immediately undertaken during this phase to ensure proper system operation. Also, test is made at each developed module prior to system integration so that module and system adjustment can be carried over immediately if system bugs and errors arise, ensuring the system's functionality.

As a result, the WSCME and server-based interactive control and management system for Samar Agricultural land referred as " Samar Agricultural land Geographic Information and management System is being developed as discussed in section 3 of this paper.

E. Evaluation

Evaluation is limited to the functionality, accuracy and reliability of the system. The system is evaluated if the desired functions such as, auto-determination of soil moisture, determination of soil mineral composition, determination of the location coordinates, transmission of data to the central server application, updates of database records, experts formulation for control and monitoring are being achieved. The evaluation of the equipment also includes comparative data analysis of the different agricultural land are using the WSCME as compared to that of soil sample laboratory result and actual land survey. Device acceptability is then computed by comparing the device data result with that laboratory result having an assumed degree of the error index of (+/-) 1.5. The degree of the error index is computed using the formula shown below:

Degree of error = Device reading result – laboratory result/ laboratory result

The system functionality evaluation is limited and based on the function of the system. The functionality level is analyzed using the Likert Scale. The system functionality criteria are shown in Table 1. In addition a purposive sampling procedure in the determination of the respondents' technical knowledge in Information Technology and/or Electronics Technology is the primary basis in identifying them. In other words, system functionalities are validated through expert's validation.

On the contrary, the evaluation did not cover software design evaluation which include, but not limited to program codes evaluation, Graphical User Interface (GUI) design evaluation as perceived by other experts and the system user.

III. RESULTS AND DISCUSSIONS

Wireless Soil Composition and Land Mapping Equipment

The outcome of the system, following the methods delineated in methodology, is the development of the Wireless Soil Characterization and Mapping Equipment (WSCME) and a server-based interactive control and management system for Samar Agricultural Land referred as "Samar Agricultural Land Geographic Information and Management System.

The developed WSCME utilizes different components such as a microcontroller, DC motors, relay module, GSM/GPS module, moisture sensor module, mineral composition sensor module and device power supply module.

The microcontroller module acts as the brain of the entire system. It handles and controls all the processes and interactions within the system. As a result, PIC18F4620 had been found to be the most appropriate PIC for the developed WSCME because of its high computational performance and it meets the system memory and I/O requirements.

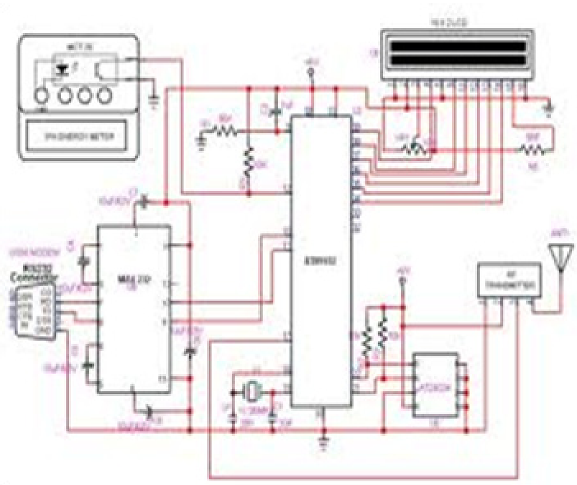

Figure 4. Wireless Soil Characterization and Mapping Equipment Circuit

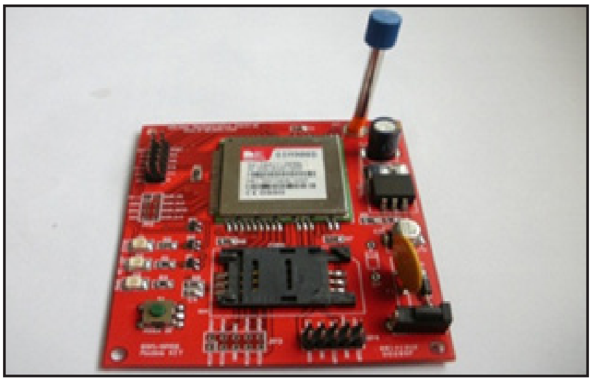

Figure 5. GSM/GPS Module

The resulting microcontroller circuit is shown in figure 4. The said circuit is being simulated in Proteus ISI Professional V7 SP1 software environment. Proteus ISI professional is an Application Software used in simulating designed circuits

As described, the WSCME has a GSM module which is a communication module of the device itself. This module transmits information that includes the soil composition and its location coordinates to a central server. In cases of remote control, this system receives SMS messages designed for specific device operation such as system reset due to device operation error. For this project, a GSM/GPS model 340 module is used as shown in figure 5.

On the other-hand, soil moisture sensors and soil composition sensor modules are being controlled and activated by the

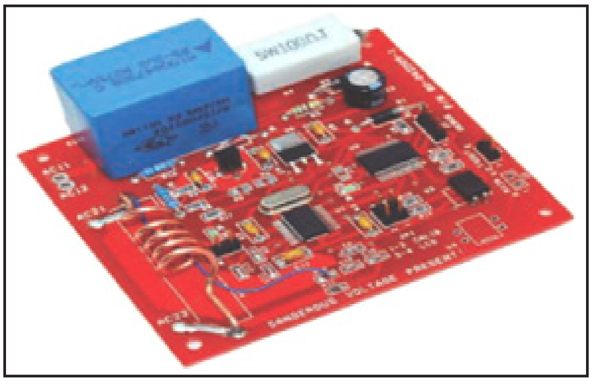

Figure 6. Soil Mineral Sensor

microcontroller. These modules determine the soil moisture content as well as the mineral composition of certain land area being sampled. For this particular study, the MGL-02345 soil mineral composition sensor module was used as shown in figure 6.

The soil moisture sensor module and soil mineral composition sensor module sends information/readings towards the microcontroller modules. This information is sent towards the communication module for transmission to Application Program in a central Server.

Samar Agricultural Land Geographic Information and Management System

The Visual Basic.Net Programming Language specifically used was in the design of the Samar Agricultural Land Geographic Information and Management. It also made use of MySQL Database as its Database platform. Following the flowchart diagram of the system and the following sample GUI interfaces have been generated as shown in figure 7.

Figure 7 shows some of the functional Graphical User Interfaces of the System which was designed integrating the Quantum GIS software, Visual Basic.Net Programming Language and the MySQL database platform.

Furthermore, the figure shows some of the information that the system generates including the general agricultural profile of Samar Province as well specific information such as Soil Composition Map, Land Use Map, Contour Map, Slope Map, Major Agricultural Crops and Crops Production. Information also includes the municipal level agricultural land profile, list of farmers cultivating the land, crops that are suited to be planted to an specific area based on soil composition, crops produce, and yields in every agricultural land location, government program and activities undertaken in every specific agricultural land which include agri-infrastructure development.

The information that the system generates can be utilized as an expert guide to whatever decision to which the farmer or government offices and/or concerned individual will undertake or make.

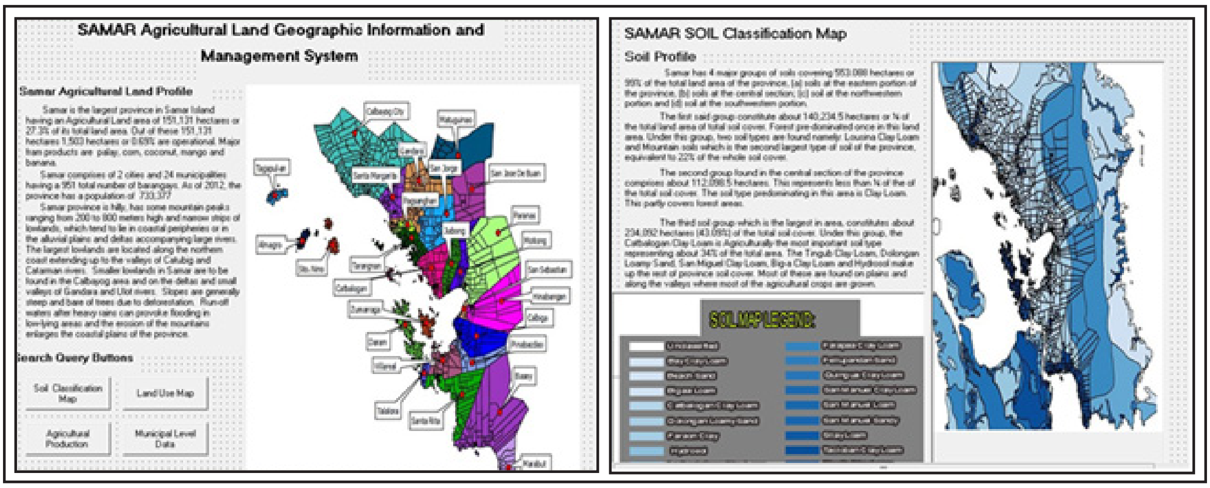

Figure 7. Sample Graphical User Interfaces

Table 2.
Wireless Soil Composition and Mapping Equipment Results

Site Location	Soil Mineral Type						
	1	2	3	4	5	6	TOTAL
1	0.12	0.20	0.07	0.18	0.23	0.20	1.00
2	0.12	0.25	0.12	0.23	0.18	0.10	1.00
3	0.09	0.32	0.17	0.15	0.15	0.12	1.00
4	0.13	0.28	0.10	0.25	0.16	0.08	1.00
5	0.07	0.30	0.13	0.21	0.22	0.07	1.00
6	0.10	0.21	0.11	0.17	0.16	0.25	1.00
7	0.08	0.17	0.15	0.18	0.19	0.23	1.00
8	0.14	0.30	0.13	0.18	0.20	0.18	1.00
9	0.05	0.24	0.07	0.20	0.23	0.21	1.00
10	0.09	0.17	0.16	0.15	0.18	0.24	1.00
11	0.12	0.21	0.14	0.20	0.16	0.17	1.00
12	0.08	0.23	0.16	0.18	0.13	0.22	1.00
13	0.09	0.27	0.12	0.13	0.09	0.30	1.00
14	0.08	0.25	0.16	0.17	0.13	0.21	1.00
15	0.13	0.28	0.10	0.25	0.16	0.08	1.00

Table 3.
Soil Composition Based on Laboratory Results

Site Location	Soil Mineral Type						
	1	2	3	4	5	6	TOTAL
1	0.08	0.25	0.08	0.15	0.20	0.24	1.00
2	0.10	0.21	0.11	0.20	0.18	0.24	1.00
3	0.07	0.28	0.15	0.14	0.14	0.22	1.00
4	0.12	0.27	0.12	0.21	0.13	0.15	1.00
5	0.04	0.26	0.10	0.22	0.18	0.20	1.00
6	0.07	0.17	0.12	0.15	0.15	0.34	1.00
7	0.09	0.20	0.13	0.17	0.19	0.22	1.00
8	0.10	0.27	0.13	0.18	0.20	0.12	1.00
9	0.05	0.21	0.10	0.15	0.21	0.28	1.00
10	0.06	0.16	0.17	0.17	0.15	0.29	1.00
11	0.11	0.20	0.14	0.20	0.13	0.22	1.00
12	0.05	0.22	0.16	0.16	0.15	0.26	1.00
13	0.08	0.25	0.11	0.13	0.12	0.31	1.00
14	0.05	0.23	0.18	0.17	0.11	0.26	1.00
15	0.11	0.25	0.12	0.23	0.15	0.14	1.00

Testing Result and Evaluations

System Device Accuracy: System device accuracy analysis had been undertaken to determine validity and acceptability. As indicated in the methodology, comparative data analysis of developed Wireless Soil Composition and Mapping Equipment with that of Soil Laboratory results from different soil samples. In particular, the developed WSCME was tested in a laboratory set-up where device adjustment and correction had been made prior to Field test.

The field tests consist of 15 agricultural land sites where soil sample taken are for laboratory analysis Results shown are in table 2 and 3 respectively.

Table 4.
Device Computed Degree of Error

Site Location	Soil Mineral Type						
	1	2	3	4	5	6	TOTAL
1	0.50	-0.20	-0.13	0.20	0.15	0.17	0.12
2	0.20	0.19	0.09	0.15	0.00	-0.50	0.14
3	0.29	0.14	0.13	0.07	0.07	0.45	0.19
4	0.08	0.03	-0.17	0.19	0.23	0.47	0.14
5	0.75	0.15	0.30	0.05	0.22	0.65	0.36
6	0.03	0.24	0.08	0.13	0.07	0.26	0.12
7	-0.11	-0.15	0.15	0.06	0.00	0.05	-0.03
8	0.04	0.11	0.00	0.00	0.00	0.50	0.17
9	0.00	0.14	-0.30	0.33	0.10	0.25	0.09
10	0.50	0.06	-0.06	-0,12	0.20	-0.17	0.07
11	0.09	0.05	0.00	0.00	0.23	-0.05	0.02
12	0.60	0.05	0.00	0.13	-0.13	0.15	0.08
13	0.13	0.08	0.09	0.00	-0.25	-0.03	0.00
14	0.60	0.09	-0.11	0.00	0.18	-0.19	0.10
15	0.18	0.12	0.20	0.09	0.07	-0.43	0.04
AVERAGE	0.33	0.12	0.12	0.28	0.11	0.29	0.11

Tables 2 and 3 depict the result from two different methods in percentage equivalent. As reflected, there are five types of minerals being considered in this study. These minerals are significant in crops production: (1) sodium; (2) potassium; (3) calcium; (4) iron; (5) manganese; and (6) others which may be composed of a combination of 1 or several minerals.

There are 15 different locations randomly selected during the device field testing. Samples were also taken out from this location and analysed in a laboratory.

Data from the two tables were compared in order to determine the degree of device error using the method stipulated in the methodology. The results are presented in Table 4.

As reflected in Table 4, the computed degree of error in all different site location ranges from 0.00 to 0.36. These results are less than the allowable device degree of error which is plus or minus 1.5. This result implies that the developed device has a very high accuracy level, and therefore data readings of this device are accurate and acceptable.

Moreover, the developed Wireless Soil Composition and Mapping Equipment (WSCME) has an over-all computed index of error equal to 0.11 which is less than the allowable index of error of plus/ minus 1.5. This result shows a very high accuracy level of the said device in all aspects of its operations and functions. Further, this high accuracy level is a very good indicator that the system can be applied directly to actual field survey and soil composition analysis without further modifying it.

On the other-hand, the device has good accuracy level in the determination of mineral type 5 (manganese) having a computed degree of error of 0.11. It is followed by mineral type 2 and 3 having a computed degree of error of 0.12. This result only indicates that the device sensor that senses this type of minerals are very effective and very accurate. However, this claim is just a presumption based on the computed index of error, and further validation is suggested.

Table 5.
System Functionality Criteria

NO	CRITERION	WEIGHTED MEAN
1	Transmission of Data between the developed Soil Composition Mapping Equipment to the developed software based application program	4.80
2	Auto determination and calculation of the 5 types of soil mineral under study	4.80
3	Provision of SMS control as alternative control mechanism for device operations	4.90
4	Reception of SMS message (specific control command) for specific control mechanism.	5.00
5	Automatic database record updates for received data which includes Agricultural Land specific location and soil mineral composition	4.80
6	Updates of GIS maps and Information based on received information	4.80
7	Automatic Soil Moisture detection	4.80
8	Automatic location coordinates determination and calculation	4.80
9	Automatic map geo-referencing formulation	4.80
AVERAGE		4.84

On the contrary, among all the type of soil mineral, the mineral type 1 is less determined by the developed SCME having a computed index of error of 0.33. Thinlys indicates that the sensors that sense this type of mineral though acceptable is less accurate as compared to others. Though this is the highest computed index of error, it still falls below the allowable index of error which is plus or minus 1.5. Hence, the device reading result is still acceptable

System Functionality: The system functionality has been verified and validated with the use of the developed system functionality questionnaire. The results are shown in table V.

The computed weighted mean for each system functionality criteria have been interpreted using a 5 point Likert Scale as follows: very functional, functional, moderately functional, poorly functional and not functional at all.

As reflected on the table, the computed functionality level in all criterions ranges from 4.8 to 5.0 which is interpreted as the functionality level of the system is very functional. And the overall computed mean for all criterions is 4.84 which again can be interpreted that the system has an overall functionality level of very functional as evaluated by the respondents.

V. CONCLUSIONS AND RECOMMENDATION

In this particular study, the Visual Basic. Net, Quantum GIS software and MySQL Database are integrated with the Design and Development of Samar Agricultural Land Geographic Information System. Results show the high functionality and accuracy level of the system that can be a good indicator that the system can be utilized and applied in the Management of Samar Agricultural Land Resources.

Further, anchored to its study objectives, the following specific conclusions were made:

1. The wireless Soil Composition and mapping Equipment was successfully made with the use of PIC microcontroller, GPS module, GSM module, soil sensor and mineral sensor and DC motor with a very high accuracy level having a computed index of error of 0.11 and

functionality level of 4.84;

2. The Samar Agricultural Land Geographic Information System has been made that can be utilized as a Geographic Guide for both the farmers and concerned government offices and/or individuals with the following Information:

   a. Geographic Agricultural land Profile of the Province with the following information (a) soil types of the different areas; (b) agricultural activities and crops that can be undertaken and planted; (c) number of farmers that cultivates the land; (d) land use; (e) government programs and project undertaken.

   b. Average Monthly/yearly production of crops cultivated, gross domestic product, the population count, farmers profile and others.

   c. Suggestive farm activities, crops to be cultivated and other agricultural information.

In contrast, it is suggested that a Pilot Testing of the System be undertaken in a small scale Agricultural Land Area in order to further validate the system functionality performance in an actual Agricultural Land Geographic Information and Management. Also, it is recommended that other design is to be made using other technology that will enhance the develop system

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