Achieving Agriculture Biotic Sustainability through Mobile-based Information System: Adapting the characteristics of Geographical Information Systems (GIS)

Full Paper

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Abstract

Agriculture is the foundation of the economy in Sri Lanka. Presently, many factors affect agriculture production leading to crop losses and food waste in Sri Lanka. An in-depth study of these factors exposed that the root causes were the improper agricultural practices followed by the farmers and inaccessibility to the required information at the right time for optimal decision-making. As a solution, earlier, a mobile-based application called "Govi Nena" was developed for farmers in Sri Lanka. In this work, we have extended the earlier version of the application to suit the different needs of farmers. This extension includes delivering the required information similar to how the information is delivered in GIS and a new module for farmers to manage real-time pest/disease incidences. Finally, the prototyped version of the application was tested among several farmers in Sri Lanka to understand the suitability of the work concerning farmers' requirements.

Keywords: Agriculture sustainability, Pest Management, Mobile-based information systems, Actionable information, Geographical information systems

1 INTRODUCTION

Agriculture is the foundation of an economy in most of the developing countries that provide the source for food supply. Presently, food insecurity is rapidly increasing worldwide due to many reasons, such as heavy pressure in population growth, food waste, and crop losses due to pest/disease incidences (FAO - How to Feed the World in 2050). As a result, the need for food is foreseen to rise by 70% (United Nations 2010). Currently, 1.3 billion tonnes of food produced in the world for human utilization consistently gets wasted all through the supply chain, from initial agricultural production down to household utilization due to the incorrect choices made by the farmers during the critical stages of the farming process (Kummu et al. 2012). Besides, the occurrences of pest/disease incidences, incorrect identification of it, and excess usage of pesticides are also some contributing factors towards crop losses. It is estimated that pest/disease incidences cause potential damage in agricultural production up to 35% worldwide (Oerke 2005).

In Sri Lanka, due to the lack of market-driven agriculture practiced in the agriculture sector, farmers used to grow vegetables without holding attention to what others are growing. Ultimately, it has resulted in the overproduction of some vegetables and the underproduction of other vegetables (Hettiarachchi 2011; Hettiarachchi 2012). The net outcome is food waste. Besides, another problem exists is the absence of information available for farmers to manage real-time pest/disease incidences. In Sri Lanka, farmers mainly rely on the information provided by expert farmers, agrochemical dealers/retailers, and agricultural experts from the government to manage pest/disease incidences. During such a situation, farmers seek advice via initiating verbal discussions or by having direct telephone conversations with them. It is not a reliable process due to many reasons. Firstly, agricultural experts cannot rely on the information provided by farmers without any visual assessment, as there are symptoms commonly occur across different pests/diseases. Secondly, agricultural experts are unaware of the information such as climatic and soil conditions of the field as these are important requirements for their decision-making process to find out the most probable pest/disease. Further, in some places, farmers had to travel far distances to contact agricultural experts, resulted in the loss of time and money of farmers due to the failure in getting timely advice on time (Yin et al. 2013).

In agriculture, a pest/disease incidence can occur anytime in-between initial seed material to the post-harvest stage. Sometimes due to the negligence behavior, farmers confirm a pest/disease incidence based on their own experience without seeking expert advice that has resulted in incorrect pesticide selection and dosage level and improper way of application (Ginige and Sivagnanasundaram 2019). Also, it led to environmental pollution, caused human health problems due to agricultural pollution and having chemical contaminated foods, and affected agricultural produce. Also, indiscriminate use of pesticides and their effects are now of significant concern in the medical and environmental sectors (Nagenthirarajah and Thiruchelvam 2010). As stated in (Wilson and Tisdell 2001), the estimated pesticide poisoning affects nearly 25 million of the agricultural workforces annually in developing countries. Therefore, it is a significant threat to the wellbeing of people, farming communities, traders, governments, and food security worldwide.

As a result of these problems, the quantity and quality of agriculture produce severely gets affected, which means the financial returns of farmers will also be compromised (van Bruggen et al. 2015). The net result is wide price fluctuations at the markets and led farmers being able to sell their produce at a lower price and sometimes not being able to sell and forcing them to discard it (Silva et al. 2012). From our earlier work and the literature, we found that the primary cause for such problems is the absence of information available for farmers in terms of agri-knowledge, management practices, availability of input such as seed material, technology, and experts advice, driving them to take wrong choices at critical phases of the farming process (Nagenthirarajah and Thiruchelvam 2010; Ginige et al. 2016). Hence, farmers must be advised with the required information in the right format during different stages of the crop life cycle for optimal decision making.

Presently, the combination of ICTs, the internet, and smartphones have had a considerable impact on several aspects of our day to day life. The utilization of smartphones has given a way of making choices much better and easier than before. According to a statistics report by the telecommunications regulatory commission of Sri Lanka, over the years, in Sri Lanka, there has been notable growth in smartphone usage (TRC 2015). As specified in (Sivagnanasundaram et al. 2018), an application of smartphones can act as a tool for farmers to make optimal choices. It has shown us the basis to investigate more of the possibilities to find a solution to these problems based on a mobile information system. We have earlier developed a mobile-based information system called Govi Nena for farmers in Sri Lanka to address some aspects of the problems mentioned above (Ginige et al. 2016).

Recently, we saw a substantial similarity between our earlier application and widely used GIS-based navigation systems. It has opened many possibilities to enhance the way of delivering the required information to farmers more effectively and in a timely manner (Ginige and Sivagnanasundaram 2019). Based on that, we reconceptualized our earlier work further to deliver the required information to farmers similar to how the information is delivered in GIS-based navigation systems in the form of "turn right" or "turn left" or deriving optimal route when there is traffic congestion. With this reconceptualization, the current Govi Nena application delivers the necessary farming activities that must be followed while growing crop(s) as a package of practices (PoPs) through farmer-wise crop calendar, and it allows farmers to report real-time pest/disease incidences and get remedial actions promptly.

This paper describes how this application can be utilized to deliver the required information to farmers and assist them in making the right choices with the least information processing. The rest of the paper is structured as follows. The background section of this paper sets the background on which this research work was carried on. Literature review compares related work conducted within the agriculture domain. The section named Research methodology describes how the research was conducted as a step by step activities and enhanced based on GIS-based advancements. The implementation details are given in the Implementation section of the paper. The learning and reflection of the research are given in the Results and Evaluation section of the paper. Finally, the Conclusion and Future work section summarize the work while elaborating on the future works.

2 BACKGROUND

In Sri Lanka, agriculture is a major sector, and about 33% of the total workforce is involved in it (Department Of Agriculture 2019). Organizing agriculture in Sri Lanka is a challenging job due to the limitations raised by land fragmentation and per capita landholdings of each farmer. Also, the significant problems identified in the agriculture sector of Sri Lanka are crop losses due to pest/disease incidences, and food waste due to the overproduction of vegetables. An in-depth study of these problems exposed that the root causes were the improper agricultural practices followed by the farmers and inaccessibility to the required information at the right time for optimal decision-making. It happened mainly due to the failure in timely information sharing between farmers and the agriculture stakeholders led to information gaps. It can be due to a wide range of factors, including native language, literacy rate, spatial location, socio-cultural norms, market facilities, and economic reasons. Ultimately, it leads to coordination failure among farming communities, and farmers get tied into a situation where they cannot make optimal decisions on time (Sivagnanasundaram et al. 2018).

Motivated by smartphone usage in Sri Lanka, especially within farming communities, a team consists of researchers from Australia, Sri Lanka, United States, and Italy began on a research project to develop a mobile-based artifact in 2011 to address the aforementioned problem (Ginige et al. 2016). It was developed based on the iterative participatory design approach to improve the flow of information within the agriculture sector. Also, the team developed an ontological knowledge base focusing on agriculture and linked with the mobile-based artifact to answer many questions farmers had. This system can predict the current crop production levels and permits farmers to choose the most suitable crop to grow that can give them a better return. Also, it allows government institutes and agri-related corporations to dynamically change the incentives granted to farmers for growing various kinds of crops. This way of delivering aggregated information helped the farmers to attain sustainable agriculture production through crop diversification.

3 LITERATURE REVIEW

In order to increase agricultural productivity, farmers should be knowledged with the best agricultural management practices and available agricultural advancements. Even the research activities in the agriculture sector have improved progressively, the findings from such works have not always been shared with farmers who can benefit from it. On the other hand, such useful findings have been circulated among people within research communities instead of disseminating to farmers who should be the target of those findings. This has resulted in the creation of the knowledge gap between researchers and agriculture stakeholders. Currently, in most of the developing countries, the farmers have been advised with conventional agricultural practices verbally by agricultural experts and fellow farmers (Kalusopa 2005). A combination of such advice and suggestions is the only option left for them to make optimal decisions. It means that there is slow progress in promoting agricultural practices among farming communities.

In Sri Lanka, the department of agriculture (DOA) is the largest government institute that focuses more on maintaining agriculture production in the country by providing varied services to farmers. Their primary vision is to achieve sustainable agricultural improvement through disseminating agriculture knowledge. Also, they render services like conducting awareness sessions among farmers, providing subsidiaries for a reasonable price, and setting policies and controls. Over the period, DOA has initiated many projects with collaboration with various ICT institutes. The Govi Gnana is one initiative system deployed in Dambulla, a district of Sri Lanka. The primary aim of this project was to disseminate the price-related information of crops to farmers to minimize the problem of market price fluctuation and help them to sell their harvest at a reasonable price. Besides, the literature states that there were a number of web-based and mobile-based information systems developed for disseminating agriculture knowledge within the farming community in Sri Lanka. Dialog trade net and 6666 agri-price index are some examples of mobile-based information systems developed by leading mobile service providers named Dialog and Mobitel in Sri Lanka. According to a survey conducted in (Silva et al. 2013), it was identified that most of the farmers are not willing to use such systems as they need information in an effective and timely manner to make optimal decisions.

In another research work conducted to find out the information requirement of rural farmers based in the Tamil Nadu state of India indicates that most of them require information on managing pest/disease incidences and possible applications to control it (Phiri et al. 2018). Similarly, the information required by rice farmers in the Niger state of Nigeria disclosed that 89.9% of the farmers require information related to pest management to minimize pre-harvest crop losses (Tologbonse et al. 2009). A survey conducted in (Hashemi et al. 2009) about farmers in Karaj, Iran, states that farmers have a varied level of understanding of pre-harvest crop losses due to pest/disease incidences. Also, the study emphasizes that farmers require a different level of training to manage those. A similar study conducted in (Rijal et al. 2018) on assessing farmers' knowledge on pest management states that the knowledge of farmers on crop losses, causes for crop losses, pesticide selection, and overall handling is insufficient. The study also emphasized the importance of providing information to farmers about various aspects of managing pest/disease incidences and suitable pesticide applications.

Further, there have been surveys carried out to identify the influence of ICT-based solutions that can enhance agriculture sustainability (Pavitrani et al. 2011; Punchihewa and Wimalaratne 2010). The results proved that adopting the right technology plays a significant part in shaping the solution a success. As specified earlier, recently, we saw a substantial similarity between the nature of information delivered to farmers in Govi Nena application and the information delivered in GIS to its users. GIS is a platform for gathering and analyzing spatial data. Over the years, there has been a notable revolution happening in many spatial related problems. Earlier the GIS-based applications have been used in the field of natural resources management (Burrough et al.), and now, many pieces of research have been initiated to explore the possibility of using GIS in the area of transportation planning. Earlier, the map information used in the current GIS was available in printed form. Then GIS digitized this information using a vector-based data structure to locate an object at a given space using geo-coordinates (Clarke 1986). Also, it enabled the development of a wide range of navigation systems. With this novel feature, GIS exhibits more in-depth insights into data, such as generating situations at a given point.

Presently, the GIS-based navigation systems provide user-specific actionable information in the form of "turn left," "turn right," or "go straight" at a junction to navigate the user to the specified location. The nature of the information generated in GIS and the way how it delivers the information attracted many users and empowered them to use and travel places easily with the least information processing. Recently, many types of research have been carried out to map the user movements using GIS applications to generate traffic maps dynamically. By combining the dynamically generated traffic maps with the user location, these systems then evolved into directing a user to a specific location not only based on the shortest distance but also based on the shortest travel time. This motivated us to reconceptualize how the required information can be delivered to farmers and empower them to make optimal choices (Ginige and Sivagnanasundaram 2019).

4 RESEARCH METHODOLOGY

This section presents the research methodology and design aspects of the physical solution that evolved from the reconceptualization mentioned in the Introduction section. To meet the practical aspects of the application, we have employed action design research (ADR) methodology to find a solution to our research problem by creating artifacts. In ADR, the researchers investigate the problematic situation thoroughly, followed by an intervention planned to improve the situation of the problem (Haj-Bolouri et al. 2016). In here, the intervention will be based on creating innovative artifacts. ADR consists of five different phases, as shown in Figure 1. This includes problem formulation, action planning, action taking, impact evaluation, and learning or reflection. Researchers can repeat these steps to create and validate their artifacts to improve it further. The need for these repetitions evolves based on the identified problems and the required validations on earlier artifacts. At this stage, the research team went through only one cycle to get the initial feel and feedback of the application from various agricultural stakeholders in Sri Lanka. The resulted suggestions will be incorporated in the upcoming cycles, followed by the current cycle.

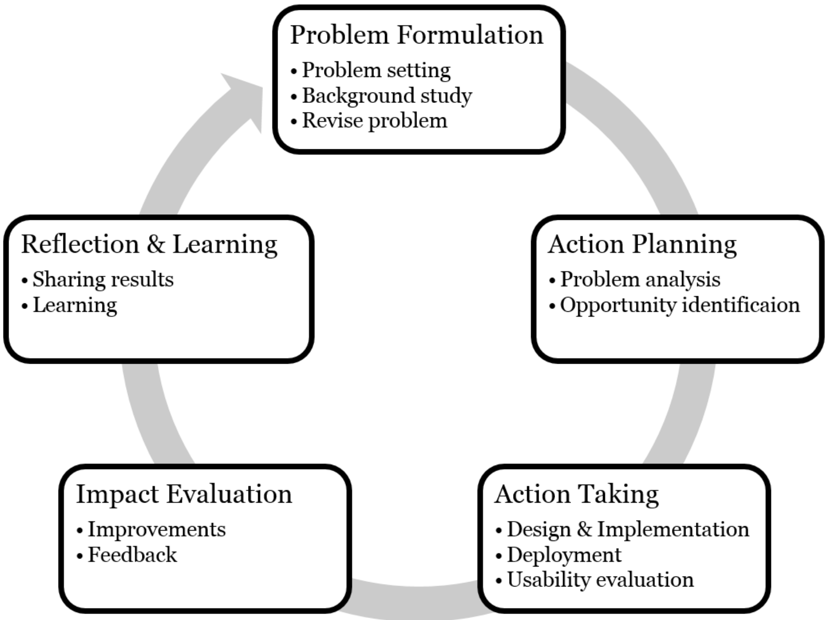

Figure 1: Activities in action design research methodology

4.1 Problem Formulation

This work started with a problem formulation phase to get an in-depth understanding of the problems in the agriculture sector of Sri Lanka. From our earlier work, as stated in (Ginige et al. 2010), we found a solution to solve the overproduction problem by assisting farmers to practice market-driven agriculture. This has been achieved by providing farmers with the current crop production level information during the crop selection phase. Hence, we have limited our investigation in this work to manage real-time pest/disease incidences and to improve the information delivery mechanism used in the earlier version of the Govi Nena application to empower farmers. These objectives led the research team to investigate more on how farmers identify a pest/disease incidence, what kind of information is available for them to make decisions, how they control the situation, and a suitable way to deliver the required information to them. Initially, we have conducted preliminary surveys among 60 farmers in three different districts of Sri Lanka to understand the factors that influenced their decision-making and extended the insights from the survey to manage pest/disease incidences. Also, we inquired them to understand their familiarity with using smartphones. The results showed that 90% of the farmers owned a smartphone, and most of them use it in their day to day activities. Over 75% of farmers stated that there was no standardized way available for them to get the required information about managing pest/disease incidences, pesticide selection, and overall handling of it. Further assessment of the results revealed that farmers' knowledge of crop losses and managing pest/disease incidence is limited.

As explained earlier, the current practices followed by agricultural experts to identify and confirm a pest/disease incidence is not a reliable process. Hence, we inquired agricultural experts to understand the information they need to confirm with the most probable pest/disease. Based on it, we found that agricultural experts need information such as; farm location, crop, and variety information, symptoms observed on the crop and distribution in the field, climatic and soil conditions of the field, and an image of the symptoms present in the crop to confirm with the most probable pest/disease. Also, they wanted the system to disseminate such situational information to nearby farmers in real-time with preventive actions to be taken, which gives extra time for other farmers to safeguard their crops. In this case, the information generated by farmers act as a situational knowledge at that time, and after aggregating similar incidences, it becomes prior knowledge later.

Further, we initiated a few discussion meetings with farmers to understand their information need during pest/disease incidences. In such a situation, farmers need the exact cause for the problem, and step by step actions to control it. Also, there was a requirement that came from agricultural experts to deliver remedial actions in the form of cultural, mechanical, biological, and chemical. In here, the chemical action is listed as the last option to reduce the excess usage of chemicals added into the environment and to reduce the overall production cost. Farmers can select the chemical option depending on the severity of the pest/disease incidence; in that case, farmers need information about the trade name of the pesticide, dosage level, and the way of applying it.

4.2 Action Planning

In the action planning phase, we transformed the gathered information in the first phase to some mock-up screens. Then we showcased it to agricultural experts and farmers to understand their initial feel and feedback. The visualization of the solution as initial mock-up screens helped both us and agricultural experts to identify the exact information flow that must happen within the agriculture sector to meet farmers' requirements about managing pest/disease incidences. As part of this study, we have come up with an information flow diagram as a basis to extend the capabilities of the Govi Nena application, as shown in Figure 2.

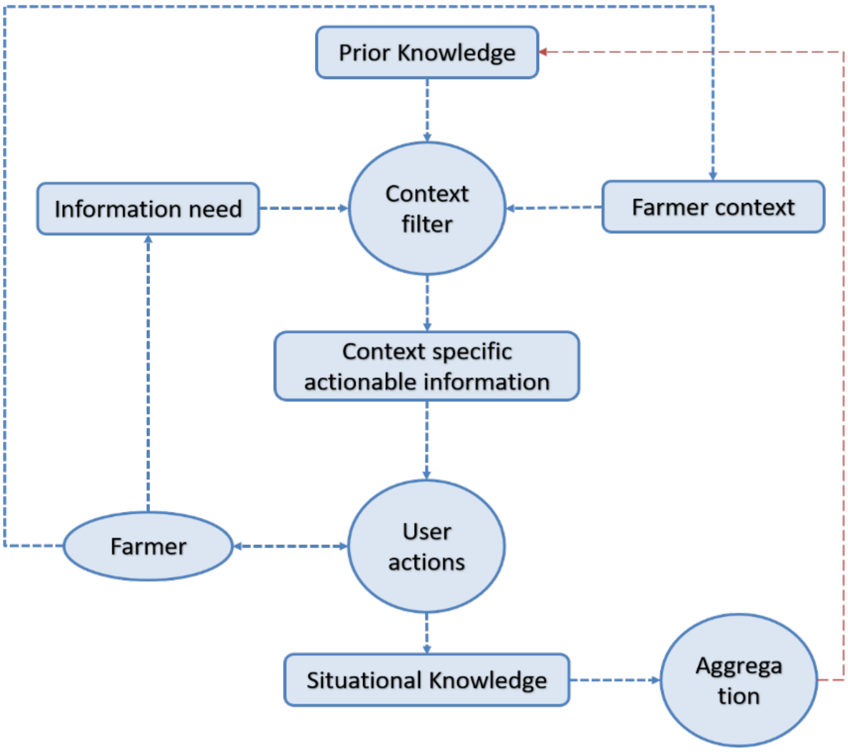

Figure 2: Information flow diagram generated for pest/disease management

Based on the similarity we observed between the information delivered in the Govi Nena application and GIS-based navigation systems, we have decided to reconceptualize and improve our previous work. Now, we have extended the Govi Nena application to deliver the required information as user-specific actionable information that requires the least information processing. This extension has enabled us to deliver the PoPs as actionable information similar to "turn right" or "turn left" instructions generated in GIS-based navigation systems, as shown in Figures 3 and 4. Also, we allow farmers to report real-time pest/disease incidences and send them with the remedial actions to be taken. The way how it generates such information is similar to deriving multiple routes when there is traffic congestion in navigation systems, as shown in Figures 5 and 6.

5 IMPLEMENTATION

From the implementation perspective, the Govi Nena application consists of several modules, as shown in Figure 7, to support different requirements of farmers. In this paper, we mainly elaborate "My Crop Calendar" and "My Crop Growth" modules developed for the extensions discussed in this paper. The My Crop Calendar is a farmer-wise crop calendar developed to list down the activities that farmers must follow while growing crop(s) to attain good productivity. Figure 4 presents an example of a crop calendar activities generated for Paddy presented in the Sinhala language, the most common language in Sri Lanka.

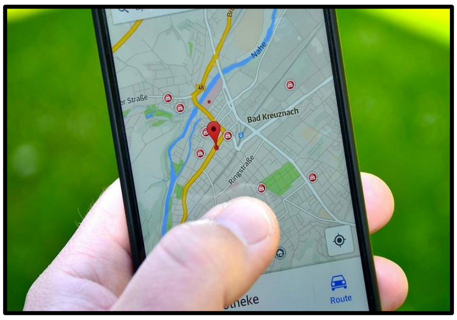

Figure 3: Navigation systems generate actionable information in the form of "turn right", "turn left" or "go straight"

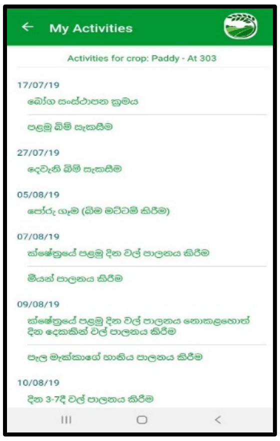

Figure 4: Govi Nena application generates activities farmer must perform as actionable information

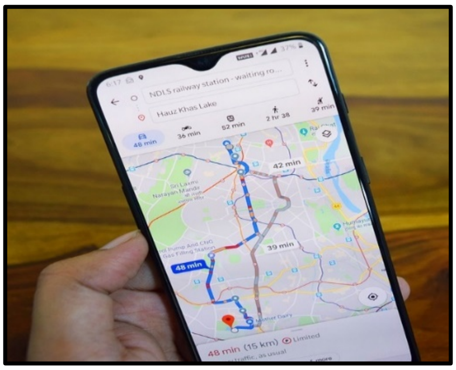

Figure 5: Navigation system generates situational knowledge such as deriving multiple routes depending on the traffic congestion

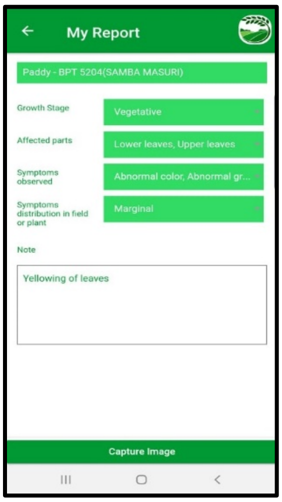

Figure 6: Using Govi Nena application to generate situational information such as pest/disease incidences

Further, My Crop Growth module is developed to assist farmers in managing pest/disease incidences. With this, farmers can report pest/disease incidences and get instant remedial actions based on the confirmation by agricultural experts. The required information for this module has been discussed in the previous section of the paper. Further, the climatic and soil conditions of the field are automatically fetched by the system based on the geo-coordinate of the farm as specified in (Sivagnanasundaram et al. 2018), and the resulted information will be sent to agricultural experts for final confirmation. Figure 6 presents the screen developed for farmers to report pest/disease incidences, and Figure 8 presents the dashboard developed for agricultural experts to visualize the reports being sent by the farmers. With the gathered information, agricultural experts can confirm the most probable pest/disease. Also, the remedial actions will be sent back to the farmers after the final confirmation by them.

Figure 7: Main menu of Govi Nena application

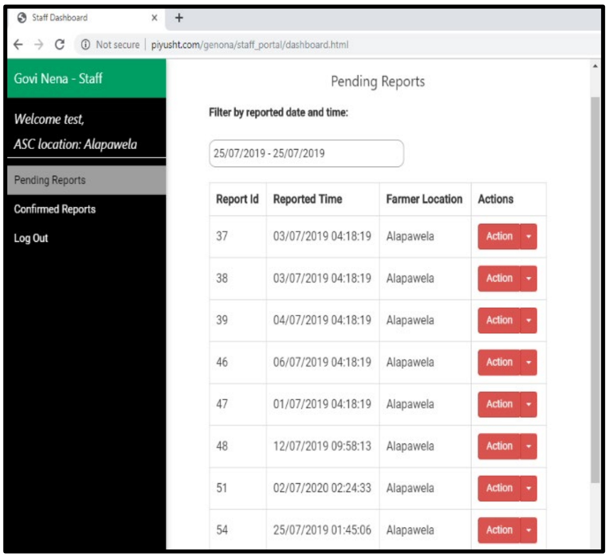

Figure 8: Dashboard to visualize pest/disease incidences

6 RESULTS AND EVALUATION

This section explains the impact created by the solution among farmers and related stakeholders of the agriculture sector in Sri Lanka. To assess the application, the prototyped version of it was deployed among 60 farmers and few agricultural experts in three different districts of Sri Lanka. Overall, farmers and agricultural experts are satisfied with the application and the rendered functionalities. Also, they find the application as effective and user-friendly due to the nature of the information delivery mechanism utilized in the application adopted based on GIS-based navigations systems. Thus, they can act on the information with the least information processing. Further, the overall needs of farmers and agricultural experts and how it addressed in the Govi Nena application are compared in Table 1.

Stages	**Farmer needs**	**Agricultural expert needs**	**Availability in Govi Nena**
Input availability of seeds, fertilizers, chemicals, etc.	Information about the input availability in nearby trusted dealer/retailer shops.	Information about good quality input and dealers who supply that at fair prices.	Yet to be implemented.
Publish information about how to grow a crop.	Information about crops and varieties for the better selection of crop.	All the suitable crops and varieties that can be grown in the farmer's location should be available.	Available via My Crops module.
	Information about how to grow crops?	Information that farmers must follow from the seed selection stage down to the post-harvesting stage.	Available via My Crop Calendar module.
	Information about controlling pest/disease and weed.	Information about practices related to preventive and curative control of pest/disease and weed along with a suitable time for the initiation of such control measures.	Available via My Crop Calendar module.
Stages	Farmer needs	Agricultural expert needs	Availability in Govi Nena
	Information about real-time pest/disease incidences reported in nearby areas.	Get real-time pest/disease incidences from farmers to understand the situation.	Available via My Crop Growth module.
Farm mechanization	Information about the machinery, overall handling of it, and places to hire.	Information about machinery hiring services.	Yet to be implemented.

Stages	Farmer needs	Agricultural expert needs	Availability in Govi Nena
Market information	Information about selling and buying prices of crops in the market.	Information about minimum support price of different crops, online trades.	Yet to be implemented.
Government subsidiaries	Information about subsidiary offered by government and agricultural agencies.	Information related to subsidiaries offered by government, non-government organisation on the agricultural input and products.	Yet to be implemented.
Extension services	Information about the availability of new crop varieties and technology advancements. Also, the information about workshops and seminars organized by the government and agricultural institutes.	Include success stories of expert farmers to empower other farmers. Publish information about various services rendered by the government and other agricultural institutes.	Yet to be implemented.

Table 1. Needs of farmers and agricultural experts and how it addressed in Govi Nena application.

7 CONCLUSION AND FUTURE WORK

A common problem observed in the agriculture sector of Sri Lanka is, farmers are not published with the required information that resulted in food waste, and failure in managing pest/disease incidences ultimately led to increased food insecurity. In this paper, we have developed two extension modules called My Crop Calendar and My Crop Growth to solve the problems mentioned above. Further, these modules were developed to publish the required information on time through farmer-wise crop calendar to assist farmers in optimal decision-making and allow them to report real-time pest/disease incidences and to get remedial actions back. Also, these extensions were designed based on the similarity observed in the GIS-based navigation systems and developed by extending the earlier Govi Nena application.

The initial deployment, which has happened among 60 farmers and agricultural experts in three different districts of Sri Lanka, showcased that they are satisfied with the services rendered by the application. Hence, this way of delivering the required information will assist farmers in making optimal decisions during the critical stages of the crop life cycle, manage pest/disease incidences, and in overall, increase the food security. As future work, we aim to investigate these additional requirements gathered from farmers and agriculture experts. Also, we are planning to extend the My Crop Growth module to predict the spreading pattern of pests/diseases through aggregating similar incidences based on farmer locations. With such insights, farmers can take preventive actions beforehand instead of waiting for it to happen.

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