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A Decision Support System for Enhancing Crop Productivity of Smallholder Farmers in Semi-Arid Agriculture

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ABSTRACT

This study aimed at investigative decision support systems for assisting strategic and tactical decision making of smallholder farmers to reduce climate risks and increase crop productivity of semi-arid areas. Specifically, the study assessed farm-level decisions used by the farmers for reducing climate risks; examined information communication and knowledge sharing strategies for enhancing decision making and designed a system for assisting the farmers in selecting appropriate options for improving crop productivity. Development of DSS was governed by design science where prototyping approach was used to allow complete participation of end-users. The proposed architecture allows difference agricultural actors participate in communicating agricultural information and sharing of knowledge with smallholder farmers. The DSS was implemented and assessed by farmers as a useful tool for accessing information and advisories in agricultural systems. More research is recommended to enable simple and affordable mobile phones be used by farmers to access wealth of agricultural knowledge and policies from research centres and government resources.

Keywords: *decision support system, strategic and tactical decisions, crop productivity, mobile phone, agriculture*

I. INTRODUCTION

There are several opportunities for smallholder farmers to be transformed into medium scale agricultural production. Among different strategies, availing decision support systems for enhancing access to agricultural information and sharing of agricultural knowledge including climate information is vital for realizing improved crop production [1]. However, existing methods for communicating information to smallholder farmers have been found to be not effective for farmers to access timely, understandable and actionable agricultural information and technologies. These methods include radio, television, extension agents and face to face communication (social gatherings at the villages). On the other hand, several software tools have been developed for analyzing different scenarios to generate recommendations and advisories to be used by farmers for optimal crop production.

Despite the development of software tools at the research centres, transferring of technologies developed required personal communication to farmers and agricultural extension workers at villages. Furthermore, the adoption of these tools remained as a challenge. Low adoption of decision support in agriculture system requires developing improved approaches of DSS development [2, 3]. In addition, the approaches for developing decision support system should consider participation of key users.

In agriculture, dissemination of climate information and sharing of agricultural knowledge can be enhanced by application of opportunities in Information and Communication Technologies (ICT). Existing dissemination methods include radio, television, face to face, and electronic mail [4, 5]. In addition, web-based system have been developed and used to disseminate agricultural information [6]. However, the use of web and mobile technologies has been inadequately explored in order to support interactive communication [7]. Realizing the benefits of these technologies, this study aims at developing an integrated system with web and mobile technologies in order to support strategic and tactical farm decisions under a changing climate for semi-arid areas.

In this study, a decision support system (DSS) to enhance strategic and tactical decisions that are linked to advance climate information with site-specific relevance. DSS have been applied successfully in agriculture and other sectors such as health [8]. Such DSS has inadequately addressed strategic and tactical farm level decision in a changing climate. Therefore, in order to improve crop productivity through improving adaptive strategies to climate variability, a web- and mobile- based DSS is essential. In this study, the overall objective of was to develop a decision support system to assist strategic and tactical decision making of smallholder farmers to reduce climate risks and hence increase crop productivity in Same District. The question that guided the development of decision support system for assisting farmers in making strategic and tactical farm level decisions was to determine a decision support system to support farmers and a range of agricultural stakeholders of different capabilities and education background.

II. RELATED STUDIES

Decision making in agriculture involves selecting an alternative choice that has improved effect to crop productivity. As a result of climate change and variability, different management strategies and technologies are adjusted accordingly for managing risks and take opportunities of climate change [9, 10]. For example, early maturing crop varieties are most suitable for seasons with low rainfall whereas high yield crop varieties are suitable in high rainfall seasons [11, 12, 13].

Proper land preparation methods in semi-arid areas had been adopted as adaptation strategy for managing risks caused by

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climate variability. Tillage practices can be used for rainwater harvesting and hence increase water available to a plant and improves soil moisture and nutrients. According to Majule [14], good tillage practices such as deep tillage, ripping tillage and tie ridging showed improved crop productivity in semi-arid areas under severe influence of climate variability. Similarly, events associated with climate variability made famers change tillage practices in Australia where different tillage options used under different climate conditions as an adaptation to climate variability [15]. These options include conventional cultivation, minimum tillage and no till.

The practices of choosing a crop to grow in a particular area has been determined by several factors including temperature, precipitation, humidity, wind, soil, vegetations cover, radiation energy and socioeconomic conditions of farmers. In short, climatic conditions, physical relief features and human preferences determine what crops could be grown in an area. However, choice of crops to be grown in particular seasons have been complicated with increased impact of climate variability especially in semi-arid areas [16, 17]. As a result, effective crop productivity has been declining due to not only inadequate rainfall but also poor decision making of smallholder farmers.

In semi-arid areas, smallholder farmers practices mainly rain-fed farming with no permanent irrigation facilities. Rainfall in these areas is unevenly distributed, highly uncertain and erratic in nature. Moreover, semi-arid areas receive annual rainfall of about 500mm or less. Because of moisture stress and uncertain rainfall, these areas are characterized by very low crop yields and hence poor economy of farmers. However, different practices have been recommended aiming at reducing moisture stress to crops through harvesting rainwater and applying improved agricultural practices [18, 19]. Still farmers are confronted with difficulties in selecting crops in response to different weather conditions for improved crop productivity, despite increased experience of growing crops in semi-arid areas and recommended options from research outputs. In order to improve decision making in selecting suitable crop for improved crop productivity, smallholder farmers need information about a particular climatic event. In other words, farmers need weather forecast information in order to make sound plans for agricultural production.

Being informed that subsequent cropping season is going to be good, poor or normal, helps farmers to better plan for their operations and make concrete strategic decisions. Risks associated with poor seasons such as total crop failure and poor crop yields could be avoided and opportunities to increase crop productivity could be taken to as to produce more. However, despite strategies such as diversification of on-farm and off-farm activities, application of improved varieties (such as drought resistant, pest and disease resistant crops), development of erosion control structures, facilitating decisions (on crop and varieties types, crop input levels), Fofana *et al*.[20] and Mertz *et al*. [21] suggested that improved yields would be realized when farmers were informed on the occurrence of events of climate variability and make opportunistic decisions.

Several studies have developed a framework that smallholder farmers need to consider for making effective tactical decisions [22, 23, 24, 12]. These frameworks govern integration of factors to consider when making effective decisions. In addition, several authors have proposed steps to follow when making decisions at farm level. These frameworks identify coping and adaptation options to climate change using simulation models. However, literature does not show an analysis of farm level decisions, and how farmer's decision making process can be supported. According to Huda *et al*.[12] farmer have different decision making styles which range from self-centered to consultancy by fellow farmers and extension workers. This implies that there is low proportional of agricultural extension agents who support farmers and tools that support strategic and tactical decision making.

Smallholder farmers have opportunities to increase crop productivity when climatic conditions favor high crop yields in semi-arid areas. In these seasons rainwater becomes abundant for crop production at all stages of crop development. Improved crop production during good seasons will be attained when farmers make sound decisions after being informed about season in an appropriate lead time. For example, farmers may invest more in higher yielding crop varieties, fertilizers, pesticides and increase acreage allocations [25].

The importance of inter-seasonal climate forecasts comes for difference tactical crop and soil management in order to mitigate the effects of dry spells and floods which may occur with the season [26, 27]. That is why demand for seasonal climate information in form of amounts and temporal and spatial distribution is crucial for improved crop yield [28]. Inter-seasonal climate forecast is useful for planning rainwater harvesting, fertilizer and pesticides applications and planting and harvesting scheduling. Crop yields are influenced by not only inter-seasonal dry-spells (droughts) but also floods which introduce serious damage to crops and soil nutrients [29]. Several studies has showed how inter-seasonal floods affects crop yields without providing assessment of adaption options by smallholder farmers to manage such risks.

There are different versions of the decision support systems/tools used for agricultural decision support including APSIM, DSSAT and PARCHED THIRST models. APSIM, which stands for Agricultural Production Systems Simulator was developed for simulating biophysical processes in farming for evaluating economic and ecological aspects of management practices in face of climatic risks [30]. DSSAT, which stands for Decision Support System for Agro-technology Transfer was also developed for evaluating crop management practices of various crops [31]. PARCHED THIRST model, which stands for Predicting Arable Resource Capture in Hostile Environments During the Harvesting of Incident Rainfall in Semi-arid Tropics is a decision making tool for assessing the influence of crop managements on crop yields. PARCHED THIRST model is also simulates the effect of application of rainwater harvesting on crop yield which is a crucial element in rain-fed semi-arid regions [32]. However, these tools have been used for the purpose of experimentation in agricultural research institutions [33].

The output of experiments from crop simulation models is then dissemination to farmers and other agricultural actors. According to Newman *et al.* [3], farmers and other agricultural actors such as input suppliers and output suppliers are not directly using such tools to support their tactical and strategic farm-level decisions. Agricultural researchers and extension services workers disseminate the research outputs to farmers and other agricultural stakeholders. However, extension services at village level which are closely support farmers at their fields have limited access to use such models for evaluating crop management practices. These extension workers translate the research outputs from simulation models for farmers instead. This is a major limitation of these models whereas farmers and extension workers are not able to use such important tools.

The use of decision support tools requires adequate knowledge on agricultural sciences, computer skills in order to produce fruitful output. This means that, smallholder farmers who have low income and low education level cannot use such tools. In addition, agricultural extension workers that operate at village levels cannot operate such tools. Despite the usefulness of these tools and the existing problems of communicating research outputs to farmers, little has been done to develop simple tools that avail agricultural information and technologies needed by smallholder farmers in rural areas [3]. This study, therefore, develop simple decision support systems that smallholder farmers and agricultural extension workers at village levels can operate and hence improves access to agricultural information and innovations.

DSS play an important role in agriculture for enhancing crop productivity and other sectors including health. Nonetheless, DSS have been widely applied in agriculture areas such as land allocation decisions, simulating yield for soybean production and climate risk analysis [6, 13]. Nevertheless, usefulness of these tools is limited due to lack of strategic and tactical decision support, inadequate literacy of rural farmers, affordability and inadequate integration of user needs by developers [2, 3, 34]. According to Newman *et al.* [2] low adoption of DSS in agriculture is attributed to limited computer ownership, lack of field testing, not end user involvement during development of DSS, complexity and possibly considerable data inputs of DSS. Yet there are, no reasons seen for changing current management methods, distrust of DSS outputs due to lack of understanding of underlying theory of the mode and mismatch of DSS outputs with decision making styles [2]. DSSAT for example have been designed for simulation by research personnel, however, these tools require massive inputs of data which are not affordable to smallholder farmers in rural areas [35, 30]. Value of DSS in agriculture can be enhanced by exploiting new opportunities of web and mobile technologies linking to existing telecentres implemented in rural areas. Such technologies increase flexibility of use and hence access to climate information [36, 37].

While developing DSS, different techniques, methodologies and tools are employed in order to enhance usability to decision makers. Most of the DSS developed in agricultural employed linear approach [38]. Perini and Susi [38] have suggested the use of agent orient methodology called “Tropos” that provides extensive involvement of decision makers during the early stages of DSS development of problem analysis. “Tropos” define development process to consist of five stages namely, early requirements analysis, late requirement analysis, architectural design and implementation. Apart from agent oriented methodology, which views a system as composed of independent actors with their own goals and interact to one another, object oriented methodology has been used in developing decision support systems. Ascough *et al.* [39] support object oriented methodologies when developing GPFARM (a decision support system for determining long-term effects of alternatives Great Plain farming).

Several authors [40, 41] have proposed a participatory approach for developing decision support systems. Newman *et al.* [3] described five steps for DSS development as: (i) identify need for the DSS, (ii) conduct a feasibility analysis (task, user, and organizational profiling, and resource requirements), (iii) establish an action plan (user skills, software development, system design, documentation), (iv) use iterative prototyping (allows the development process to evolve, based on evaluation from potential end users), and (v) release and train users. Eliashberg *et al*. [42], Ruland and Bakken [43] and Newman *et al*. [3] suggest a range of participatory approaches including participatory learning, action learning, action research and soft system methodologies (having psychological, social and cultural elements) and hard systems methodologies, which support user involvement.

There are several adaptation strategies to climate variability in crop production that are mapped to climatic events. However, it is still not known which strategic and tactical farm level decisions are useful to smallholder farmers when integrated to climatic events. There is enough knowledge on the use of tradition and ICTs based communication systems. However, it is not known which potential, simple and low cost ICT tools are affordable by low income smallholder farmers with poor or no electrical power coverage in accessing agricultural information. There are decision support systems and tools to support strategic and tactical farm level decisions. However, the focus of these tools is not targeted to smallholder farmers and agricultural extension workers at village levels. Hence, the role of simple and interactive applications for providing information and agricultural advisories to farmers is not adequately addressed. Several approaches have been proposed and used to develop decision support systems and simulation models but emphasize on participatory decision support system developments. There is no unified framework that caters across different users with diverse technical and socio-economic background.

III. PROPOSED ARCHITECTURE OF DSS

According to systems theory, all systems are composed of sub-systems, and all systems are themselves sub-systems to larger systems [44]. This theory allows systems to be decomposed

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into smaller components where each component interrelated with other sub-systems (environments) using defined interfaces, have boundaries, possess a specific purpose and constraints. These interfaces form the interaction framework with the surrounding components through input and output systems. Figure 1 shows the decomposition of a decision support system to independent modules that interact with one another. Two main components of DSS are the mobile phone communication manager and web-based communication manager. In this set up, different users that communicate can use different platform to share information. For example, when meteorological agent updates rainfall forecasts, farmers and extension workers get such information through mobile phone interface. Similarly, when farmers and other DSS users register themselves for the forecasts, then meteorological agent and agricultural actors would be able to see registered farmers through web interface.

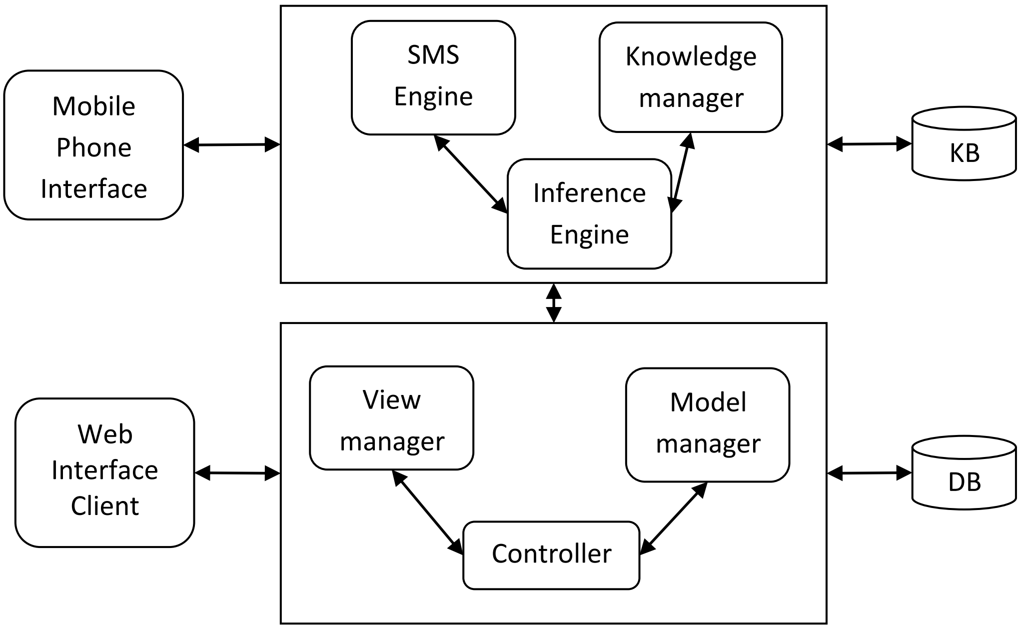

Figure 1: DSS architecture (DB – Database, KB-Knowledge base, SMS-Simple Message Service)

Source: Drawn by researcher, 2013

This study developed a system to enhance communication using mobile phones and internet application for accessing not only climate information directly from meteorological services but also agricultural knowledge from other farmers, agricultural extension workers and research institutions through a centralized database. The developed database provides a depository of agricultural information and knowledge of climate, market and agricultural inputs required for various decisions making at farm-level. This allows automatic generation and coordination of advisories for farmers in linking climate forecasts, inputs availability and strategic and tactical decisions.

Figure 2 shows entity relationship diagram for modeling data of DSS. The model was then used to implement a database using MySQL database management system (DBMS). The design decision of data model allowed both data and knowledge to be stored for the decision support system. For example, a crop entity contains a forecast-code field to provide a mapping between the forecast and the choice of crop. This knowledge was captured from the respondents survey and literature review. If was found that, high yielding crop varieties were suitable when the seasonal climate forecast was normal to above normal while short duration and drought resistant crop varieties were suitable when forecast was normal to below normal. With this design, when a farmer request an advisory about the crop to grown, then the DSS scans the current issues seasonal climate forecast and recommend suitable crops. Further, this knowledge could also be linked with topographical zones and other socio-economic status of smallholder farmers and hence a farmer could be provided with specific forecast.

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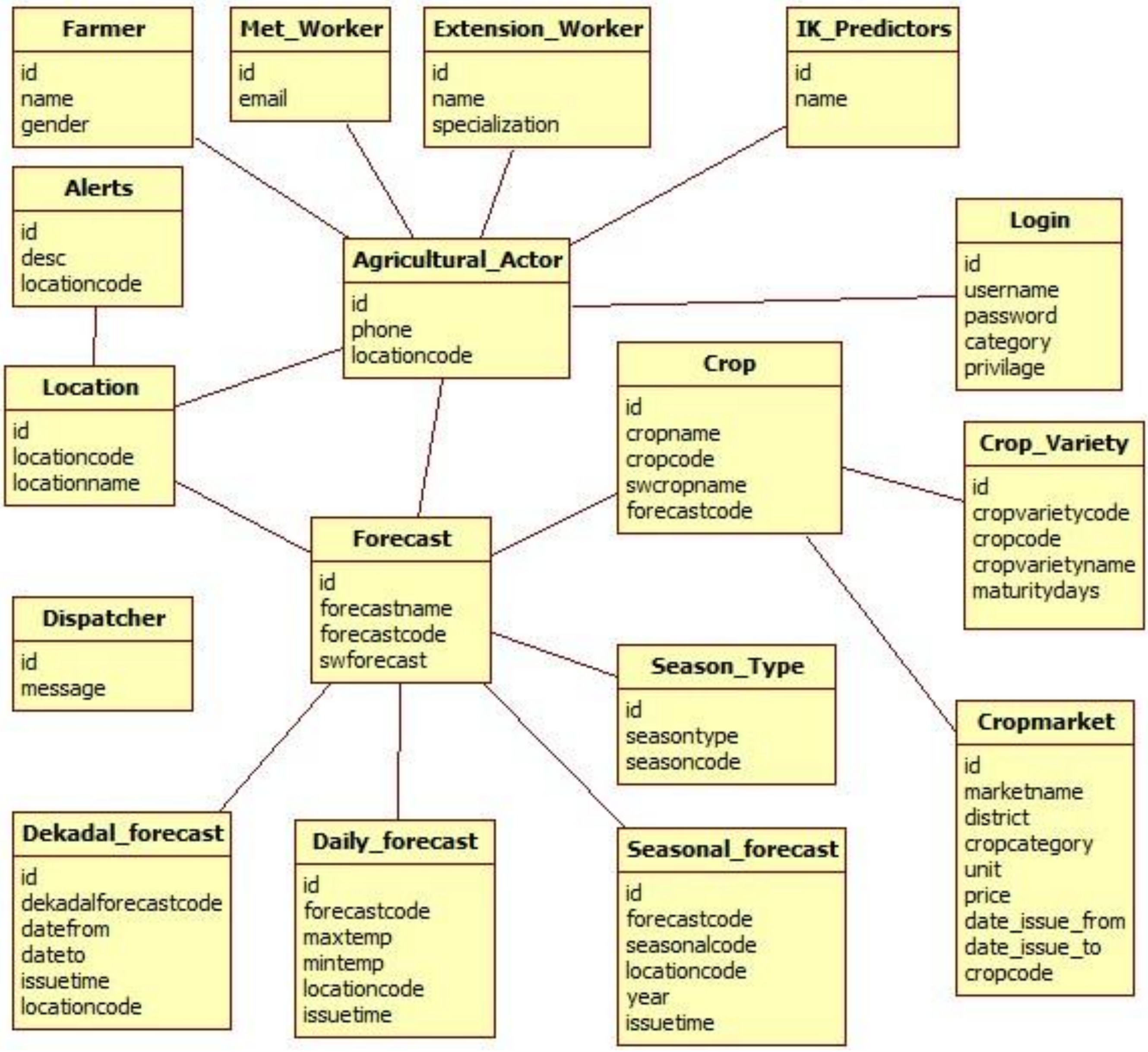

Figure 2: Entity relationship diagram for a DSS

Source: researcher design, 2012

IMPLEMENTATION OF DSS

Development phase is about implementation of artifacts based on the design or conceptual model in the previous phase. At this stage, requirement definitions, database of STFD and decision models were implemented using suggested tools and techniques in software development approaches. During the implementation phase, a web platform was suggested because it provides online interaction among agricultural actors and system artifacts. In addition to web platform, mobile phone platform was also used for implementation. The motivation of interfacing with mobile phone platform was driven by the needs of farmers in rural areas where the access to agricultural information for informed decision making was poor. Using simple and affordable mobile phones, farmers were able to query for climate and weather forecast and market information from the decision support system maintained by Tanzania Meteorological Agent (TMA) in Tanzania. Figure 3 shows the web interface with information about seasonal climate forecast for Morogoro areas, Tanzania of 2013 as updated by TMA. The seasonal climate forecast showed normal to below normal of rainfalls for a season of Masika of March to May of 2013.

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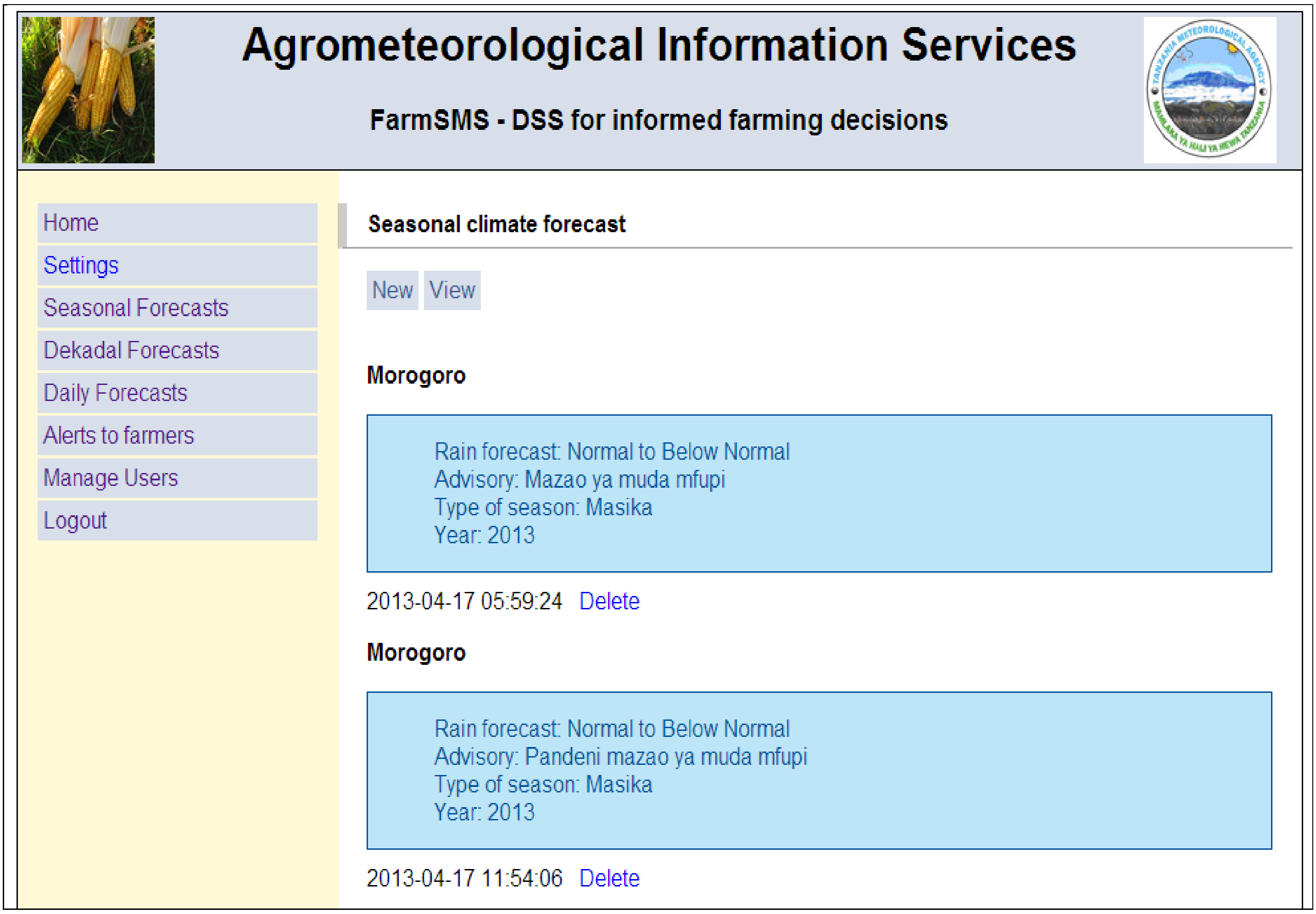

Figure 3: Web interface for communicating alerts to SMS user

The role of TMA is to keep DSS up-to-date with seasonal climate and weather forecasts. When new forecast information and abnormal weather events was issued TMA, then DSS was updated and in turn forwarded that information to subscribed farmers and other agricultural actors. Not only climate information but also advisories concerned with selection of crops and crop varieties, selection of land preparation methods and timing of field crop management operations were generated and communicated to the subscribed farmers. Seasonal climate forecasts information was issued before the start of cropping season and was kept in the database system throughout the cropping season. However, a weather forecast was issued daily, decadal and monthly. One of the challenges of forecasts to farmers was the terminology used to describe the forecasts and linkage with farming decisions. It was suggested to use terms such as above normal, below normal, normal, normal to above normal and normal to below normal. Based on rainfall long term averages, farmer may easily understand whether such forecast would be of beneficial to crops or not.

Figure 4 shows part of web interface that displays the list of agricultural actors registered to receive seasonal and weather forecasts when updated by TMA through their mobile phones. The systems allowed farmers and other agricultural actors to register using their mobile phones. The system also allows unregistered user to query for agricultural information and advisories. For example, the user could be able to ask for seasonal climate forecast of the current or upcoming season, in turn the system finds out if such information was updated and hence send forecast information to the use without human intervention. Similarly, the user may ask for recommended crop varieties for the upcoming season, and in turn the system uses updated seasonal climate forecasts and knowledge about the suitability of crop varieties under different seasonal climate forecasts to communicate to farmer a list of recommended crop varieties.

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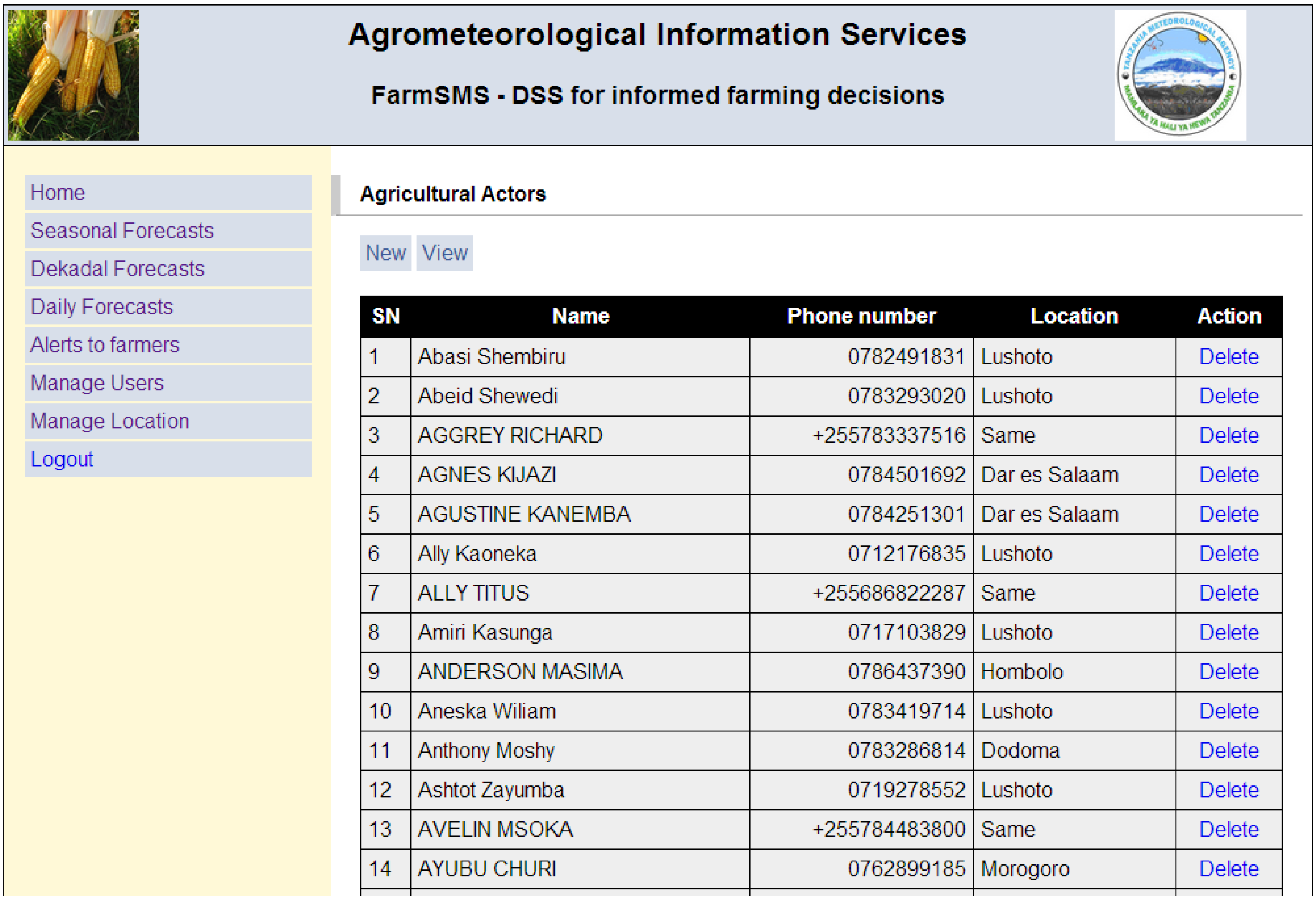

SN	Name	Phone number	Location	Action
1	Abasi Shembiru	0782491831	Lushoto	Delete
2	Abeid Shewedi	0783293020	Lushoto	Delete
3	AGGREY RICHARD	+255783337516	Same	Delete
4	AGNES KIJAZI	0784501692	Dar es Salaam	Delete
5	AGUSTINE KANEMBA	0784251301	Dar es Salaam	Delete
6	Ally Kaoneka	0712176835	Lushoto	Delete
7	ALLY TITUS	+255686822287	Same	Delete
8	Amiri Kasunga	0717103829	Lushoto	Delete
9	ANDERSON MASIMA	0786437390	Hombolo	Delete
10	Aneska Wiliam	0783419714	Lushoto	Delete
11	Anthony Moshy	0783286814	Dodoma	Delete
12	Ashtot Zayumba	0719278552	Lushoto	Delete
13	AVELIN MSOKA	+255784483800	Same	Delete
14	AYUBU CHURI	0762899185	Morogoro	Delete

Figure 4: Web interface showing registered agricultural stakeholders

Source: researcher design, 2012

System Evaluation

This stage was critical for users to get used and experience the product developed and provided feedback which lead towards improvements of the system. The output of this phase was the desirable product because it involved a series of iterations and improvements as per user feedbacks. One of the strategies of adoption of computer artifacts was involving user during all stages of product development. While saving as adoption strategy for users, the same technique was used to satisfy not only usability but also acceptability because users felt ownership of the DSS.

Figure 5 shows an interface depicting one of the mechanisms used to evaluate the operation of the DSS. Communication that the respondents made was monitored and evaluated from the DSS SMS engine interface. Further, the respondents were asked whether they were getting the reply that was related to the question they queried. The respondents showed a positive feedback to the DSS and asked for more information such as market information and services to be incorporated. The positive responses from respondents imply further research on simple and affordable mobile phones on how they could benefit smallholder farmers in rural areas.

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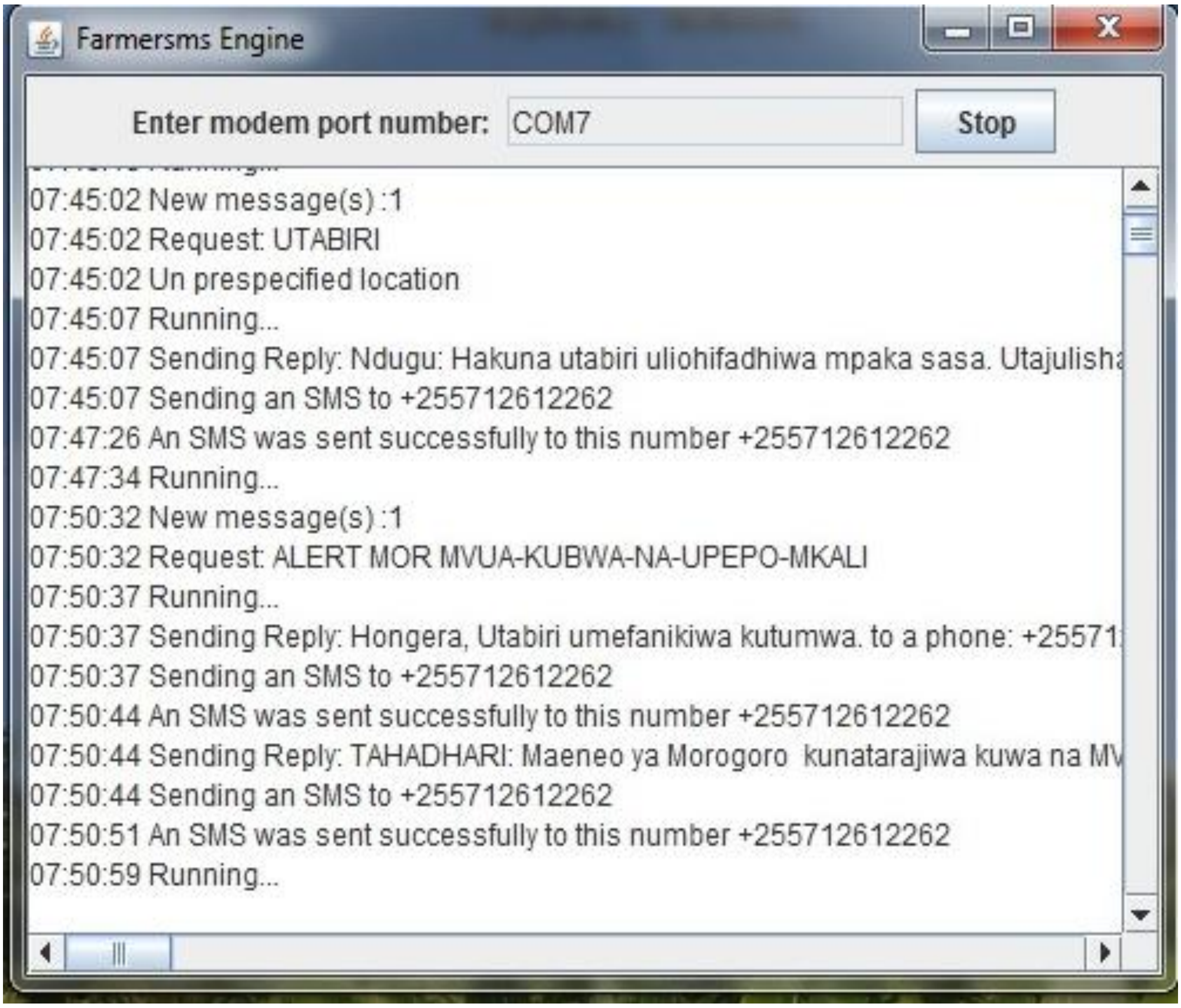

Figure 5: SMS Engine interface showing communication process of SMS using mobile phones

Source: researcher design, 2012

Challenges of development DSS

The design of user interface adopted in this study considered usability principles with focus on varieties of users with difference in education background, novice to ICT technologies and multiple technologies. Therefore, the focus of the study was linked to supporting farmers in rural areas having low education level and living in conditions unavailable computing facilities due to lack of power and ICT infrastructures. As a result, the user interface design considered the use of mobile phones which are simple and low cost and yet be able to access computing facilities and agricultural knowledge at the backend. Not only farmers but also other stakeholder including meteorological service agents and extension workers use mobile phones for communicating information to and from farmers in an interactive way.

The format of information used in communication was made simple to input but supported with data coding for the meanings. The Figure 6 below, shows a sample format of data input used by farmers to ask for seasonal climate information of a particular cropping season. When the request for seasonal climate forecast is sent in form of a text message, the application at the backend determine the current forecast as issued by meteorological service agency of the current or upcoming cropping season. If such information is not available, notification on the unavailability is issued to farmers and extension workers.

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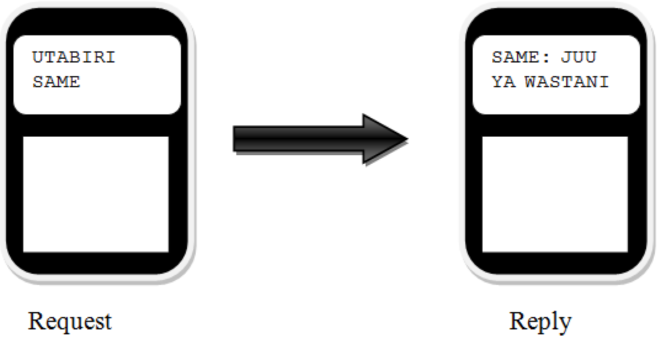

Figure 6: Request and reply communication model for asking seasonal climate forecast by farmer

Source: researcher design, 2012

The model of communication using mobile phone was in two ways. The first mode was by request and reply format of client-server architecture. The second mode was register once and notify mode where farmers and extension workers are registered and get notification of information when available. For example, notification is activated after updating season climate information following unexpected abnormal event such as strong winds, floods and excessive dry-spells. When farmers and extension workers registered for these services then they access whenever they are available and use for farm level decision making.

IV. CONCLUSIONS & RECOMMENDATIONS

Conclusion

Addressing farmers' needs for improved access to information resources, in terms on timeliness and linked to farming decisions, the study designed a framework that can be used to develop decision support systems for rural farmers. The framework was then used to develop a DSS for assisting farming decisions of farmers in semi-arid areas of Same district, Tanzania. The consideration of a design, reflected the rate of adoption of ICT in rural areas of developing countries, characterized by inadequate infrastructures of power distribution for ICT facilities and socio-economic status of smallholder farmers in rural semi-arid areas.

DSS was developed as a web based online software application system. The system has three main tiers, that is, user interface, computation modules and database end. To support multiples users, the user interface was designed to enable interaction with the system using mobile phones (using SMS technology) and web interface. Computation modules serves as a link between user interface and database end as well as handle most of computation in providing advisories and recommendations to farmers. The database end consists of stored data and knowledge and hence forms a basis for providing recommendations to farmers based on observed status of nature.

Recommendations

It is recommended that, efforts to improve adaptation capacity of the smallholder farmers should target extended use of ICTs, such as mobile phones for improved access to climate information and advisories. Also, using ICTs agricultural research centres should extend agricultural findings to farmers so that their outputs could be used by farmers. It is recommended that, further research on the area of development of decision support system should focus on understanding decision makers before building decision support systems. Although decision support system models play significant role in developing and testing new farming technologies, it is recommended that, development of decision support system in agricultural should focus on linking inputs from research and make research results accessible to farmers and other agricultural actors. This research proposed an approach for linking scientific and indigenous climate forecasts, it is recommended further research should go further to integrate national climate forecasting agents with international climate forecasting centres.

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