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A Monitoring System for Transboundary Foot and Mouth Disease (FMD) considering the Demographic Characteristics in Gairo, Tanzania

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Abstract-Foot and Mouth Disease (FMD) is present in many countries, including Tanzania. Gairo is among the districts that frequently face FMD. This study found that the current mechanism for communicating FMD in Gairo district suffers from a long chain of information flow that causes delay and insufficient information for FMD control. Therefore, this study aimed to explore the implementation of an information system named "Monitoring System for Transboundary Foot and Mouth Disease," developed purposely to provide a standard platform for communicating FMD between livestock keepers and other stakeholders in the district. The system enables timely sharing of FMD events such as outbreaks, precaution measures, clinical signs, and negative impacts using Short Message Services (SMS), Unstructured Supplementary Service Data (USSD), and Voice Calls (robo-calls) through the mobile phones. Also, livestock keepers may report FMD outbreaks direct to the system using feature phones. The Statistical Package for Social Sciences (SPSS) was used to analyze data and Microsoft Visio was used for drawing the system architecture and information flow diagram. Finally, the system was implemented using PHP hypertext processor, JQuery, HTML, JSON, JavaScript, MySQL, and Apache webserver.

Keywords-voice broadcasting; livestock keepers; FMD events; Short Message Service (SMS); robo-calls; Unstructured Supplementary Service Data (USSD); zero-grazing (smallholder dairy); agro-pastoralist; pastoralist

I. INTRODUCTION

Tanzania has the third largest livestock population in Africa, with 25 million cattle approximately contributing 7.4% of the National GDP [1]. However, the annual animal production growth rate is low, at 2.2% because of low livestock reproductive rates and the high mortality due to increased disease prevalence [1]. Regardless of other diseases, FMD has been given great attention because of its high mortality, especially in calves, its ability to cause a significant loss in milk production and draught animal power, and hinders international trade [2]. FMD is a transboundary disease caused by a virus from the Picornaviridae family. The disease affects domestic and wild cloven-hooved animals such as sheep, goats, pigs and buffaloes [3]. There are currently 7 known serotypes of the FMD virus and many more subtypes. Type A, O, SAT1, SAT2 and SAT3 serotypes are present in Tanzania [4]. FMD is transmitted from one animal to another through direct or indirect contact, e.g. by contact with contaminated inanimate objects (often referred to as fomites). The FMD clinical signs include high fever (up to 42°) accompanied by severe depression and inappetence [5]. Other clinical signs are the appearance of wounds on the feet and tangle of the animal [5]. The FMD is currently present in Asia and Africa and in one country in South America [4].

In Tanzania, Gairo is among the districts that frequently face FMD. Since the disease has no cure, immediate information sharing during the outbreaks is mandatory for mitigating the disease [6]. The big challenge in Gairo district is the long chain of communication for FMD outbreaks. Usually, the Ward veterinary officers receive FMD outbreaks from immediate livestock keepers either by routine visits or phone calls. Sometimes, the veterinary officers leave unreported cases

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due to the unfriendly terrain that hinders the access to remotely livestock-keeping communities, especially during rainy seasons. Normally, the veterinary officer upon receiving the information, reports the incident to the District Veterinary Officer (DVO) either by phone or by a visit to the DVO's office. The DVO forwards the information to the Directorate of Veterinary Service (DVS) that has the mandate of uploading data to the Global Surveillance Systems. Sometimes, communication breakdown may happen if somebody is irresponsible along the reporting chain. Similarly, whenever there is a threat of FMD, the veterinarians use to visit individual livestock keepers to alert them about the disease and precautions measures. Therefore, the current reporting mechanism causes delay and insufficient information provision for the control of FMD in Gairo district. Also, the process of visiting livestock keepers for collecting or giving information is costly and requires the deployment of more veterinarians in order to be more effective. This study explores the implementation of an information system named Monitoring System for Transboundary Foot and Mouth Disease, which might reduce the communication barriers among livestock stakeholders in the district taking into account the livestock keepers' demographic characteristics. The Monitoring System for Transboundary FMD is not the first system to monitor animal health. Several electronic devices and software systems exist for similar purposes [7-12]. An excellent example of such devices is the Cattle Monitoring System that uses a wireless network, which monitors cows' body temperature and heartbeat to determine their general health [8]. Another system is the Cattle Health and Environment Monitoring System that monitors the cattle's body temperature and heartbeat along with the farm's temperature and humidity [12]. The devices are normally attached to the cattle's body. The challenge of these devices is that they provide information only when the cattle have already been affected by the disease. Therefore, they are inefficient in controlling FMD, which requires more preventive measures as it has no cure [6]. Some countries use surveillance systems for communicating animal disease outbreaks, which replace the paper-based reporting mechanism [9]. However, these information systems depend on the input data from veterinarians, laboratories, and other healthcare providers that act as primary sources of information [4, 10]. The systems contradict other FMD surveillance studies that emphasize livestock keepers as the primary source of outbreak information for early disease detection. On the other hand, a few surveillance systems enable livestock keepers to report disease outbreaks directly to the system but failed to consider the education level and livestock keepers' demographic characteristics on the devices that are mandatory for accessing the system. As a result, livestock keepers access to the system is limited due to the lack of devices and skills. For example, most surveillance systems are web-based and emphasize on smartphones and computers to report disease outbreaks. At the same time, most livestock keepers, especially in developing countries, own feature phones that cannot browse the internet [11]. Similarly, the systems communicate the disease outbreaks, precaution measures, clinical signs, and negative impacts through websites, while livestock keepers lack skills and devices for browsing the internet [9,13]. Also, few systems are integrated with Short Message Service (SMS) alerts for disease outbreaks while many livestock keepers, especially in developing countries, have no formal education and cannot read SMS though they own mobile phones[13]. The partial involvement of livestock keepers in FMD control, contributes to the factors affecting the information flow to the existing surveillance systems. Therefore, the proposed Monitoring System for Transboundary FMD is a surveillance system that accommodates the current system deficiencies. The proposed system is similar to other web-based surveillance systems but enhances livestock keepers' interactions through their feature phones. The system allows the following interactions with livestock keepers using their feature phones: (1) It enables them to report FMD events directly to the surveillance system using USSD code and SMS, (2) the system maintains FMD awareness to livestock keepers by periodically reminding them of FMD precaution measures, clinical signs, the negative impact, and transmission pathways using SMS and voice messages (robo-calls). Not only that, livestock keepers may access precaution measures, clinical signs, adverse effects, and transmission pathways of FMD at any time from the system through the USSD menu using their feature phones (Figure 4).

II. MATERIALS AND METHODS

A. Description of the Study Area

Gairo is a district in the Morogoro region, Tanzania. It is located between the 36'500E-37'200E latitude and 6'400S-5'500S longitude. The reason for selecting Gairo district as the study area was the fact that it combines three cattle farming systems (smallholder dairy, agropastoral, and pastoral), high incidences of FMD outbreaks, and accessibility.

B. Sample Size for System Requirement Gathering

Demographic information was collected, including mobile phone usage and education level and the overall process of communicating FMD among livestock keepers and other livestock stakeholders was observed. From the 6 selected villages (Kilama, Chogoali, Chakwale, Kilimani, Gairo town, and Ibuti), 180 livestock keepers were interviewed (Table I). The interviewees were the head of their families, regardless of gender. The number of households to be interviewed was selected by using the rule of thumb to determine the sample size of households which states that a minimum sample size of 25-30 households is appropriate for a village has 100 to 500 families [14]. To capture the farming systems, all 54 villages in the region were stratified into pastoral, agropastoral and smallholder dairy farmers. Thereafter, the 3 groups were listed in the excel sheet, 2 villages were randomly selected from each group for data collection, and 30 households from each village were randomly chosen and interviewed [15]. Lastly, a focus group discussion involving 15 veterinarians of 15 Wards of Gairo district was conducted, and the results were recorded. The focus group was purposely to gather information on the overall process of communicating FMD outbreaks in the district. After that, the Statistical Package for Social Sciences (SPSS) was used to analyze the data and draw the frequency distributions table. Finally, the waterfall model was used for the development of the system [16]. The results indicate that there was a long chain of communication for FMD outbreaks in the district. Also, the results indicate that 91% of livestock

keepers own feature phones, and 9% own smartphones (Table I). Most livestock keepers used mobile phones to receive voice calls and send and receive SMSs (Table I). About 60% of livestock keepers had primary school education while 33% had no formal education at all. Therefore, the study suggests that SMS, USSD code, and automatic broadcasting calls (robo-calls) may be the best options for communicating FMD events among livestock farmers and other stakeholders in Gairo district. Technically, SMS, USSD, and robo-calls are suitable for those who have primary school level education and above, whereas robo-calls alone will benefit those who have no former knowledge and can't read or write SMS messages. However, all the mentioned technologies will satisfy most livestock keepers because the majority owns feature mobile phones.

TABLE I. LIVESTOCK KEEPERS' DEMOGRAPHIC CHARACTERISTICS

Variables	Frequency	Percentage (%)
Livestock keepers own mobile phones (N=170)		
No	27	16
Yes	143	84
Total	**170**	**100**
Mobile phone usage (N=143)		
Smartphone	13	9
Feature phone	139	91
Total	**152**	**100**
Level of education (N=171)		
Primary School	103	60
Secondary School	10	6
University	1	1
No Formal Education	57	33
Total	**171**	**100**
Mobile phone usage (N=144)		
Sending and receiving SMS	114	39
Making and receiving calls (including robo-calls)	141	48
Surfing the Internet	10	3
Social Networking	11	4
Other	19	6
Total	**295**	**100**

III. SYSTEM ARCHITECTURE AND WORKING PRINCIPLES

The Monitoring System for Transboundary FMD comprises of several functional blocks that depend on each other to operate (Figure 1). The blocks include the FMD awareness maintenance module, FMD incidents/outbreaks reporting module, Databases (PDB1, TDB, PDB2), and USSD API. The FMD awareness module is responsible for maintaining FMD awareness to livestock keepers by periodically (with reference to operating system time) broadcasting precaution measures, clinical signs, negative impacts, and FMD transmission pathways in SMS and audio format (voice calls) from the permanent database (PDB1). During the SMS or audio broadcast, the system calls or sends SMS to more than one mobile numbers at once. If a livestock keeper responds to a voice call, the system plays the audio file prior uploaded to the system. The broadcasting time interval for each awareness SMS or audio file is specified when uploaded to the surveillance system through the specific menu (Figure 7). Also, livestock keepers may use the USSD menu (e.g. *150*009#) to access FMD awareness descriptions using mobile phones (Figures 1, 2, and 4). The FMD awareness descriptions and the USSD menu were translated into English for readability in this paper. However, in the actual system, the information is in the native (Kiswahili) language (Figures 3, 4, and 7). On the other hand, the FMD incident/outbreak reporting module enables livestock keepers to report FMD outbreaks to the system using SMS or USSD code. The livestock keeper may notify the FMD outbreaks to the system by sending SMS indicating the number of FMD suspected cattle to a given mobile phone number. The alternative way is to use the USSD menu. For example, Figure 3 shows the livestock keepers' procedure of reporting FMD outbreaks using option number 1 of the USSD menu. Once received in the system, the suspected number of cattle is stored in a temporary database (TDB) and labeled as unverified information.

The system differentiates the suspected herds from the apparently healthy herds using blue circles, as indicated on the system's disease spatial distribution map (Figure 8). The veterinary officers validate the incident by calling and physically visiting the area. If the outbreak report is valid, the number of affected cattle is stored in the permanent database (PDB2) for future use after the veterinarian clicks the "Accept Cases" button to verify the FMD reported cases page (Figures 1, 2, and 6). After that, the system broadcasts SMS and voice calls to other livestock keepers, informing the incidents and suggesting precaution measures (Figures 1-2). Again, the system differentiates the confirmed FMD herds from the apparently healthly herds using red and orange circles on the system's disease spatial distribution map (Figure 8). Note that, livestock keepers should first be registered to the system to receive or send information.

The USSD application user interface (USSD API) connects the FMD incident/outbreak reporting module with the USSD server (Figure 1). Before implementing the USSD API, one should purchase the USSD service from the provider and configure the callback URL after registering and logging in to the USSD server account [17]. The FMD awareness maintenance module, FMD incident/outbreak reporting module, and the USSD API were implemented using PHP, JQuery, HTML, JSON, JavaScript, and MySQL, in an Apache webserver. The Monitoring System for Transboundary FMD is also composed of other third-party software and hardware such as voice gateway, SMS gateway, voice modems, and SMS models that support its operations. Voice gateway provides automatic voice call services to the system through the voice modem pool (Figure 1) [18, 19]. It acts as a communication interface between the FMD monitoring system and the voice modem pool attached to the server's USB port. The SMS gateway provides SMS services to the system [20]. The SMS modem pool is connected to the SMS gateway software for routing SMS to the mobile network (Figure 1). The SMS gateway act as a communication interface between the FMD monitoring system and the SMS modem pool attached to the server's USB port.

IV. SYSTEM SECURITY

Procedures for developing a secure web-based information system, such as using parameterized queries when implementing the system login script to avoid SQL injection attacks, etc. had been followed during the implementation phase [21]. The livestock keepers should first be registered in

the system in order to receive or send information to it. Other stakeholders, including veterinarians, have the privilege to register livestock keepers in the system. Apart from livestock keepers, different stakeholders may access the system by using their username and password on the login page (Figure 8) [22, 23]. The system administrator registers stakeholders by asigning the username and a temporal password that must be changed the first time the user logins into the system. Strong password policy [24] has been followed while developing the change password section. Only registered stakeholders are allowed to access different parts of the system based on privileges assigned by the system administrator during registration. The server machine was hosted in a room with biometric access for authorized personnel only.

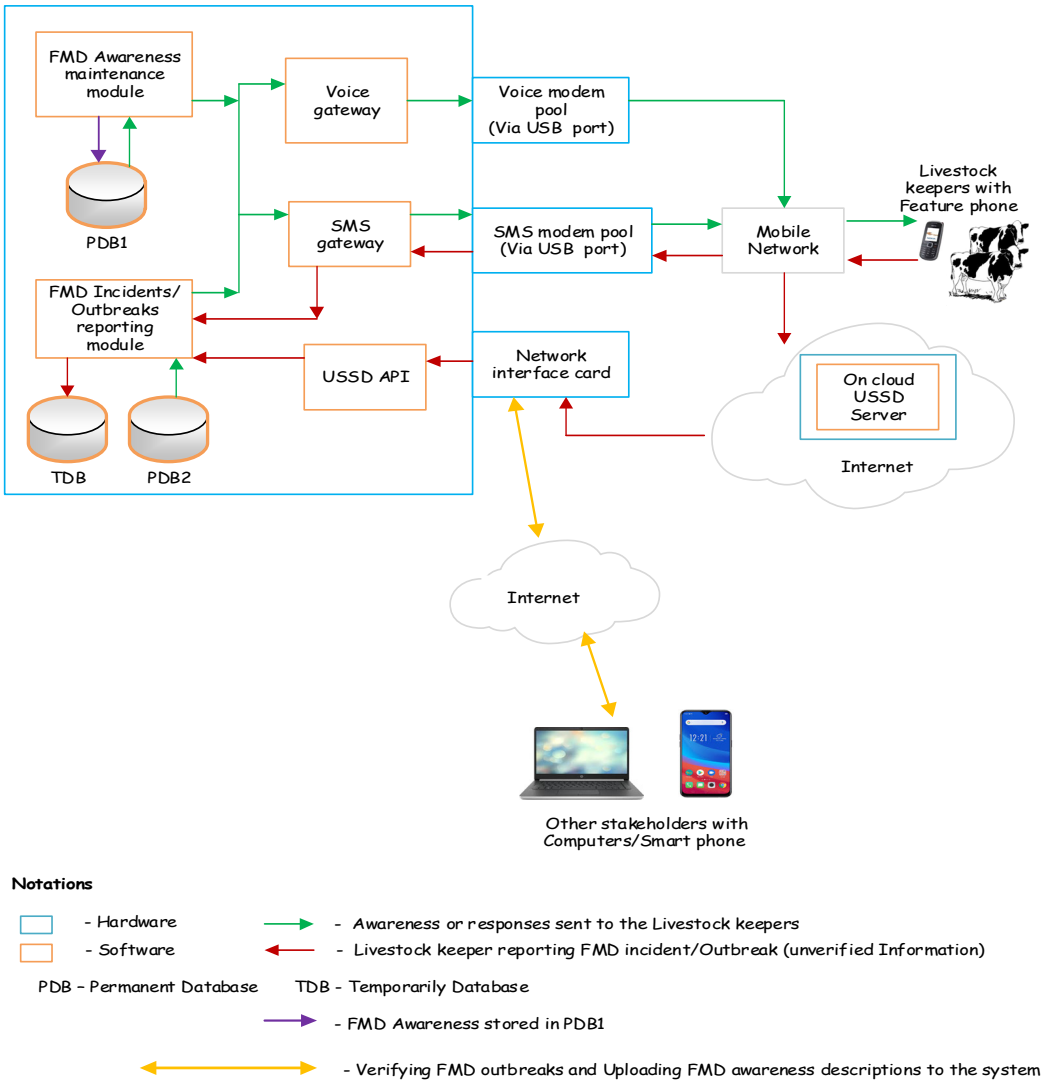

Fig. 1. Block diagram of the system architecture.

V. RESULTS

Figures 3 and 4 are the USSD menu shown on the livestock keeper's mobile phone after dialling a specific USSD code. The USSD menu allows livestock keepers to report FMD outbreaks or access different FMD awareness descriptions such as transmission pathways, precaution measures, clinical signs, and negative impacts from the server. Figure 3 shows a livestock keeper reporting 67 FMD suspected cattle to the system after choosing option number 1 of the USSD menu. Upon completing the request, the system stores the 67 cattle to the system for verification purposes (Figure 6). Veterinarians may use this information to verify the FMD outbreak validity by calling and physically visiting the livestock keeper. Later on, veterinarians may either update the number of suspected animals to reflect the actual number of victims or discard the information as invalid (Figure 6). Figure 4 shows the SMS feedback after the livestock keeper requested FMD transmission pathways from the system by selecting option number 2 of the USSD menu. The descriptions were uploaded to the server by other livestock stakeholders, including but not limited to veterinarians, researchers, and research institutions (Figure 7).

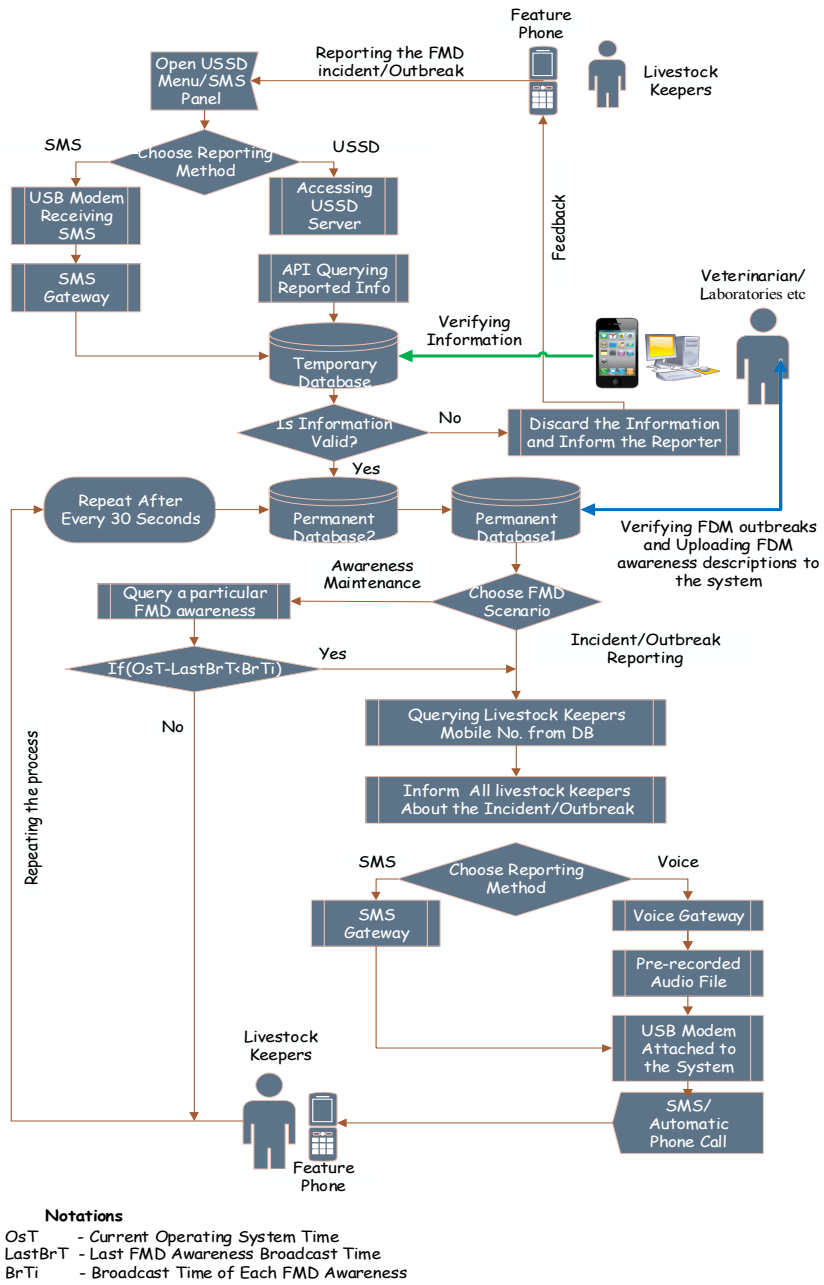

Fig. 2. Data flow in the system.

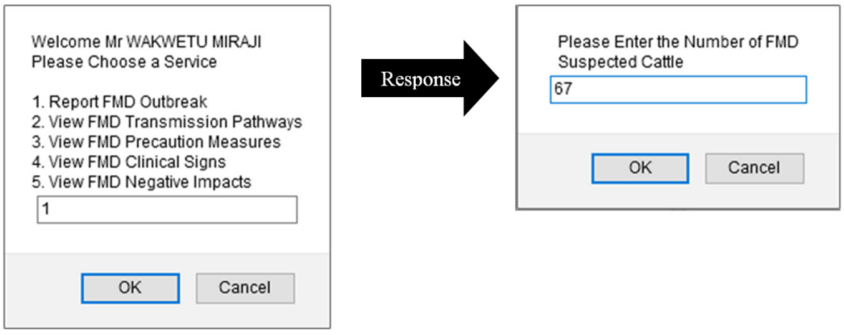

Fig. 3. Reporting FMD outbreak using USSD menu.

The system accepts name, gender, mobile phone number, cattle shed location (latitude and longitude), age, etc. (Figure 5). The system allows access only to registered livestock keepers. The mobile number enables the livestock keeper to communicate with the surveillance system using USSD, voice calls, and SMS. Also, veterinarians may use the number for management purposes, including calling livestock keepers at any time or after the report of an FMD outbreak for verification. Veterinarians may also verify the FMD reported outbreaks to the system after physically visiting the livestock keeper and observing the actual number of cattle suffering from FMD (Figure 6). The login page is also the systems' home page with cattle shed and kraal spatial distribution map generated by the Google maps (Figure 8). The map indicates the cattle sheds and kraals as circles generated by the system after registering the livestock keeper's particulars in the system for the first time in line with cattle's shed and kraal (herbs) location details (latitude and longitude) (Figure 5). Different colors are used to indicate herds FMD status. For example, the herd appears green when no FMD case is reported by the livestock keeper (an apparently healthly herd). It appears blue when the livestock keeper reports an unverified (unconfirmed) FMD case, red when the reported FMD case is confirmed, and orange when unconfirmed and confirmed cases co-exist in the same herd. Otherwise, the status remains green (Figure 8).

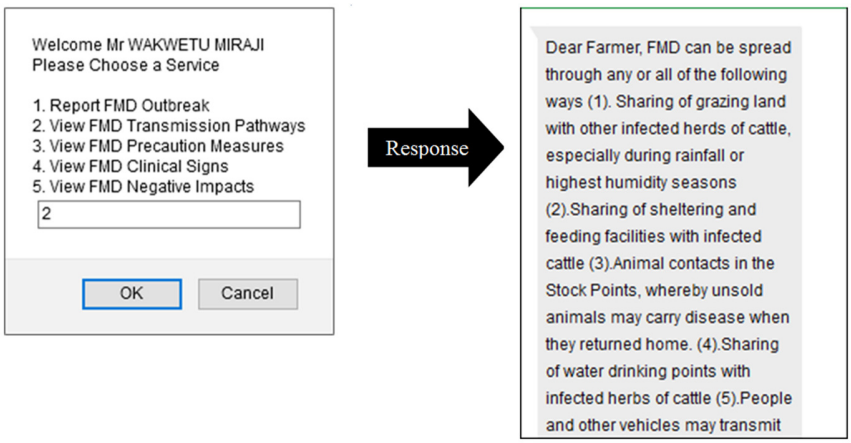

Fig. 4. Accessing FMD transmission pathways using the USSD menu.

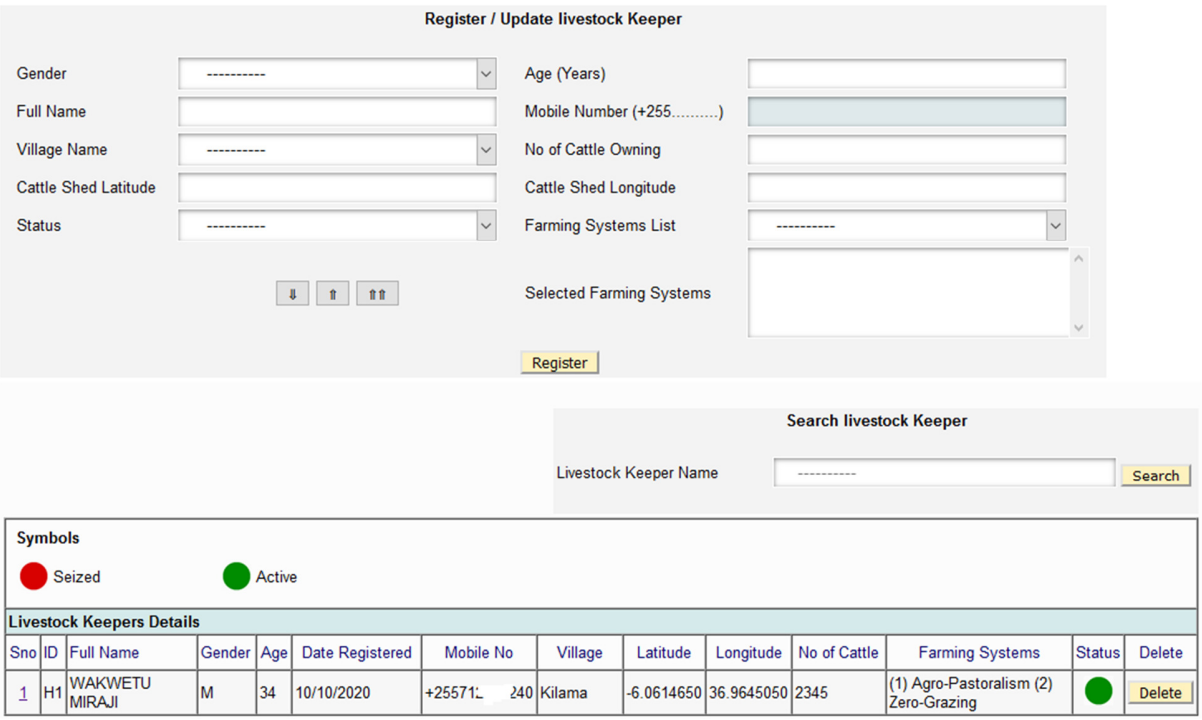

Fig. 5. Livestock keeper's registration form.

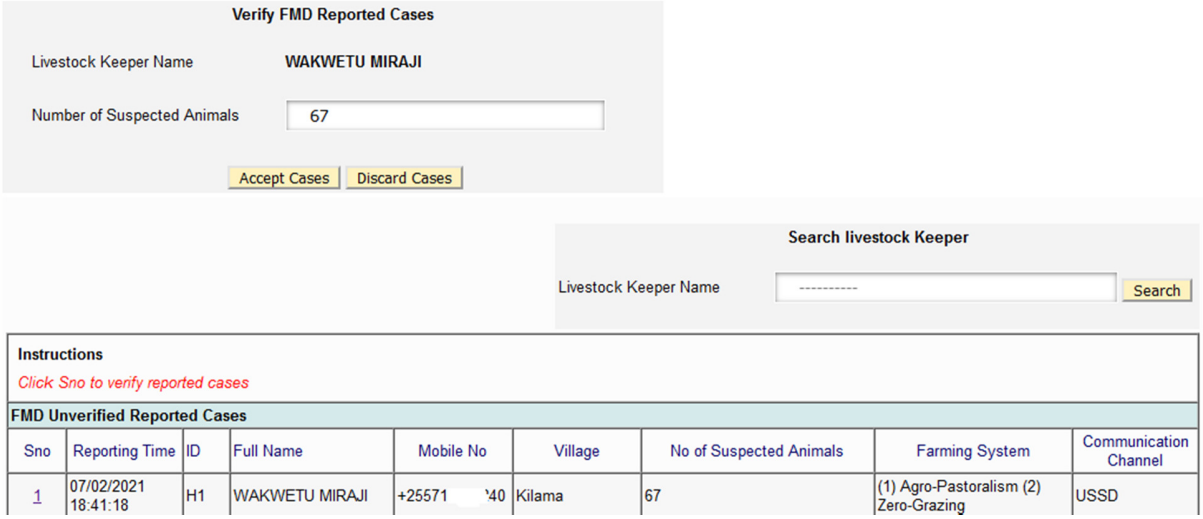

Fig. 6. Verifying FMD reported cases.

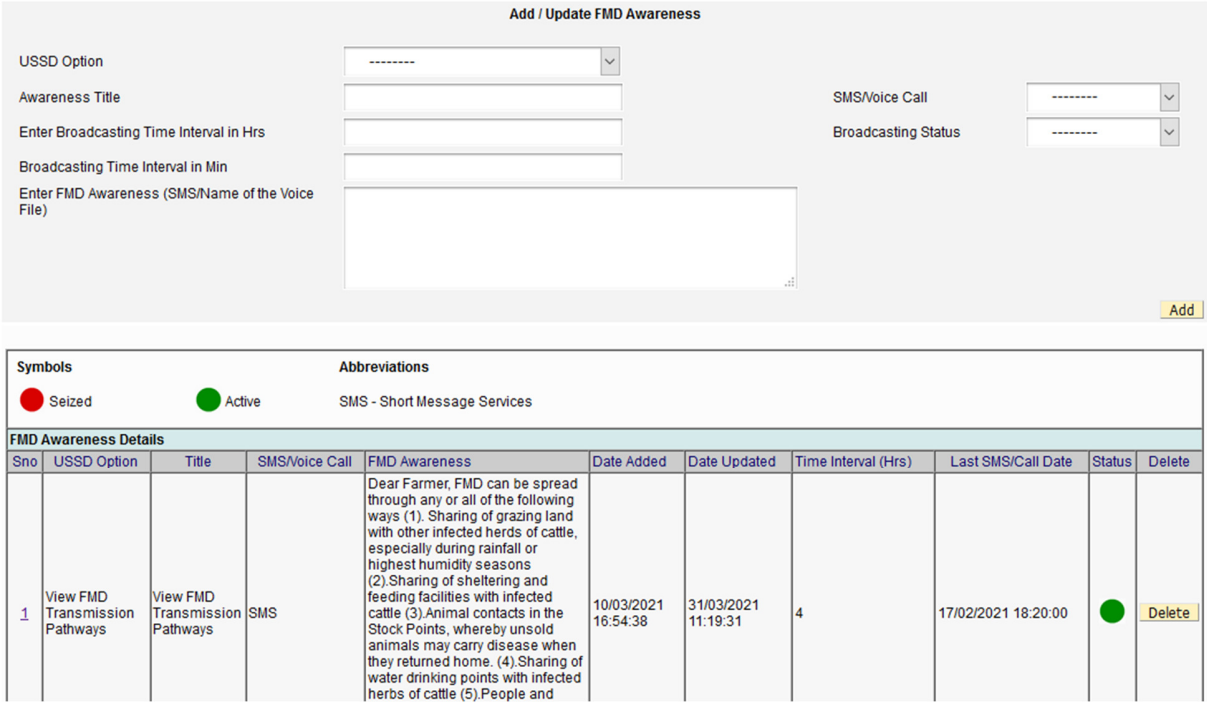

Fig. 7. Uploading FMD awareness description to the system.

VI. Discussion

Apart from the proposed Monitoring System for Transboundary FMD, there are many other existing web-based, mobile-based, and integrated (mobile and web-based) systems developed for similar purposes [7, 9, 11, 25-27]. They offer limited access to the local communities, who are the main stakeholders in animal disease reporting since a disease always starts from their cattle [26]. In the case of existing web-based surveillance systems, only the top-level stakeholders such as laboratories, researchers, and international agencies can upload or access disease information to the system because they have the necessary skills and devices [10, 11]. Unfortunately, most livestock keepers, especially in developing countries, were excluded from the use of these systems due to the lack of skills and tools to access them (Table I). There are also existing mobile-based animal and human health surveillance systems such as the EMA-I and AfyaData, which collect nearly real-time surveillance data in the local communities' context [25, 27], but still, they deny livestock keepers the ability to communicate the surveillance data to the respective authorities directly. Instead, the organizations utilize veterinarians and Community Health Reporters (CHRs) in the livestock-keeping communities to collect the surveillance data for them on behalf of livestock keepers with the use of smartphones. This

mechanism of collecting data leaves many unreported cases, especially in the hard-to-reach livestock-keeping communities [26] and requires more veterinarians and CHRs in the field in order to be effective and well facilitated.

The presented Monitoring System for Transboundary FMD is designed to cover the existing surveillance systems' deficiencies. The extra integrated USSD and automatic voice call (robo-calls) features in the Monitoring System for Transboundary FMD provide two-way communication to the server to the local communities that lack internet access. As a result, livestock keepers can access and receive information directly from the server using any mobile phone (feature or smartphone). These features differentiate this system from the rest. The system continuously maintains awareness to livestock keepers by reminding them disease precaution measures, clinical signs, negative impacts, and transmission pathways in SMS and robo-calls. Also, livestock keepers can access this and any other uploaded information to the server using a USSD menu instead of web browsers. Different stakeholders may also access similar information using web-browsers, smartphones, or PCs with internet access like in the other surveillance systems [7, 9, 11, 25-27]. Similarly, the system enables livestock keepers to report disease outbreaks through the USSD menu.

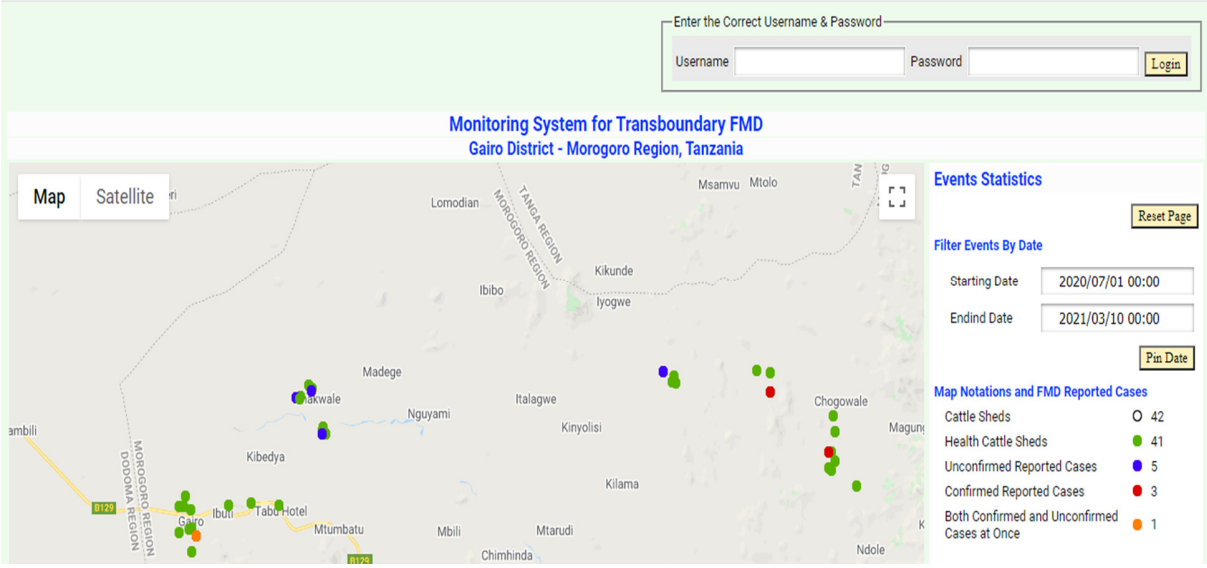

Fig. 8. System login page with cattle's shed and kraal spatial distribution map.

The current study believes that the total involvement of livestock keepers in animal disease surveillance will enhance early disease outbreak detection, reporting, and will provide real-time quality data for fast response to disease epidemics allowing more efficient disease control. Also, periodically receiving various FMD events in SMS or voice calls increases the FMD awareness of the livestock keepers. Policymakers may also use the FMD secondary data in the system for decision-making like in other surveillance systems (Figure 8). This study found that 91% of livestock keepers in the Gairo district own feature phones (Table I), which is comparable with the data from [26]. It was also found that the majority of livestock keepers use mobile phones for calling (48%) and sending SMS (39%). The sufficient number of livestock keepers owning feature mobile phones and their calling and sending SMS preferences motivated the use of USSD and robo-calls services in the proposed Monitoring System for Transboundary FMD. Lastly, the system generates a spatial distribution map of FMD suspected and affected cattle sheds or kraals generated on the home page to determine the disease distribution behavior for a specific period (Figure 8), unlike other surveillance systems that generate spatial distribution in regional and country-wise levels.

VII. Conclusion

The proposed Monitoring System for Transboundary FMD provides a common platform for communicating FMD data among livestock keepers and transmit information across the ladder. Adopting the surveillance system will enable FMD awareness maintenance to livestock keeper's communities, timely sharing of FMD outbreaks, and prompt preparedness and responding to the district's disease epidemics. The system can even be adopted in other endemic livestock diseases.

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