A MOBILE BASED SYSTEM FOR PESTICIDES AUTHENTICITY VERIFICATION: A CASE OF TANZANIAN MARKET

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ABSTRACT

Pesticides authenticity plays a great role in human health and environmental protection also economic progress of users, dealers and the government. In ensuring that authentic pesticides are sold in Tanzania, laws have been enacted and government bodies given mandate to enforce these laws. Despite the efforts, counterfeits are still found in markets. Data collection of this study involved one staff from pesticides regulatory authority (Tropical Pesticides Research Institute-TPRI), a total of six staffs from pesticides registrants/formulators/importers and 170 pesticides users preferably farmers all from Arusha region. Methods used were interviews and questionnaires.

Findings revealed there is no any information system which is used by TPRI in managing pesticides information as well inspection is done on experience in threat areas. Furthermore, the dealers declared being victims of their products being counterfeited and pesticides customers have no reliable means of authenticating pesticides during purchase. Due to that, an ICT based solution to the identified problems was developed. The system contains two main parts which are a mobile application developed using Android Studio and web application using Python Flask framework having MySQL managed database.

Therefore, this study not only targets in resolving the issue of authentic pesticides products, reporting of problems for products which haven't worked as expected and the pesticides uses health tips. But also, management of pesticides information, handling of reported complaints and locating counterfeits by the TPRI. It likewise promises increase in the Tanzanian government revenue through levies.

DECLARATION

I, Catherine Cleophace Ngirwa do hereby declare to the Senate of The Nelson Mandela African Institution of Science and Technology that this dissertation is my own original work and that it has neither been submitted nor being concurrently submitted for degree award in any other institution.

Catherine Cleophace Ngirwa — 28th February, 2019

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The above declaration is confirmed

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CERTIFICATION

The undersigned certify that has read and found the dissertation acceptable by the Nelson Mandela African Institution of Science and Technology.

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DEDICATION

I memory of my dear parents, Dr. Cleophace Aloys Ngirwa and Mrs. Cortilda Balthazar Ngirwa, all I wish you could be well and alive, but then there is time for everything under the sun.

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ABBREVIATIONS

ICT	Information and Communication Technology
TPRI	Tropical Pesticides Research Institute
HTML	Hypertext Markup Language
PHP	Hypertext Preprocessor
CSS	Cascading Style Sheet
OCR	Optical Character Recognition
ODK	Open Data Kit
SUS	System Usability Scale
JSON	Java Script Object Oriented Notation
PAVS	Pesticides Authenticity Verification System
HTTP	HyperText Transfer Protocol
ISO	International Standards Organization
IEEE	Institute of Electrical and Electronics Engineers

CHAPTER ONE

INTRODUCTION

1.1 Background Information

In Tanzania, there are regulations that govern commercial distribution of pesticides; the Pesticides Control Regulations Act No.18 of 1979 section 41(8), which states that "*Every person who for commercial purposes or disposal in any way for use by the public imports, manufactures, formulates or compound any pesticide shall register that pesticide in accordance with the Act and these Regulations"* (Tropical Pesticides Research Institute, 1984). In enforcement of these laws, The Tropical Pesticides Research Institute (TPRI), which is the government body, has been given mandate to enforce the pesticides law by management of pesticides dealers and products as well as inspection. Despite the efforts done by TPRI, non-genuine pesticides are still found in the market. Non-genuine (counterfeit) pesticides are those which are not registered, having low/incorrect active ingredients, trademark infringed or misbranded (Singh *et al.*, 2015).

Particularly, Liao and Ma defined product authenticity as; *"originality, quality commitment and credibility, heritage and style persistence, scarceness, sacredness and purity of the product"* (Liao and Ma, 2009). With respect to that, in this study authentic pesticide product refers to the one which have conferred to quality required by the TPRI.

Different scholars explained problems caused by counterfeits pesticides. Which includes; harm to the environment and people, damage in reputation of counterfeits producers, food value chain and plant-protection industry. They similarly identified that counterfeits pesticides leads to loss of government income (Fishel, 2009; Hargreaves, 2015). Reasons of using non-genuine (counterfeit) pesticides in India were described; which comprises lack of awareness amongst the farmers also difficulty in differentiating between genuine and non-genuine products (Singh *et al.*, 2015).

In addition, Europe pesticide business estimated to lose about $260-$370 million U.S. dollars in 2009 due to counterfeited products. Statistics shows that Europe seized 190 tons of counterfeit pesticides between 2015 and 2016. On the other hand in China and India illegal pesticide is believed to comprise about 30-20 percent of the pesticide markets in these countries respectively (Europol, 2016; Fishel, 2009).

For instance, 83 percent of 30 African countries face the problem of counterfeit pesticides (Matthews *et al.*, 2011). A study done by Deloitte in Uganda concluded that the rate of counterfeiting is highest for herbicides, followed by other agro-inputs (Ashour *et al.*, 2015). Correspondingly, AGENDA for Environment and Responsible Development in 2012 reported that, about 40 percent of pesticides sold in Tanzania suggested substandard or wrong dosage means; not containing the required ratio of active ingredients for the product to perform (Lahr *et al*., 2016).

The choice of mobile based system for authentic pesticides service to stakeholders is mainly due to the rise use of mobile phones in Sub-Saharan Africa which comprise about 60 percent of the population. In particular, mobile phones are evolving from simple communication tools into service delivery platforms as telecommunication market matures. For example in Tanzania about 80 percent possess mobile phone, where 40 percent of them uses mobile internet services (Aker and Mbiti, 2011; Tanzania Communication Regulatory Authority, 2017).

Furthermore, pesticides regulatory authority in Tanzania shares information concerning authentic pesticides through pesticides gazette. The gazette contains details on registered products and it is published in the regulatory authority's website for stakeholders to access (Tropical Pesticides Research Institute, 2011). But then, how many pesticides stakeholders (pesticides users) who are aware of the existence of the gazette? The worst part is that the gazette is rarely updated as the one accessed in March, 2017 was last updated in 2011.

1.2 Problem Statement and Justification

1.2.1 Problem Statement

Currently, pesticides users' faces challenge of information concerning genuine products as for now the information is only available through the TPRI's website. The information is rarely updated, the one accessed in 2017 was last updated in 2011 (Tropical Pesticides Research Institute, 2011).

From media reports, inspection of pesticides by the regulatory authority is done based on experience and not the fact about possibilities of counterfeits in the area which they are inspecting (IPPMedia, 2017).

Not only that, but also from the research done in Dodoma town in central zone of Tanzania by

Shao and Edward revealed that about 52 percent of agro-input customers do not check anything to validate the authenticity of the pesticides products during purchase (Shao and Edward, 2014).

Therefore, all these exposed problems in the pesticides industry and shows there is a need of solution to the identified problems.

1.2.2 Research Justification

There is a need of a reliable way of authenticating pesticides in the market, so as to improve the accessibility of the information to customers also providing a means of locating counterfeits to the Tropical Pesticides Research Institute- TPRI.

In the same way, an urgent need of a better way to make the information accessible to the dealers and pesticides customers was suggested as only very few have a chance of rare visit from the pesticides inspectors (Lekei *et al.*, 2014).

Moreover, the choice of mobile based system for pesticides authenticity verification is due to development of telecommunication market in Tanzania. Where the penetration is approximately 80 percent of Tanzanians (Appendix 1). Those using mobile internet services are 40 percent of the population (Appendix 2) (Tanzania Communication Regulatory Authority, 2017).

1.3 Objectives to Complete the Research

The research objectives are divided into general and specific objectives.

1.3.1 General Objective

To develop a mobile and web-based systems for verifying authenticity of pesticides in the market in Tanzania.

1.3.2 Specific Objectives

(i) To identify and analyze requirements for the mobile and web-based systems for pesticides authenticity verification to be developed.

(ii) Development a mobile and web-based systems for pesticides authenticity verification.

(iii) Validation of the mobile and web-based systems for pesticide authenticity verification system

1.4 Research Questions

(i) What are the requirements for the development of a mobile and web-based systems for verifying the authenticity of pesticides in the market?

(ii) What are the building blocks of the design and coding of a mobile application, a database and a web portal for managing verification of pesticides authenticity?

(iii) What technique(s) can be used to validate the developed mobile and web based systems for verifying authenticity of pesticides in the market?

1.5 Research Framework

Research framework gives a clear understanding on the services which would be provided by the proposed solution as shown in Fig. 1. From the research framework there are two main parts which are mobile and web applications. The mobile applications captures product information sends to the server for matching and gets response on the product status.

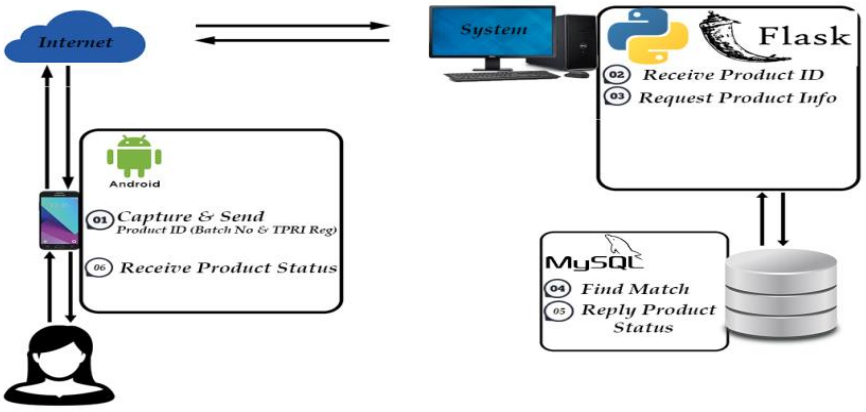

Figure 1: Research Framework

1.6 Significance of the Study

The study provides mechanisms and tools for:

(i) Enabling authenticity verification of pesticides products using information sent from the mobile application.

(ii) Providing feedback on best practice of using the particular requested product.

(iii) Sensor of more prone area of counterfeits in Tanzania.

1.7 Research Approach

The research was carried out in Arumeru district which is in Arusha region in Tanzania. In collecting the needed information from various groups of pesticides stakeholders, both qualitative and quantitative research methodologies were used. Where the methods involved were; semi-structured interviews and Open Data Kit (ODK) prepared questionnaires. The obtained information was analyzed both qualitatively and quantitatively so as to have the needed requirements in development of a mobile and web applications for pesticides authenticity verification and management of pesticides information respectively.

Thereafter the developed mobile based system which contains two main parts which are a mobile and web applications were tested. Testing contains two main phases, a preliminary and final testing. The gathered comments and recommendations in the preliminary testing phase were implemented to the system ready for final testing phase. Finally, the discussion on the results and recommendations for future work was done.

1.8 Personal Motivation

The driving force to this study, is contributing to other researches in combating counterfeits pesticides in Tanzanian market. In this dissertation several works have been identified and their contribution acknowledged towards the journey of making sure that authentic pesticides are sold. Being an ICT expert, have been motivated to figure out and even implement the power of ICT towards societal problems solving, specifically to the pesticides authenticity verification in Tanzanian context.

1.9 Intended Stakeholders

This research targets in cracking problems encountered by pesticides stakeholders around Tanzania. Which includes, the TPRI, pesticides registrants/importers/formulators, pesticides retailers, pesticides customers especially farmers and professionals in software engineering. It contributes to understanding of theories and practices in the software development life cycle; from requirements elicitation, requirements specification, system design and development to its validation.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter presents literature review on the related work in combating counterfeits pesticides; strengths of these works and analyzed weaknesses. Similarly, the chapter describes on the proposed solution, mobile technologies and conclusion to the chapter.

2.2 Related Work

The Information and Communication Technology (ICT), plays a great role in human life. It has been used as a tool for providing education opportunities to underserved who are geographically dispersed through teleconferencing technologies (Tinio, 2002). Also, in business, through e-commerce has been able to cater many customers in shorter time and in effective manner while increasing a competitive edge of a particular business (Carnoy, 2005).

On the other hand, different ICT approaches and methods have been suggested and others even implemented towards combating counterfeits. Those efforts includes the cloud technology, mobile and syndication technologies, rapid alert systems, coded stickers, website seals and cyber warning and all of these can be a success by conducting authentication and verification related activities, which involves; organizations and stakeholders collaborations as well as public awareness campaigns (Isah, 2012).

The following are ICT efforts which have been done by different stakeholders in developed and developing countries to combat counterfeit pesticides;

Starting with the Microsoft Access managed database proposed in Greece (Vassiliadou *et al.*, 2011)**.** It provides information on the recommended and genuine pesticides and information on how to use them. It facilitates communication between the regulatory authority and potential users and dealers of the pesticides. But, only computer literates and those having access to computers can use the system.

Then, regulatory Information System in Taiwan (Fei, 2014)**.** It covers the registration, quality regulation also establishment and evaluation of maximum residue limits and field monitoring of pesticide residues. It also, provides information to users of the services concerning the use of products. However, the system only supports other regulatory authority functions and there

is no room for products authenticity verification by other pesticides stakeholders especially customers.

Furthermore, a Short Message Service (SMS) system for pesticides products verification in Kenya (Syngenta, 2011). The Kenya Plant Health Inspectorate has established this simple SMS system that allows farmers to check the authenticity of agro-inputs seeds, fertilizer, chemicals by sending text that contains dealer's license number and gets an SMS confirming the status. Nevertheless, registered products are produced in several batches and may happen that a particular batch not to contain the expected quality, for that case this SMS system pave a way for substandard products batches in the market.

Another work is the electronic verification system, using SMS in Uganda (Ashour *et al*., 2015). For the product to be authenticated by the system, it has to have a secret code attached to it. Customers have to scratch-off the code to get secret number to send by SMS to the system and receive an SMS confirming the authenticity of the product. Only products with valid scratch code, considered authentic. But then, this system requires restructuring of the whole packaging system so as to accommodate authentication codes.

Lastly, an ICT model to combat counterfeits agro-inputs in Tanzania (Shao and Edward, 2014). The proposed model requires communication between the regulatory authority and the manufacturers on agreed code to be kept on the products then update the server for customer to authenticate during purchase through SMS. Only products with valid scratch code, considered authentic. Nevertheless, it needs restructuring of the whole packaging system so as to accommodate authentication codes.

2.3 Proposed Solution

This study targets on a mobile application which emulates pesticides inspection personnel and reciprocate the process to end users. By doing this, different pesticides stakeholders will be able to verify authenticity of the products, by entering the batch number and get instant response on the status of the product.

On the process, the Global Positioning System (GPS) location of the sender shall be captured so as to be used in creating maps with markers for products which doesn't have a match in the database. The map makes the inspection concentration to the threats areas shown in the maps.

Particularly, the reply message includes the specifications of the genuine product for the requester to match with the physical product. If the product is not found in the authentic database, system gives an alarm message that the product is counterfeit. As well, the system generates various management reports for the regulatory authority use.

2.4 Review of Concepts

This study targets on the development of the mobile application for pesticides authenticity verification and a web application for management of pesticides information. Review on the concepts concerning mobile technologies and data exchange methods between mobile and web server was necessary. Conclusion to this chapter presents the chosen technologies.

2.4.1 Mobile Technologies

Mobile technologies are used in handheld or palmtop devices like mobile phones, smartphones, Personal Digital Assistants (PDAs) and their peripherals. They are called mobile because they can be trans-ported from one location to another. Their mobility is due to due to their portability and durability in battery life. These characteristics provides flexibility in usage in different environments (Keengwe and Bhargava, 2013; Kucirkova, 2018).

Involvement of mobile technologies in various aspect of human life has completely changed the way services are offered. In health care mobile technologies has improve monitoring, tracking and communication. After introduction of the mobile technology into the marketplace it's important to make sure that users get involved with it. Among the mentioned way of keeping users interest to the application is gamification. This is the idea of applying game mechanism to non-game context so as to motivate users (Law *et al.*, 2011; Mwammenywa and Kaijage, 2018; Nayebi *et al.*, 2012; Shin *et al.*, 2012; Steinhubl *et al.*, 2013).

Nevertheless, adoption of mobile technologies in products authentication hasn't been common especially in Tanzania. So far there is work done by the Tanzania Food and Drugs Authority (TFDA) in authenticating pharmaceuticals in the country. This proposes the use of secret code in the pharmaceutical products. When user wants to buy the product, he/she just scratches to get the secret code and sends the code for authenticity verification. However the products authentication part of the project have not yet been implemented, working part is for people to report in case there are any side effect encountered in using the pharmaceuticals (Mvuma *et al.*, 2017).

In performing the intended services, mobile technologies softwares (mobile applications) may require data exchange with remote server. Data exchange between the mobile application and web server can be suitably performed by JSON (Java Script Object Notation). "*JSON is a light-weight format for exchange of data. It has become an ideal format to exchange data which can be read and written easily*". Having data exchange means processing is done in the remote server and not the mobile application. This helps in optimizing communication mechanism and create a solid background framework from the remote server (Aher *et al*., 2014). Data to be exchanged by the mobile application with the remote server may be extracted from image captured then processed or input of text direct by user for product authentication request.

(i) Image Processing for Product Authentication

"*Image processing involves changing the nature of an image in order to either improve its pictorial information for human interpretation or render it more suitable for autonomous machine perception*" (Mcandrew, 2016). Knowing the uses of the image to be processed paves the way to techniques or algorithms and technologies to be implemented in achieving the goal (Russ, 2011).

Different techniques and technologies have been described and others even implemented in different literatures. In rendering image for autonomous machine perception, the following published works (Constantin *et al.*, 2018; Conway, 2011; De Moraes Navarro and Prati, 2014; Mithe *et al.*, 2013; Sabau *et al.*, 2009; Tumu, 2013) have presented techniques like usage of OCR tools and OpenCV which are image processing tools in combination with different libraries like Tessaract, Mobile Vision, Google Machine learning library, which uses python software package, Matlab, PHP and Android as framework technologies for both pre-processing, post-processing and character recognition from images.

OCR (Optical Character Recognition) tool is used in image processing by converting text in the image into readable text. It is used with standard Tessaract library which processes text areas with symbols, numbers or letters and extracts for further processing (Kichuk, 2015).

"*OpenCV (Open source Computer Vision) is an open source C++ library for image processing and computer vision. It primarily aimed at real time image processing and it is a library of many inbuilt functions"* (Malathi and Neduncheliian, 2014).

"OCROpus1 is a Python software package which implements image pre-processing tools and character recognition based on machine learning" (Conway, 2011).

Image captured can be processed in the mobile application or sent to the remote server for processing. Sending image to the remote server is a viable solution as it reduce processing burden for mobile device. But it is restricted by an increased internet bandwidth/data of the end user. For high system accuracy the image quality must be of high quality which is a limitation to most of the smartphones available in developing countries. It is also to be noted that, image processing using Google Machine learning library does not work well with dotted printed texts in the pesticides products. Where most of the pesticides products have batch number, TPRI registration number, production and/or expiry date printed in dotted.

Another challenge to image processing is arrangement of information on labels based on the current labelling of pesticides products in Tanzanian. Where batch number and TPRI registration numbers are not near, which may require user to take more than one picture to capture the needed information for product authentication.

(ii) Data Input for Product Authentication

In this option, user of the mobile application has to input data of the product to the application for it to be sent to the server for authentication. Data exchange for authentication between mobile application clients and the server helps in optimization of communication mechanism by improving efficiency of data query (Aher *et al.*, 2014). Advantage to this option of text input for product authentication is that user will be able to input all the needed information even if the information is scattered in the product label.

2.5 Conclusion

Based on the literature review, there are a lot of different efforts which have been done by stakeholders worldwide in combating counterfeits using different information and communication technologies as describe earlier in this chapter. Addition to that, the chapter presents concept of mobile technologies and their applications. It as well presents two main options for product authentication requests which are image processing and data input for product authentication.

From the presented options, data input option for product authentication was chosen to be implemented in this research. To start with this study concentrates in development of the mobile application for use in pesticides products authentication. Later on the study proposes

its extension to include USSD codes so as to cover even pesticides customers with featured phones

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

This chapter presents various materials and methods used in the development of the proposed solution. Starting with clearly understanding the study area, mapping of the stakeholders, data collection methods, sample size and sampling technique, characteristics of requirements, system requirements, requirements specification, system dependencies, conceptual modelling of the system, system design, system validation approaches and conclusion.

3.2 Research Study Area and Stakeholder Mapping

This is a study was conducted in Arusha region located at 3.3869^0S, 36.6830^0E coordinates. Arumeru district was opted since it leads other districts in Arusha in use of pesticides. It comprise a total of 49 292 households involved in agriculture (The United Republic of Tanzania, 2012).The whole process of data collection took place from January to March, 2018.

In discovering the needed groups of people and/or pesticides dealers to involve in data collection, mapping of influential stakeholders was important. Stakeholders refers to people who affects or can be affected by the endeavor, they can be direct or indirect involved in it (Beringer *et al.*, 2013). Stakeholders mapping refers to the process of identifying human or non-human groups which are involved to the subject arrive at relatively small but comprehensive lists. This process leads to better understanding of the stakeholders power, influence and interest similarly their involvement to the project (Mohan and Paila, 2013; Petruney *et al*., 2010; Reed and Curzon, 2015). Figure 2 below shows mapped stakeholders of a mobile based system for pesticides authenticity verification.

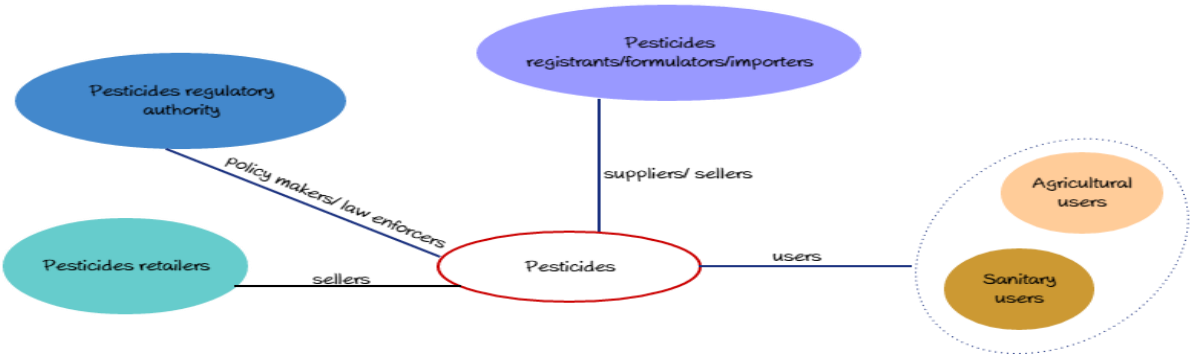

Figure 2: Mapping of Pesticides Stakeholders in Tanzania

From the mapped groups of pesticides stakeholders, three groups were selected;

First group was pesticides regulatory authority, which is the government body given mandate for pesticides laws enforcement. It is officially called Tropical Pesticides Research Institute (TPRI).

The second group was pesticides registrants/importers/formulators. These are companies which have been registered for importation, distribution, formulation also selling of pesticides products in the country. Since they merge by engaging also in retail selling of pesticides products, then shall be used in representing the retailers.

Third selected group was pesticides users or customers of pesticides. These are customers or end users of pesticides products. They can be grouped into sanitary and agricultural users. Literature shows that, there is a massive increase in importation of agricultural pesticides especially insecticides, fungicides and herbicides from year 2005 to 2013 than disinfectants (Appendix 7) (Lahr *et al*., 2016). Due to that, agricultural users which mark the largest population of pesticides customers were involved in collecting the needed information for this study.

3.3 Data Collection Methods

Mixed methods to data collection were used, which is a combination of qualitative and quantitative methods of data collection and similarly the results should be analyzed both qualitatively and quantitatively (Tashakkori and Teddle, 1998; Tashakkori and Teddlie, 2010). From qualitative methods, interview was used and for quantitative methods, questionnaire was

used to gather the needed information from the pesticides stakeholders. Different groups of pesticides stakeholders were identified including the targeted information from each group.

3.3.1 Sample Size Determination and Sampling Technique

Sample size determination for quantitative approach, Conferred to (Ajay and Micah, 2014); "*Sample size determination refers to technique of electing the number of observations to include in a sample. Sample size is an important feature which used to make inferences about a population from a sample. Selecting sample size is based on cost of data collection and statistical power*". Formula used in this study to determine sample size for the study, was Yamane's simplified formula, as shown below;

$$n = \frac{N}{1 + N(e)^2}$$

Where; n is the sample size, N is the population size, and e is the level of precision.

Applied information from this study are as follows; N = 49 292, e = 0.08 and 95% confidence level.

When the information was applied to Yamane's formula we got a sample size of 156 responses. (Ajay and Micah, 2014), allows addition of 10% to 30% for compensation of uncertainties like no response, which may happen during data collection. Therefore, the collected sample size for quantitative method was 170 respondents, in answering Open Data Kit (ODK) prepared questionnaires attached in (Appendix 16). They were prepared using the ODK tool and then transfer filled forms to the ODK server during data collection. The ODK has been used since it is mobile, faster and reliable means of collecting needed information from target audience (Hartung *et al.*, 2010).

Guideline from (Patton, 2002); "*There are no rules for sample size in qualitative inquiry. Sample size depends on what you want to know, the purpose of the inquiry, what's at stake, what will be useful, what will have credibility, and what can be done with available time and resources*". Based on availability of interviewees, time and cost criteria, then one staff from TPRI and one staff from each six randomly selected companies were interviewed. Random selection of companies was chosen as way to give them equal chance to participate in the study (Martyn Denscombe, 2014; Meng, 2013).

3.4 Data Analysis Methods

These are methods used in presentation of the collected data from TPRI, pesticides registrants/formulators/importers and pesticides users. Data collected from interview analyzed based on the interviewer understanding during the session and quantitative data from questionnaires were analyzed using excel.

3.5 System Requirements

This section provides an answer to the first research question which states that; *"What are the requirements for the development of a mobile based system for verifying authenticity of pesticides in the market?"*

Software requirements or system requirements acts as a bridge between real world problem that exists and the software system (Sommervile, 2011). The requirements are there for clear understanding of the problem that the software system expects to solve. Also can lead to success of the developed software to the target users (Katina *et al.*, 2014). Mostly, requirements aims at ensuring that the developed software provides the desired functionality and utility also align to the needs of expected audience (Baresi *et al.*, 2010; Keating *et al.*, 2008).

Ian Sommerville defines software system requirements as *"the descriptions of what the system should do, which includes the services that it provides and the constraints on its operation"* (Sommervile, 2011). They can be divided into; user and system requirements. Where user requirements refer to constraints on the system while system requirements is more detailed description of what the system should do. Due to that software requirements for pesticides authenticity verification system were developed. Since the system to be developed comprises of two basic parts with different user groups on each or the sides, then user and system requirements where developed.

Table 1: User requirements for mobile part of the PAVS

(i)	The mobile application shall respond on the status of the requested pesticides product by showing details of the manufacturer, product details including usage in English and Swahili, also TPRI registration number of the requested product
(ii)	The mobile application shall provide a form for user to report problem for the products which haven't worked as expected
(iii)	The mobile application shall display pictures and descriptions on the safety measures to be taken in using pesticides products

Table 2: System requirements for mobile part of the PAVS

(i)	On every pesticides authenticity request, batch number of the product shall be filled by the requester then send for matching with stored details in the database for status reply to the mobile application
(ii)	On the last working day of every month the mobile application shall be updated so as to review and increase pesticides use safety measures as new and reviewed products instructions arrive at the TPRI
(iii)	For every problem to be reported picture on the instructed part of the product shall be taken and particular descriptions on usage and complaints then sent to the server

Table 3 : User requirements for web part of the PAVS

(i)	The web application shall provide a form for new user to register to the system for access
(ii)	Registered user shall be able to login and manage (add, view, edit and delete) details on registered and permitted pesticides products
(iii)	Registered user shall be able to view and print details and location of the pesticides authentication flags
(iv)	Registered user shall be able to view and print details on the reported complaints from the mobile application

Table 4: System requirements for web part of the PAVS

(i)	Access to the system shall be only after registration of the user
(ii)	The system shall automatically record all logs per user activities
(iii)	On the first working day of every week, reports on authenticity request requests and maps shall be printed to be worked on
(iv)	The system shall automatically reply on the pesticides authenticity requests and save details of the requester and the requested product
(v)	The system shall automatically reply on the success delivery of the reported complaints

3.6 Characteristics of Requirements

Different characteristics of requirements have been explained in different literatures (Pandey *et al.*, 2010; Sommerville, 2011; Wiegers and Beatty, 2013) and from the pool, this study worked on the following qualities as described in Table 5.

Table 5: Characteristics of requirements for PAVS

Characteristic	Description
Completeness	Mapping of pesticides stakeholders was done and selected groups of pesticides stakeholders in Tanzanian context were involved by collecting needed information for the requirements to be implemented during design and coding of the PAVS.
Correctness	The PAVS shall be validated against objectives. This shall help in ensuring that target user's needs have been considered effectively.
Consistent	The requirements for PAVS have been stated in such a way that there were no conflicts in requirements.
Relevance	Based on the identified needs of pesticides stakeholders in Tanzanian context. The requirements were specified to ensure that information concerning pesticides authenticity can be accessed by users.
Modifiable	The connection with the respondents participated in user research was maintained in such a way that they can be contacted for more clarification, changes and/or suggestions. Then adjust the system accordingly. System expects to be validated before final version.

3.7 Requirements Specification

Requirements specification refers to a serious phase in software development that describes capabilities that a software system must possess. This plays a foundation for design, coding as well as foundation for software testing (Wiegers and Beatty, 2013). Before design of the mobile based system for pesticides authenticity verification, specifying requirements for it was crucial. As when a requirement didn't appear in the requirements specification shouldn't expect it to appear as the functionality in the system.

Basically, requirements specification is functional and non-functional requirements. Where functional requirements are statements of the services the system should provide, how it should react to particular input and how it should behave in particular situation while for non-functional requirements are the constraints on the services or functions offered by the system.

Table 6: Functional requirements for mobile part of PAVS

Actor	Requirements	Description
Pesticides user	Request authenticity of pesticides	The pesticides user shall be able to request authenticity of pesticides products to the database through the mobile application
	Report complaint	Shall also be able to report complaints for pesticides which haven't worked as expected
	Learn on the safety measure of using pesticides	Shall be able to learn of the safety measures in using pesticides
Pesticides inspector	Request authenticity of pesticides	The TPRI inspector shall be able to request authenticity of pesticides to the database through the mobile application

Table 7: Functional requirements for web part of PAVS

Actor	Requirements	Description
Pesticides inspector	Enter/update details of registered and permitted pesticides	The pesticides inspector shall be able to manage details of registered and permitted pesticides
	Prepare complaints report	The pesticides inspector shall also prepare list of complaints reported by pesticides users
	Prepare authenticity request reports	The pesticides inspector shall also prepare reports on the authenticity request flags so as to be used in scheduling areas to be inspected
System administrator	Monitor system activities	The system administrator shall be able to monitor system activities
	Manage system users	The system administrator shall also be able to manage system users; register and update user profiles

Table 8: Non-functional requirements for the PAVS

Requirement	Description
Security	Web application authenticates the user before any interaction with it
Performance	It is not affected at any time as it is expected to be installed in user's phone
Reliability	The system ensures user functions are performed correctly as required by the user
Usability	The mobile based system for pesticides authenticity verification ensured to be learnable, memorable, effective and ease to use for the target audience
User Experience	The mobile based system for pesticides authenticity verification expects to provide a great user experience which shall be captured during eye tracking test in software evaluation to target users

3.8 System Design

This section answers the second research question which states that; *"What are the building blocks of the design and coding of a mobile application, a database and a web portal for managing verification of pesticides authenticity?"*

Information systems are described as designed products that involve interaction between human beings and machines which impact people, organizations and society in general (Hevner *et al.*, 2004). International Standards Organization (ISO) defines software design as *"the software engineering life cycle activity in which software requirements are analyzed in order to produce a description of the software's internal structure that will serve as basis for its construction"* (ISO, 2015). As well, design puts more emphasis on the functional nature of what is to be produced, not only the look; it includes all aspects of user experience and web design, it takes into account also usability and accessibility (Horton *et al.*, 2013; Mehalik and Schunn, 2006).

Notably, the International Standards organization (ISO, 1998), defined usability as the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction. The product (whether a web system, or mobile) shouldn't make people think more than they should as people have limited mental capability, design a usable product is possible by putting user's first during the process which can be termed as user-centred design or human-centred design (Krug, 2014; Rubin *et al.*, 2008). The International Standards Organization (ISO, 2010), defined human-centred design as *"an approach to systems design and development that aims to make interactive systems more usable by focusing on the use of the system and applying human factors/ergonomics and usability knowledge and techniques"*.

In addition, accessibility is one of the qualities of usability, as it is not possible to say a product is usable while not accessible. Other qualities from ISO definition are; efficiency, effectiveness and satisfaction of targeted users (ISO, 2010; Krug, 2014; Rubin *et al.*, 2008).

For instance, User experience refers to attitude arise when user interact with the product, facility or environment (Bevan *et al.*, 2015). User experience can be altered by expectations, psychological state, context in which the system runs and characteristics of an interactive system (Ardito *et al.*, 2008; Vaananen-Vainio-Mattila *et al.*, 2008).

Combinable, different techniques for building usability have been indicated in literature (Rubin *et al*., 2008). Figure 3; describes some questions asked and methods applied in answering them so as to develop a usable product.

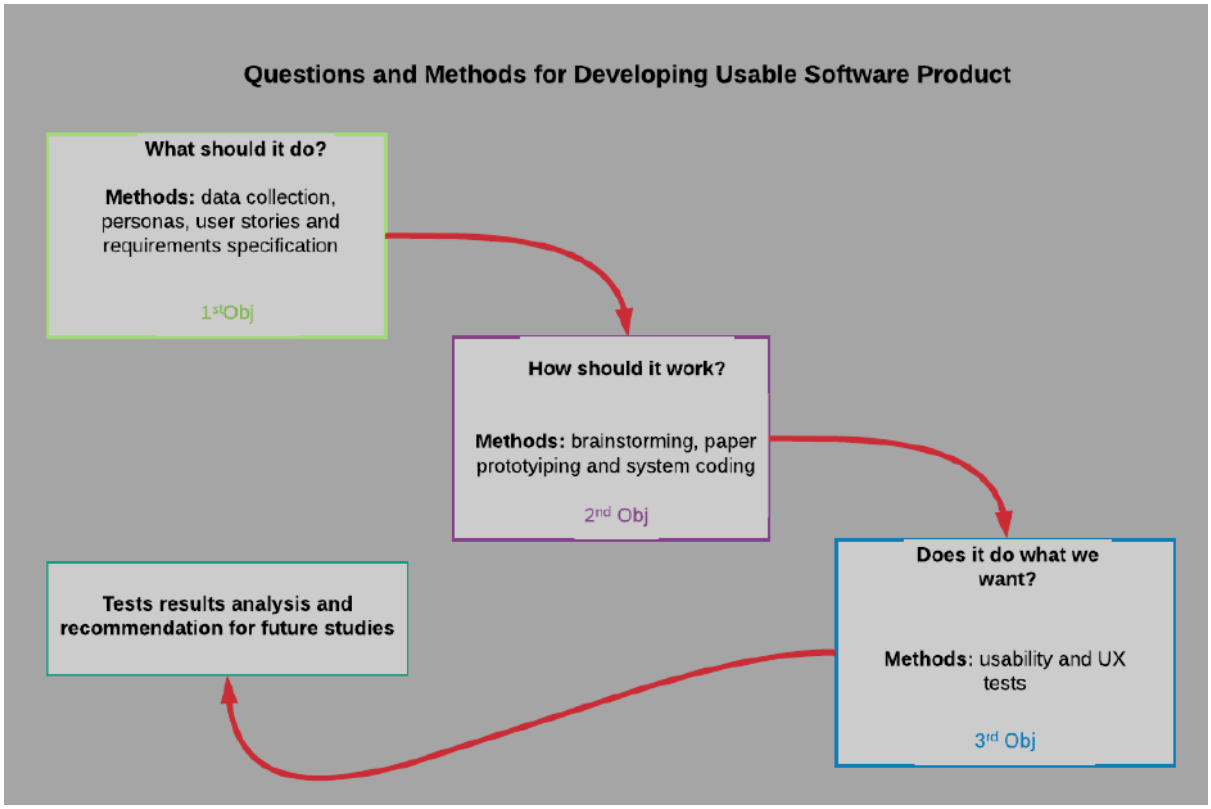

Figure 3: Questions and Methods for Usable Product

Source: (Amended from Rubin *et al.*, 2008)

First question: what should it do?

In clearly understanding of services and functionalities offered by the pesticides authenticity verification system. The following methods were implemented which includes; data collection, personas development, user stories and system requirements specification.

Data collection user groups were identified and involved through interviews and questionnaires. Interviews were done with the TPRI staffs and the pesticides registrants/formulators/importers. Questionnaires involved farmers as the literature shows there is largest imports of agricultural pesticides in Tanzania (Lahr *et al.*, 2016).

More understanding of the users the product serves, the need for personas development from user research is important. In fact, personas helps to visualize and communicate how users will

interact with the system (Horton *et al.*, 2013; Ma and Lerouge, 2007). For pesticides verification system, three personas have been developed where two of them visualize farmers who use pesticides for agricultural purposes, and one for the pesticides regulatory authority staffs. After that system requirements were specified based on the user research done. See all of the three personas in Appendix 8, 9 and 10 respectively.

Also, User stories have been used as a way of capturing specific system requirements which are desired by target users. The main purpose is to increasing usability of the software product (Lucassen *et al.*, 2015; Moreno and Yagüe, 2012). In ensuring that an information system was built based on the users' needs; user stories are essential. As they build a bridge of communication between system users and software development team. Adding to that, they help in identifying system functionalities based on user's needs (Cohn and Kent, 2004). More detailed in user stories Appendix 11.

The second question: How should it work?

Methods implemented in answering this question involves; brainstorming, paper prototyping and system coding.

Brainstorming involves thinking beyond obvious solution. For pesticides authenticity verification system, the session come about with adding industry news to the apps will increase users' interests to the product. Indeed, the reminder on the existence of the application to the user's mobile phone.

Then, paper prototyping, wireframes were developed so as to communicate on information flow in the system (both mobile and web apps). Wireframes can be used to effectively communicate the software interaction in more detailed manner, also helps users to suggest on changes early before development (Li *et al.*, 2010; Lopuck, 2012). Wireframes for mobile part of the pesticides authenticity verification system have been included in Fig. 4, 5, 6 and 7 for mobile application. As well Fig. 8 and 9 are wireframes for web application.

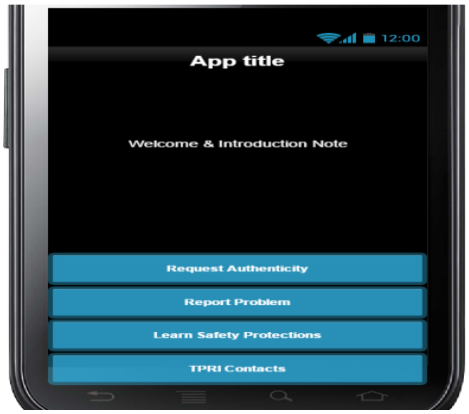

Figure 4: Home Page

Figure 5: Authenticity Request

Figure 6: Report Complaint

Figure 7: Safety Measures

Wireframes for web application;

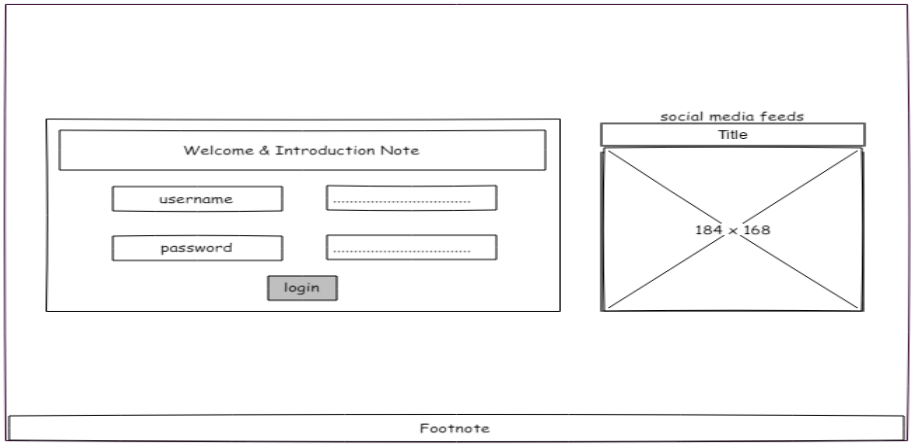

Figure 8: Wireframe for login page in web application

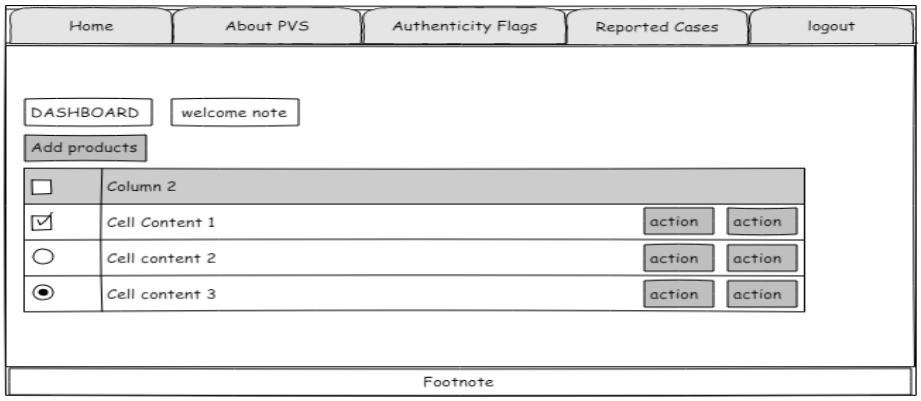

Figure 9: Wireframe for dashboard of web application

Coding of the pesticides authenticity verification system used Python Flask framework with HTML, CSS, JSON and JavaScript for web application and used Android studio for mobile application. The database managed by MySQL.

Flask is a lightweight web application micro-framework written in python, which makes use of python's flexibility to provide relatively simple template for web application development. The only dependency in this framework is Python Standard Library. No need of third part for form validation, communication with database and HTTP communication (Aggarwal, 2014; Grinberg, 2014).

Decision on which database language and tool to use relies in data model, according to (Silberschatz *et al.*, 2011) *"data model is a collection of conceptual tool for describing data, data relationships, data semantics, and consistency constraints"*. Different scholars (Berg *et al.*, 2013; Ramakrishnan and Gehrke, 2003; Silberschatz *et al.*, 2011) described various data models like; network, hierarchical, object-based, semi-structured and relational data models. With exception to relational data model, other models have difficulties in maintaining relationships between data they store, difficulties in alteration of the databases and their unfamiliarity in database industry which becomes a problem in their adoption, evolution and maintenance in future.

Relational data model uses tables (relations) to store and manage data and their relationships. MySQL is a free relational database tool with proven performance, reliability and ease of use. It supports relationship between data stored in the database which helps in overcoming redundancy. It as well works better with Flask framework (Agarwal and Raj, 2018; Gyęrödi *et al.*, 2015).

Third question: Does it do what we want it to do?

The developed pesticides authenticity verification system evaluated based on all information and objectives set in accomplishing it in this study. Chosen methods in answering these questions involve usability and user experience tests. Reasons for the choices and descriptions on their applications have been discussed more in the Section 3.10.

3.8.1 Data Flow Diagram (DFD)

Data flow diagram (DFD) refers to tool used to depict system needs and show its business functions (Kendall and Kendall, 2013).

Level 0 data flow diagram shows information flow between external entities and the system. Figure 10 below explains level 0 of the pesticides authenticity verification system. The system interacts with the mobile application of authenticity verification. Where information exchanged involves requesting and reply on the product status from mobile and web application. The web application interacts with three groups of users, which are system administrator, pesticides registrar and pesticides inspector.

Where level 1 data flow diagram shows information flow and processes involved at each stage, also data stores involved when process completes. Figure 11 below shows the functions.

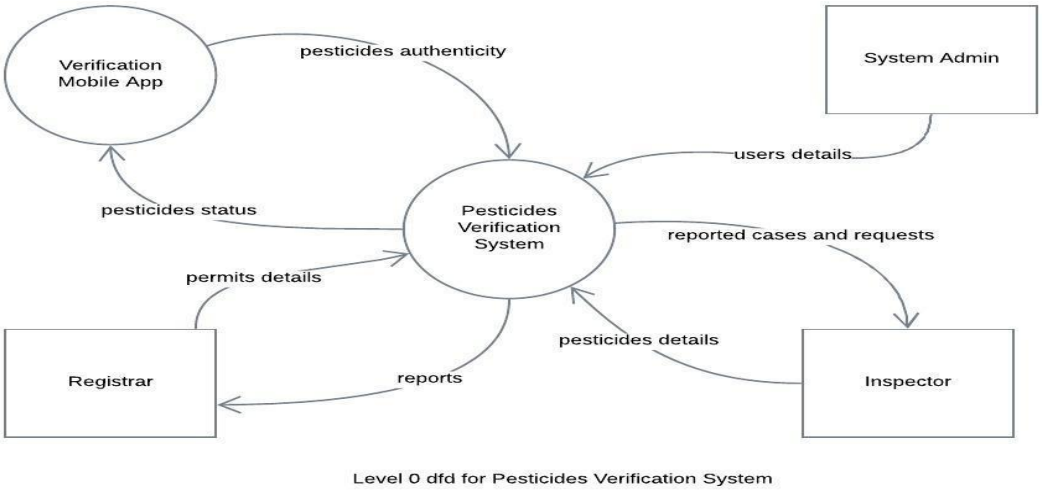

Figure 10: Level 0 DFD for PAVS

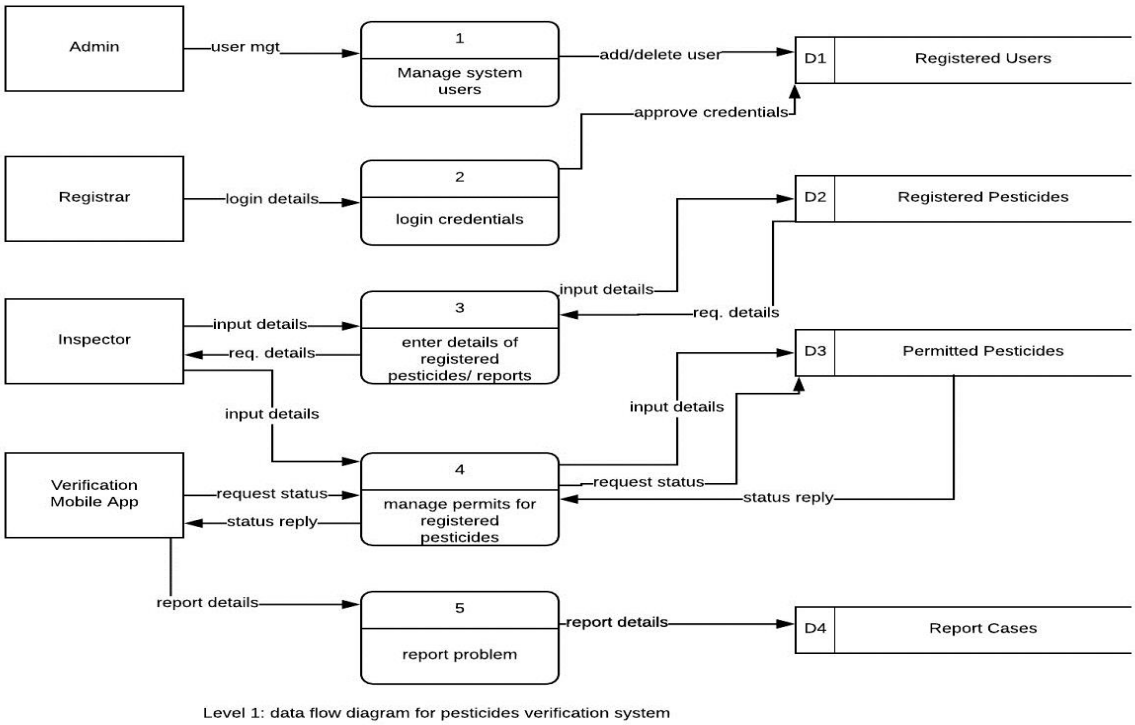

Figure 11: Level 1 DFD for PAVS

3.8.2 Conceptual Modelling of PAVS

(i) Use Case Modelling

Use cases have been used in conceptual modelling of information systems. Which helps in depicting the system functionalities and main functions performed by system users, they describes what the system does and not why it does. Use cases as well contain actors, use case symbols along with connecting lines. Where actors are external entities to the system and plays a particular roles, and they are always outside the scope of the system. The communicating lines connects actors to the system defines boundary (Adams *et al.*, 2013; Kendall and Kendall, 2013; Murali *et al.*, 2016).

In relation to the pesticides authenticity verification system two parts which are web and mobile application with different actors in each part. Two use case diagrams were prepared for each part of the system.

Figure 12 describes the use cases for web application. Where there are two actors; pesticides inspector and the system administrator. The pesticides inspector performs changes in the registered and permitted pesticides products, prepares complaints reports and authenticity reports to the system. The system administrator monitors system activities and manage system users.

Also, Fig. 13 is use cases for the mobile application. It involves two types of user groups which are pesticides user or customer and the pesticides inspector. The pesticides user is able to request pesticides authenticity, report complaint and learn on safety measures in using pesticides products. On the other hand, pesticides inspector uses the mobile application only for requesting authenticity of the products.

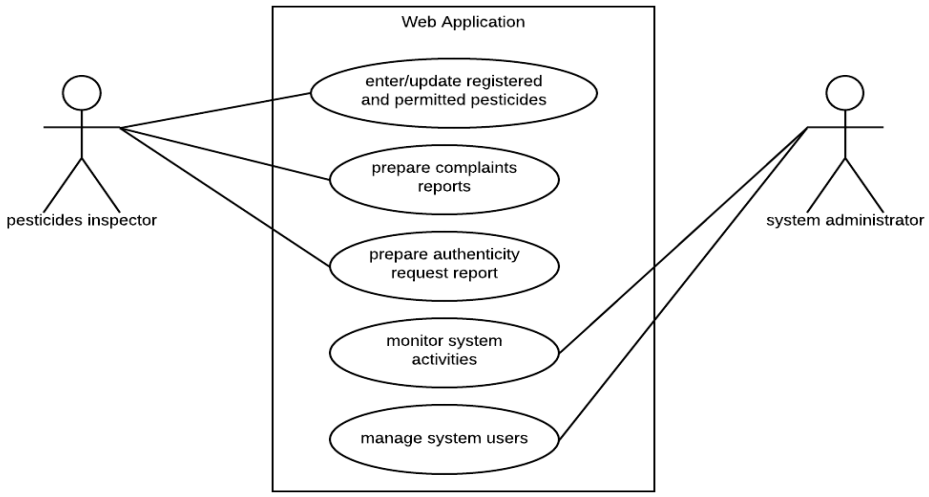

Figure 12: Use case for web application

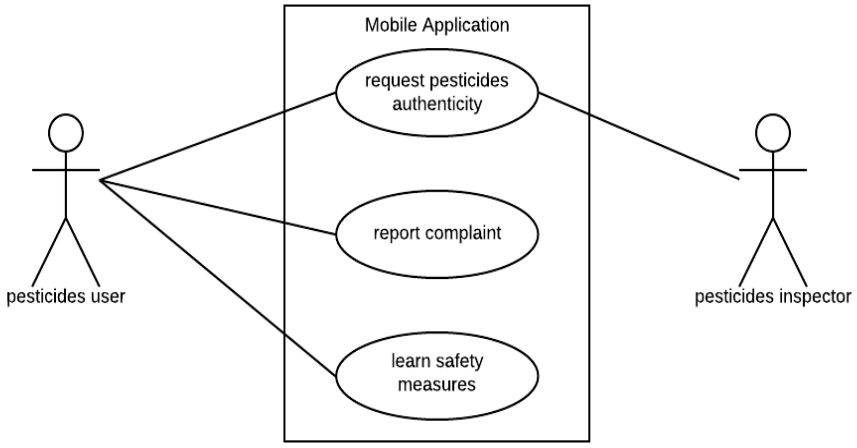

Figure 13: Use case for mobile application

(ii) Entity Relationship Diagram (ERD)

Entity relationship diagram refers to diagrams that help in defining scope of the system and boundaries by showing entities involved and their attributes. Furthermore, entity relationship diagram defines relationship between entities and helps in forming queries in a database and information system based on the diagram (Brady and Loonam, 2010; Kendall and Kendall, 2013; Ochodek *et al.*, 2011).

The diagram in Fig. 14 below shows an entity relationship diagram for the pesticides authenticity verification system. Functionalities entities involved are explained as follows.

Pesticides inspector prepares list of registered and permitted pesticides. Also views the reported complaints and authenticity requests from the mobile application. Then, the pesticides user request authenticity of the product during purchase and reports complaint for products which haven't worked as expected, all using the mobile application. Entirely these functionalities are viewed and managed by the pesticides inspector through the web application.

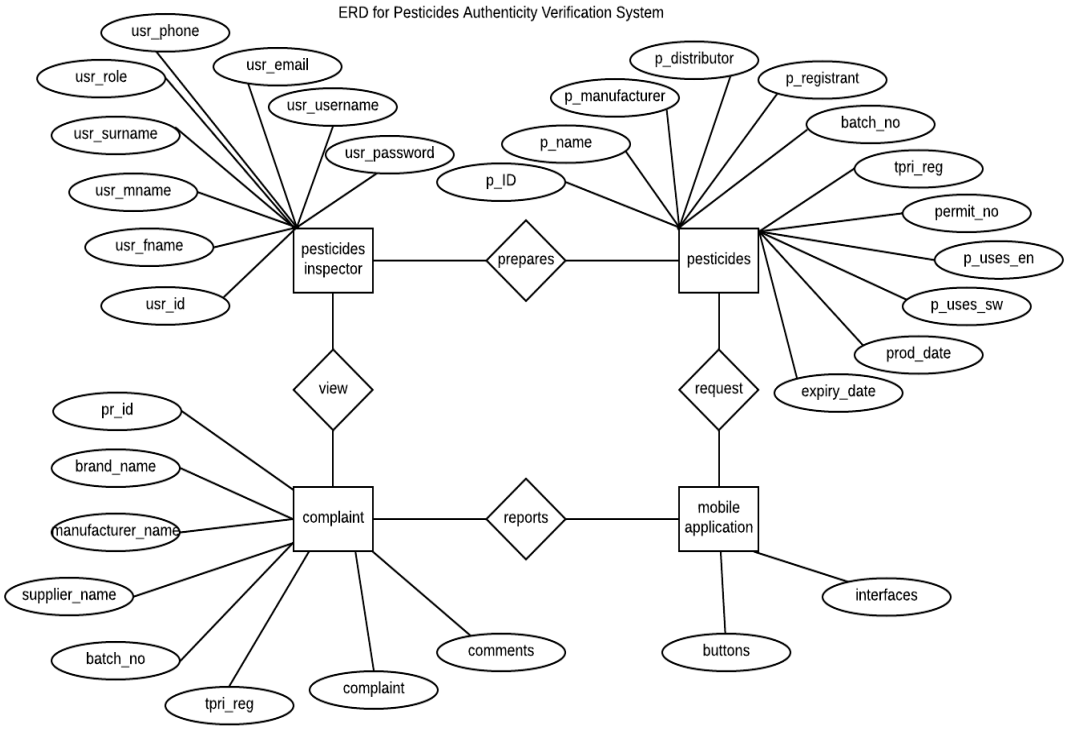

Figure 14: Entity relationship diagram for PAVS

3.9 System Assumptions and Dependencies

3.9.1 System Assumptions

The following are the assumptions which were made during development and technology selection of the pesticides authenticity verification system. Since the system contains two main parts, hence the assumptions are explained based on the part of the system. For the mobile application part of the system;

(i) Retail shop sellers have access to smartphones for buyers who don't have one to authenticate pesticides products during purchase.

(ii) All pesticides buyers who go to buy pesticides know how to read and write Swahili.

(iii) All host smartphones to the application can provide access of location, internet camera to be able to assist in pesticides authenticity verification and complaint reporting.

For the web application part of the system;

(i) All TPRI staffs who manages pesticides information and inspection processes have knowledge in using computers**.**

(ii) There is a regular update of information whenever pesticides have been permitted after lab analysis**.**

(iii) The web application is hosted in a server that is on (accessible) 24/7 so that users can have services of requesting authenticity and reporting problems when arise during the usage of pesticides products**.**

3.10 System Validation Approach

The section answers the third research question which states that; "*What technique(s) can be used to validate the developed mobile based system for verifying authenticity of pesticides in the market?"*

Purposely, testing or validation of the system is done so as to increase its value by identifying and working on problematic points and recommendations from various system stakeholders. There are different methods in system validation such as validation through simulation of the system. Another is validation through analysis of heuristics where experts evaluate the system then give their feedback for developers/ designers to work on them. Also method of usability test, which occurs when one person at a time tries to use the product to figure out what it is and perform some tasks (Batarseh and Gonzalez, 2013; Boring *et al.*, 2015; Rubin *et al.*, 2008).

This study concentrates in usability testing for the validation of the developed mobile and web-based systems. The reason for choosing usability test is because it tends to concentrate in user's needs to understand the system problems from user's perspective and after use the gathered information to redesign the system for better feedback (Chang, 2015). There are numerous methods which are used in system usability testing as discussed in literatures.

(Battleson *et al.*, 2001), described three types of usability tests which are; inquiry, inspection and formal usability tests. The inquiry methods involve requesting user's view concerning the

system in testing, it comprise focus groups, interviews, questionnaires and surveys. The inspection method involves experts in the field to give their opinions on the system. Inspection is not expensive as heuristic but it is not useful in errors identification. Inquiry and inspection does not involve actual users but formal usability test involves actual user either in the field or lab. Formal usability test identifies more errors compared to enquiry and inspection.

(Krug, 2014) described two types of usability tests. First is expert review usability test which involves usability experts in evaluating the system or site. Second is the usability test which involves actual users in the field. Expert usability test is very expensive and it reveals less errors compared to usability test.

Furthermore, (Rubin *et al.*, 2008) detailed described two main approaches of formal usability test and a less formal test. Formal usability test which aim at proving a requirement under experiment. The second method involves iterative tests which expose usability faults and then corrected and the system being ready for another iterative test.

Based on time and costs criteria, pesticides verification system's usability testing proposed in two phases as described in the test model in Fig. 15.

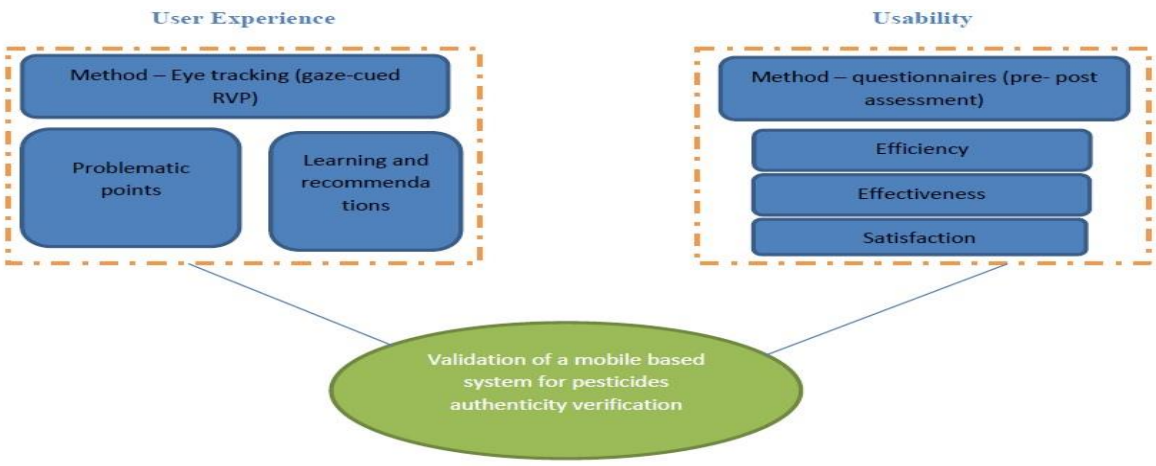

Figure 15: Test Model for PAVS

Source: (Amended from Moebs, 2011)

Two phases of the validation of the system are the preliminary test and final testing phases. The recommendations and observed problems from preliminary test have been used as building blocks for improvement of the system before the final testing. Guide to number of participants

involved in the testing was from, Norman's group which suggests selection of minimum of 5 participants from each group of stakeholders for validation testing (Nielsen, 2012). This number is enough to catch more errors. Increasing number of participants above five is not guarantee to more errors. There are two target user groups of pesticides authenticity verification system, which are staffs from Tropical Pesticides Research Institute and farmers. Therefore, each of the test phases contained a total of ten participants, five from each group.

From the test model, the usability test on a mobile application part of the system involved actual users in the fields. Methods of questionnaires both pre and post assessment were used. The following qualities were tested; efficiency, effectiveness and satisfaction. A complete test plan for usability test Appendix 13.

Then is user experience test on web application part of the system; which was tested using eye tracking at TPRI offices in Ngaramtoni Arusha and Dar es Salaam regional office. Evaluation has been done using gaze-cued Retrospective Verbal Protocol which is a better method as it produces more words, comments and reveals usability problems after the user has completed the test (Bojko and Krug, 2013). Test plan for TPRI inspectors Appendix 14.

3.10.1 Preliminary Test

(i) Introduction

The preliminary test of the mobile and web applications for pesticides authenticity verification involved two user groups. The first group was a total of five staffs from Tropical Pesticides Research Institute (TPRI) head office in Ngaramtoni, Arusha and Dar es Salaam regional office. They were tested with both mobile and web applications. The second group involved five mixed age group farmers with pesticides buying experience. They are from ward of Kikwe in Arumeru district in Arusha region. They were tested only with the mobile application.

The mobile application was installed in a smartphone which runs android 8.0, and the web application launched in Firefox 59.0.1 running locally.

The results show that the tool is usable as the usability scale exceeds 68 for both groups despite minor changes proposed by participants to be worked on for improvement so as to increase usability and user experience of the tool to its intended stakeholders.

(ii) Methodology

In order to measure usability of the developed mobile and web applications, questionnaires method (both pre and post) were prepared to be answered before and after the test respectively. The main goal for this preliminary test was to discover problematic points through observation, on the other hand gather user comments, make recommendations and prioritize them accordingly.

Session for each participant starts with answering the pre-test questionnaire. After the pre-test, user is supposed to perform a test. Where the following are the tasks that user is supposed to perform and the benchmarked time.

For the mobile application, a participant is expected to request authenticity of the product by providing the batch number then get a response on the status of the product within 4 minutes. Report a complaint by taking a picture of the product, then provide batch number, TPRI registration number, name of the place where the product was bought and the complains and get a reply on the successful delivery within 5minutes. Participant expected to understand safety measures provided in the image slider within 4 minutes.

For the web, it is expected that participant would be able to understand what the application is all about and how to get started in 2 minutes. Registration and login should take 4 minutes. Login and be able to add, edit and delete details of permitted pesticides within 10 minutes. Similarly the participant should be able to navigate and view lists of authenticity requests and the reported complaints within 4 minutes.

After mobile and web testing the participant should answer the post-test questionnaire.

3.11 Conclusion

This chapter provides answers to three research questions listed in Chapter 1, section 1.4.

The system and user requirements described in section 3.5, provides answers to the first research question: *"What are the requirements for the development of a mobile and web based systems for verifying the authenticity of pesticides in the market?"*

Furthermore design presented in section 3.8, delivers answers to the second research question: *"What are the building blocks of the design and coding of a mobile application, a database and a web portal for managing verification of pesticides authenticity?"*

Finally section 3.10 offers answers to the third research question on the chosen validation techniques. The research question: *"What technique(s) can be used to validate the developed mobile and web based systems for verifying authenticity of pesticides in the market?"*

The material and methods presented in this chapter arrange for results of data collection, developed system and the two system testing phases presented in chapter 4.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

In the previous chapter various materials and methods used in design and development of the proposed system for pesticides authenticity verification has been presented clearly. Which included; understanding the study area, mapping of the stakeholders, data collection methods, sample size and sampling technique, characteristics of requirements, system requirements, requirements specification, system design, system validation approach, system dependencies, conceptual modelling of the system and conclusion.

This chapter presents results and discussion from data collection and system validation. It also includes conclusion made on each of the results collected and the general conclusion to the chapter. Thereafter, the chapter presents some screenshots of main functionalities of the mobile and web applications. Furthermore, the chapter offers results of the two phases of system testing.

4.2 Research Study Area Results and Discussion

4.2.1 Tropical Pesticides Research Institute (TPRI) Interview Results

Interview done with officers at the TPRI used as a means of knowing generally the regulatory authority's functions in regard to pesticides management, pesticides quality control and how often it is done also the procedures. Also, if there is any electronic system used in sharing of information with registrants/formulators/importers, also electronic system for management of pesticides products, inspection process and challenges.

The Tropical Pesticides Regulatory Authority (TPRI) in regard to pesticides management is concerned with registration of pesticides products, registrants/formulators/importers and registration of pesticides retailers. It is concerned with regular quality control of pesticides products which are imported or formulated to be used in the country. Also the authority is responsible for inspection of the products once in the market, making sure that they are registered and of the acceptable quality.

Nevertheless TPRI is responsible for inspection on regulations abidance by the registrants/formulators/importers and the sellers of pesticides. Toxicity of pesticides raises the

need of raising public awareness on how to handle them also the wastes after use of the products. The diagram below in Fig. 16 explains pesticides risk reduction measures.

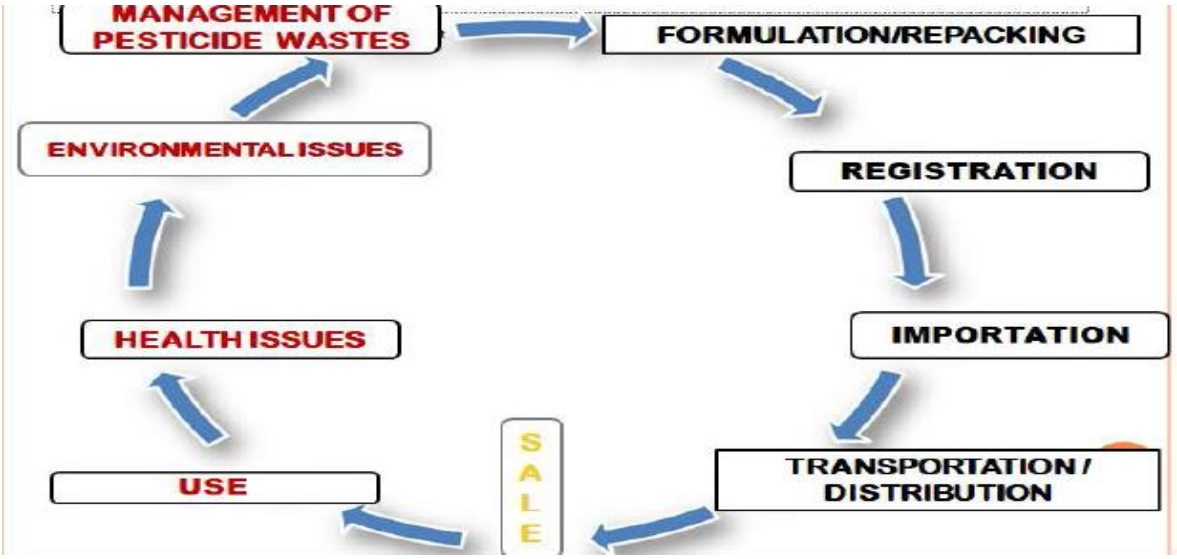

Figure 16: Pesticides life cycle

Source: (Registrar of Pesticides – TPRI)

For the entire cycle to function as required and reduce the risk that might be caused by pesticides use, the pesticides law sets out some requirements for the balance of the cycle. These laws require; only registered pesticides to be used in the country. Also, before and after registration different permits has to be issued for the imported pesticides to be legally sold. Certification of pesticides business (sellers, pest controllers, pesticides importers and formulators) has to be ensured. Not only that, but also ensuring health of pesticides users and environmental safety.

Eventually, pesticides registration requirements involve; application for pesticides registration and submission of pesticides dossier. It is the document which contains technical information about the product; material safety data sheet, toxicological data, environmental studies and the analytical method of the formulated products. To ensure that the product works as declared in the technical dossier, bio efficacy is carried out to validate. It is carried out for three cropping seasons. The bio efficacy report is issued based on the performance of the product in the field and the technical dossier. There are committees which are concerned with approval of the reports. These committees are; Pesticides Approval and Registration Technical Sub-Committee and National Plant Protection and Advisory Committee.

When the product is approved, the registrant is informed and before importation of pesticides products, requests are submitted to TPRI.

The authority strictly checks whether the requested products are registered and the requester is the registrant of that particular product, upon satisfaction permit is issued. For every batch of the pesticides products imported, samples are taken and certificate of analysis is issued for products which meets quality. Basically, TPRI identifies products by batch numbers. This is due to the fact that, in case the particular product has been identified to not being working as expected then all of the products in that batch has to be written off from the market.

Despite, the efforts and procedures to ensure that the products are of the expected quality, still during inspection products which are not registered or with trademark infringed are found in the market. Inspectors use printed lists of products registered to refer to. This raise the need of the regulatory authority to go further in checking if for those registered products have been issued import permit and the certificate of analysis, if not they constrained to be sold.

Among the initiatives done by TPRI to reduce counterfeits in the market includes educating shops sellers. This started early 2005 and up to 2017 about 2000 sellers have been educated (as stipulated by the registrar of pesticides during the interview). The knowledge is based on how they could identify counterfeits by understanding labels of particular product. It has been of help in reducing counterfeits but still there are sellers who haven't been complied. They take advantage of farmers not having the knowledge they (sellers) have and sell counterfeits.

Among the challenges faced by the inspection team is the scarcity of resources especially money to reach more areas. Also, all of the regulatory authority's functions are conducted in paper based mode. This makes it difficult in organization of the required information at real time.

Although, through a mobile based system for pesticides products authenticity verification, provides an effective use of scarce resources by going to the target areas which the counterfeits have been indicated by the system. Also eliminating the need of inspectors using papers as reference during inspection as all of the details concerning the products are available through a mobile based system. The mobile based system for pesticides products authenticity verification only save the scarce resources but also nourish the businesses of the genuine products. It as well promises increase of government revenues through TPRI, preserve

environment and reduce the negative impacts they cause to the health people who use the counterfeited products.

4.2.2 Pesticides Registrants/Formulators/Importers Interview Results

These are the registered agents for importing, formulating and even distributing and retail selling of particular pesticides products in Tanzania. Interviews was done with six companies namely; Bajuta International Ltd, Meru Agro-Tours and Consultants Co. Ltd, OSHO Chemical Industries Ltd, Balton Tanzania Ltd, Triachem Tanzania Ltd which are registrants and importers. Also, with Ultravetis East Africa- Kenya Ltd which are the formulator of pesticides. Their means of storing information, actions which have been taking so far in combating counterfeits were required. Also, those staffs views on development of a mobile based system to combat counterfeits by pesticides users.

From the findings, 4 among 6 interviewed companies do not have electronic systems to store details of products. The whole procedure of importation and/or formulation to distribution is done on paper based. The situation is similar even for those possessing the electronic information management systems. Exchanges information with TPRI is done in paper based.

Correspondingly these companies declared to have been receiving reports of counterfeits from their sales representatives around regions and have been reporting to authorities about the problems. Respondents seconded the idea of a mobile based system for pesticides products verification. Quote from one of the respondents "*That idea shall work, just make sure that the displaying results to the users are more detailed for user to be able of distinguishing counterfeited from genuine*".

4.2.3 Pesticides Users Questionnaire Results

A quantitative approach by the use of questionnaire used to collect information from agricultural pesticides users' awareness on counterfeits pesticides. The questionnaire also gathers information on their current practice in pesticides authentication. The selected region was Arusha, since it's among the leading regions in agriculture in the country. Participants from Arumeru district which is the leading district in Arusha region for use of pesticides especially insecticides and fungicides were involved (Appendix 3 and 4) (The United Republic of Tanzania, 2012).

The data collection involved the wards of Akheri, Kikwe and Nkoanrua in Arumeru district, geopoint were collected during each response which assisted in mapping of the area of study (Appendix 5 and 6). A total of 170 responses were collected using questionnaires prepared in Open Data Kit (ODK). The ODK has been used since it is a mobile, faster and reliable means of collecting needed information from target audience (Hartung *et al.*, 2010). Four categories of pesticides selected which are; insecticides, fungicides, herbicides and acaricides. Insecticides are pesticides used in control of insect pests on horticultural crops, control of alphids, thrips on roses and French beans. Fungicides are pesticides used in control of fungal diseases on horticultural crops, cabbage webworms also control of late blight on tomatoes. Herbicides are pesticides used in control of broadleaved weeds in banana, weeds control under minimum tillage in rice, also in horticultural crops. Acaricides are pesticides used in control of cattle ticks and tsetseflies also ectoparasites. The following are the findings as analyzed from the responses collected.

(i) Respondents Demographic Characteristics

Adults male and females with pesticides buying experience were involved. Percentage female respondents involved, as shown in Fig. 17 is 12.94% from Akheri, 2.94% from Kikwe and 11.76% from Nkoanrua. The percentage of male respondents is, 20.00% from Akheri, 12.94% from Kikwe and 39.41% from Nkoanrua. Also, the percentage of respondents who knows how to read and write, 32.35% from Akheri, 2.35% from Kikwe and 51.18% from Nkoanrua, for those who don't know how to read and write, 0.59% from Akheri, 13.53% from Kikwe and none from Nkoanrua.

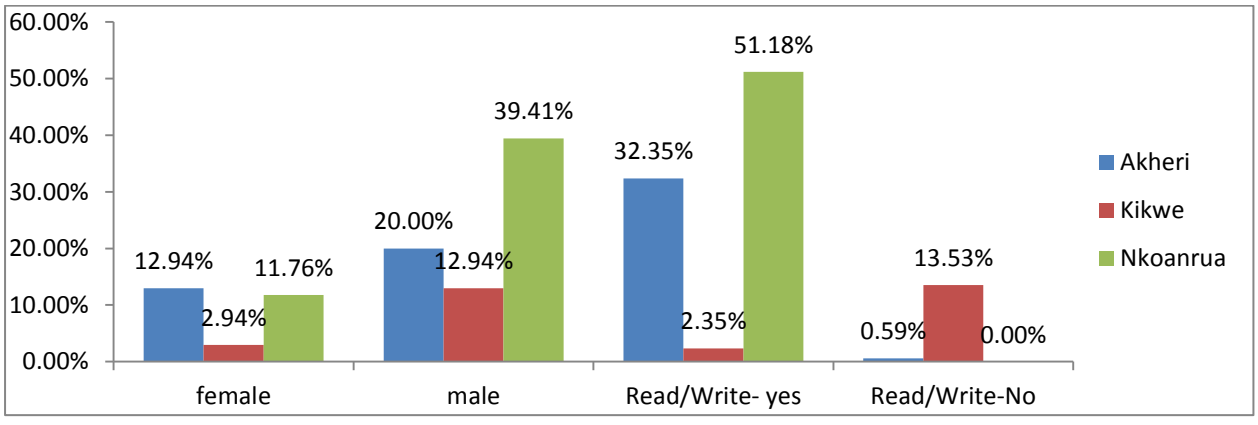

Figure 17: Demographic Characteristics of participants

(ii) Categories of Pesticides

In order to know which category of pesticides mostly used by farmers of Arumeru, four selected categories were used. From the percentage ratio of the respondents, insecticides indicated to be the most used contains 81.18%, followed by acaricides, herbicides and fungicides as shown in Fig. 18, below.

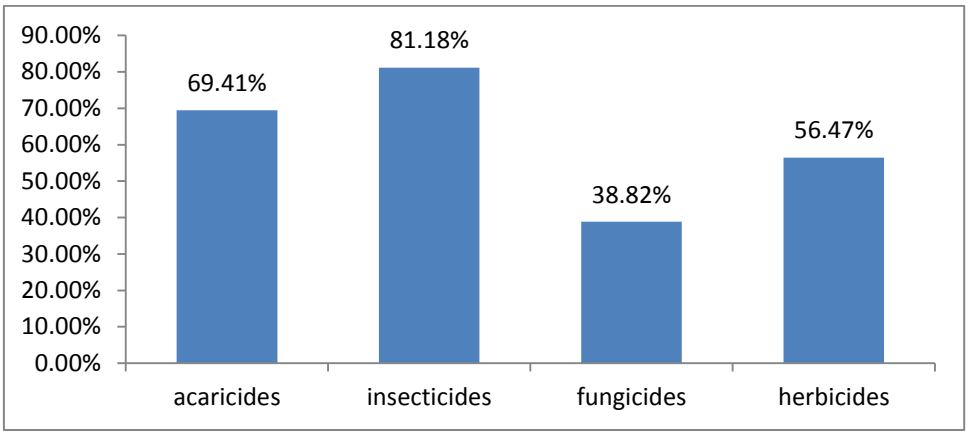

Figure 18: Categories of pesticides mostly used

(iii) Counterfeit Pesticides Awareness

Information about awareness of counterfeits pesticides was collected. The findings show that 85.88% of respondents are aware as shown in Fig.19. Where the leading source of information being 'other sources' by 64% followed by television, radio, newspapers and social media as shown in Fig. 20. These other sources were mentioned as; hearing from colleagues and personal experience of buying and/or using counterfeits pesticides.

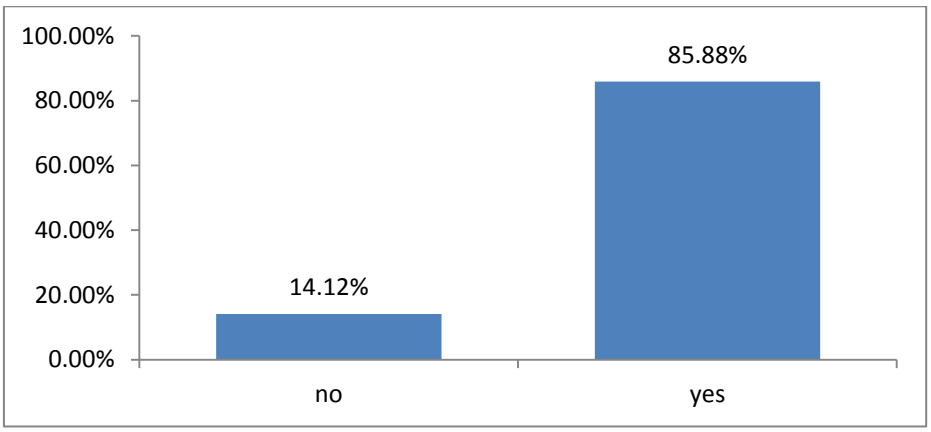

Figure 19: Awareness on counterfeits pesticides

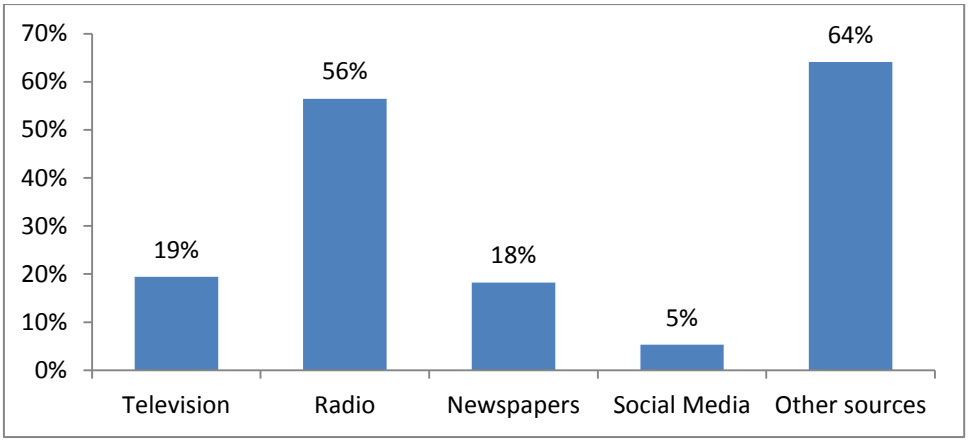

Figure 20: Sources of information on counterfeits pesticides

(iv) Magnitude of Counterfeit Pesticides

Despite high awareness on counterfeits pesticides as shown above, still findings as analyzed in Fig. 21, shows that 73.28% of respondents bought counterfeits pesticides and didn't report the incidents. Those who bought and reported are only; 26.72% respondents. Among the mentioned reasons of not reporting is not knowing the proper channel to follow, and for those reported where they bought were blamed by sellers not being following the usage instructions properly.

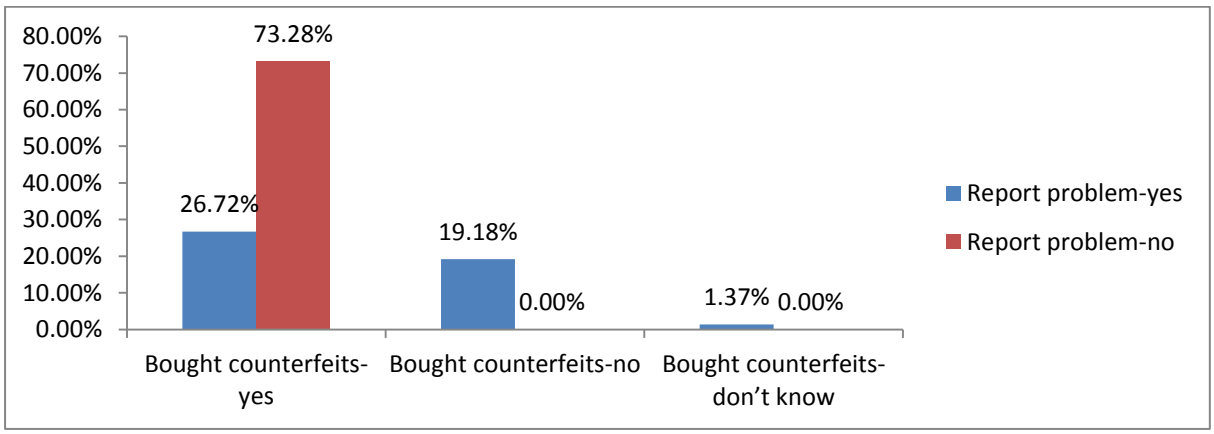

Figure 21: Buying and report counterfeits pesticides

(v) Authenticity Verification Method in Use

Given the large incidents of buying and/or using counterfeits pesticides despite high awareness, the interest of knowing the methods which respondent uses verifying authenticity of pesticides emerged. Where from the analyzed findings as shown in Fig. 22; expiry date leads by 91%,

followed by those checking brand, types ingredients and lastly for those who checks nothing just trust what the sellers suggests.

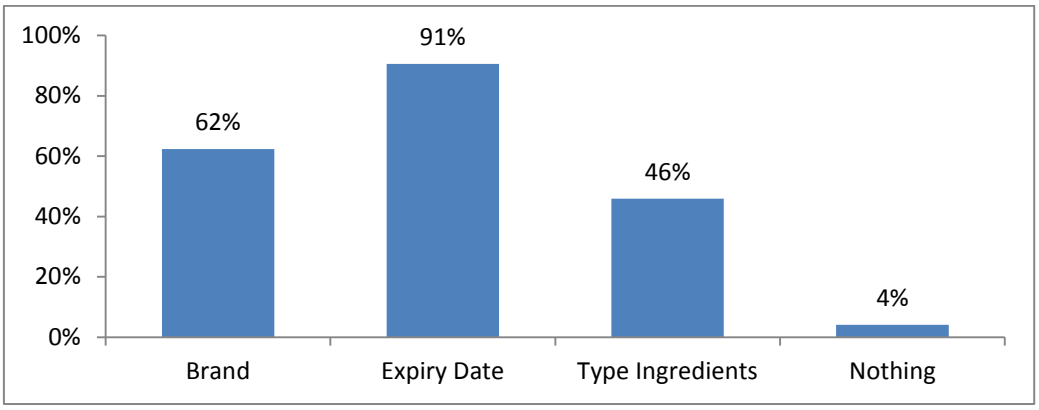

Figure 22: Pesticides authenticity verification methods in use

(vi) Possession of Mobile Phones per Type

As this study targets on a mobile based system, respondent's mobile phones possession per type was necessary as shown in Fig. 23. Where the possession of mobile phones among respondents was high; 95.29% and 75.93% possess featured phones and 24.07% possess smartphones. Those possess smartphones declared to be using them in getting information about farming through browsing, farming forums and social media.

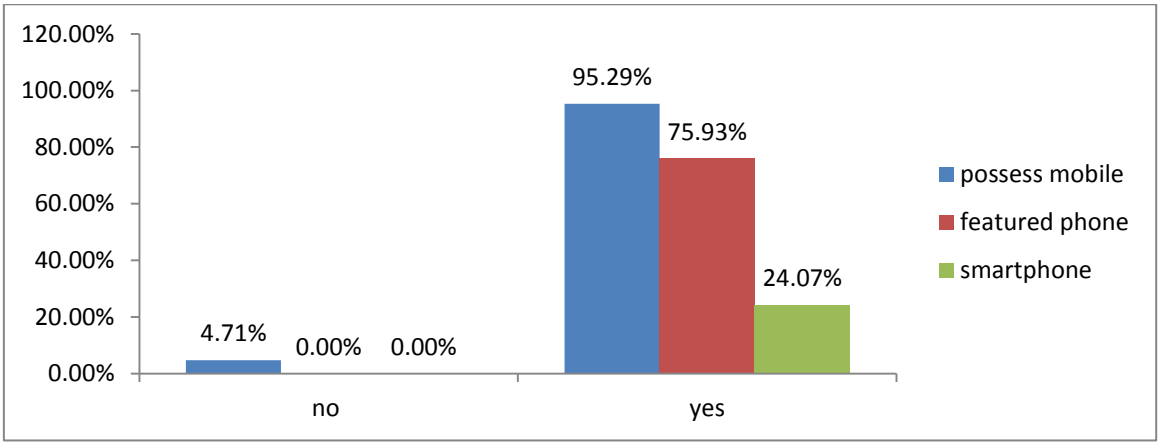

Figure 23: Possession of mobile phones per type

(vii) Heard of Counterfeits and Mobile Phone Possession

Correlation analyzed between hearing of counterfeits and mobile phone possession. Figure 24 shows that respondents who have heard of counterfeits and possess mobile phones were 82.94% despite which type of mobile they possess.

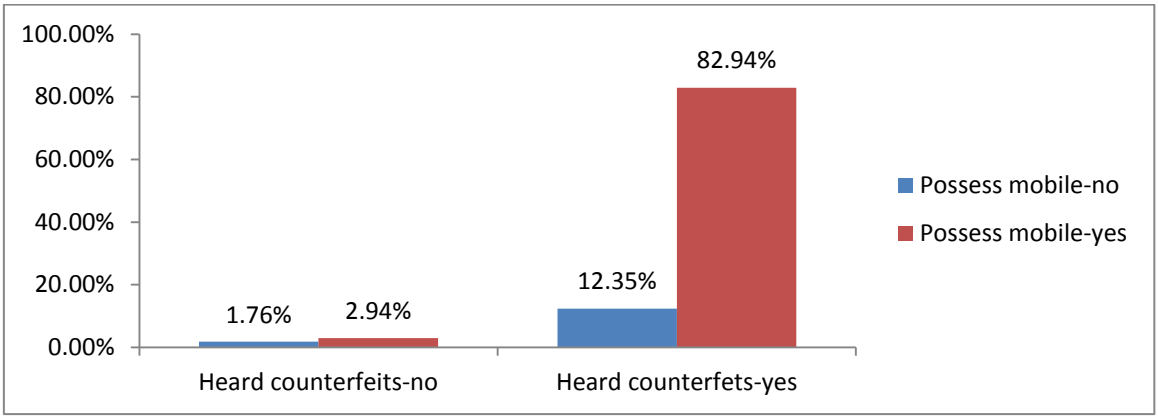

Figure 24: Awareness of counterfeits and mobile phone possession

(viii) Mobile Phone for Pesticides Authentication during Purchase

Target of the study was shared among respondents on the use of mobile phone in verifying authenticity of pesticides during purchase; respondent's opinions were collected concerning the matter. From the responses as shown in Fig. 25, more than 70% of respondents seconded the idea.

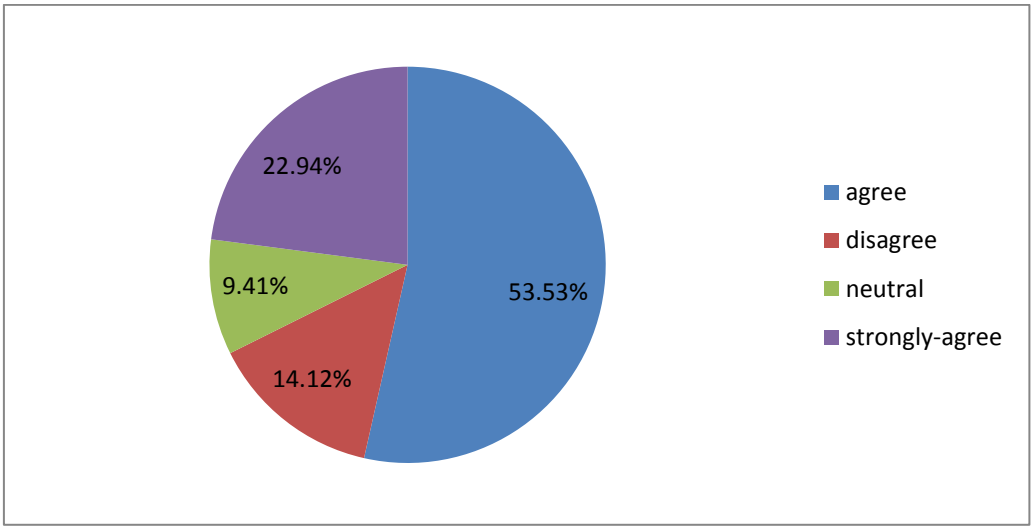

Figure 25: Views on a mobile based system for PAVS

4.2.4 Research Study Area Conclusion

Based on the findings which have been analyzed both qualitatively and quantitatively the following conclusion is made. That, despite high awareness of counterfeits pesticides by pesticides users, still high percentage of respondents declared being victims of buying counterfeits pesticides. So, there is a huge need of a more reliable method of authenticating pesticides in the market.

For the side of the regulatory authority, there is no any existing system which stores information of authentic products. Not only that, but also pesticides inspectors are still facing challenge of locating counterfeits in regions. They only rely on experience and printed copy to verify products authenticity in the markets during the inspection process.

Obviously, through web part of the mobile based system for pesticides products authenticity verification, serves in effective use of scarce resources by going to the target areas which the counterfeits have been captured from the requests from pesticides users to the system. Also eliminating the need for inspectors using papers as reference during inspection where the mobile application can be used in checking product authenticity. Where all of the details concerning authentic pesticides, products can be accessed from the database through a mobile application. This mobile based system for pesticides products verification will not only save the scarce resources. But also nourish the businesses of the genuine products, increase government revenues through the regulatory authority, preserve environment and reduce the negative impacts they cause to the health of people who use counterfeited products.

4.3 PAVS Main Functionalities

Based on the requirements defined in chapter 3, section 3.5 and the design in section 3.8, the system for verifying authenticity of pesticides in the market named Pesticides Authenticity Verification System (PAVS) was developed. It contains two main parts the mobile and web applications. This section shall explain main functionalities provided by the PAVS to its intended users.

4.3.1 Mobile Application Part of PAVS

The developed mobile application part of PAVS provides the following services; pesticides authenticity verification, complaints reporting for products which haven’t worked as expected

and safety measures tips in using pesticides products. All functionalities of mobile application are written in Swahili for better understanding and usage of the application by the pesticides users.

For requesting authenticity of the pesticides product to be bought user selects the ‘Uliza Ubora’ button in the home page shown in Fig. 26 then the page which is Fig. 27 opens, which requires user to input TPRI registration number of the product and the batch number. When user clicks ‘Bofya kuuliza ubora’ then the dialog confirming the status of the product opens. If the product is authentic the dialog that contains information of the requested pesticide opens Fig. 28, for user to match with the real product he/she is about to buy. But if the product is not in authentic database, the alarm message as shown in Fig. 29 opens; that the product is not authentic.

Reporting complaint for products which haven’t worked as expected, user has to click ‘Ripoti tatizo’ button in the main page, then the page for user to fill in the details concerning the product to be reported opens as in Fig. 30. Where user has to take a picture of the product, then fill in the batch number, TPRI registration number, a place where the product was bought and the problem raised and then user clicks ‘Bofya kutuma taarifa’ and the reply dialog appears if the complaint received successfully, if not the toast (flash message) that requests user to try again appears. The failure may usually be caused by the problem in internet connection, which causes communication cut-off.

Figure 26: Main page

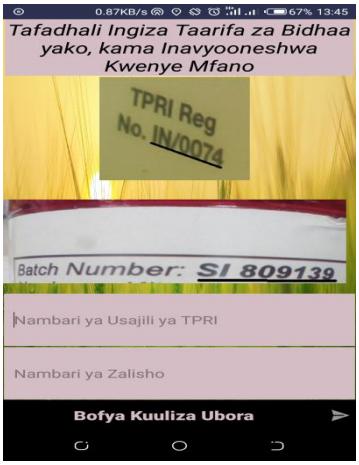

Figure 27: Authenticity request page

Figure 28: Positive reply dialog

Figure 29: Negative reply dialog

Figure 30: Complaint reporting

Figure 31: Safety measures

4.3.2 Web Application Part of PAVS

The developed web application part of the PAVS receives then records the information and requests from the mobile application. It allows registered users to register and/or login, manage information concerning authentic pesticides and views and prints authenticity requests and map showing the location of the requests. Also registered user can view and print reported complaints.

Figure 32 below is the index page of the PAVS, where new user to the system can register by clicking on the register link or login if already user.

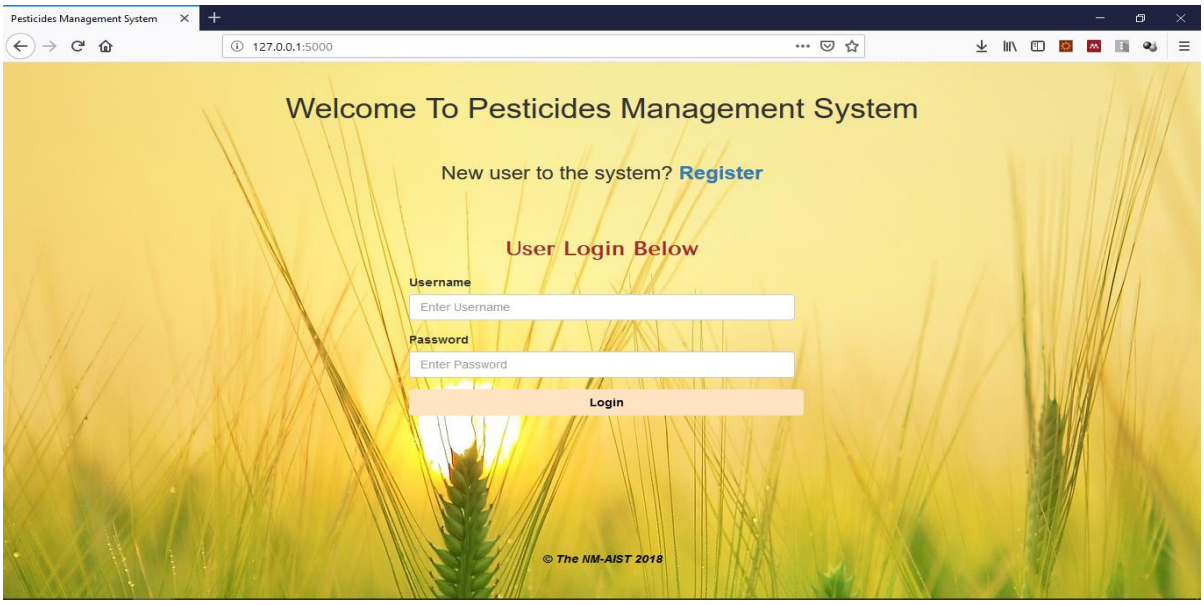

Figure 32: Index page of the PAVS

Figure 33 below shows the page which allows registered user to add, edit, delete, search and print information concerning any authentic pesticides that user would like. The system allows user to copy files to clipboard, print directly from the system, transfer files to excel or pdf for authentic pesticides information stored in the system.

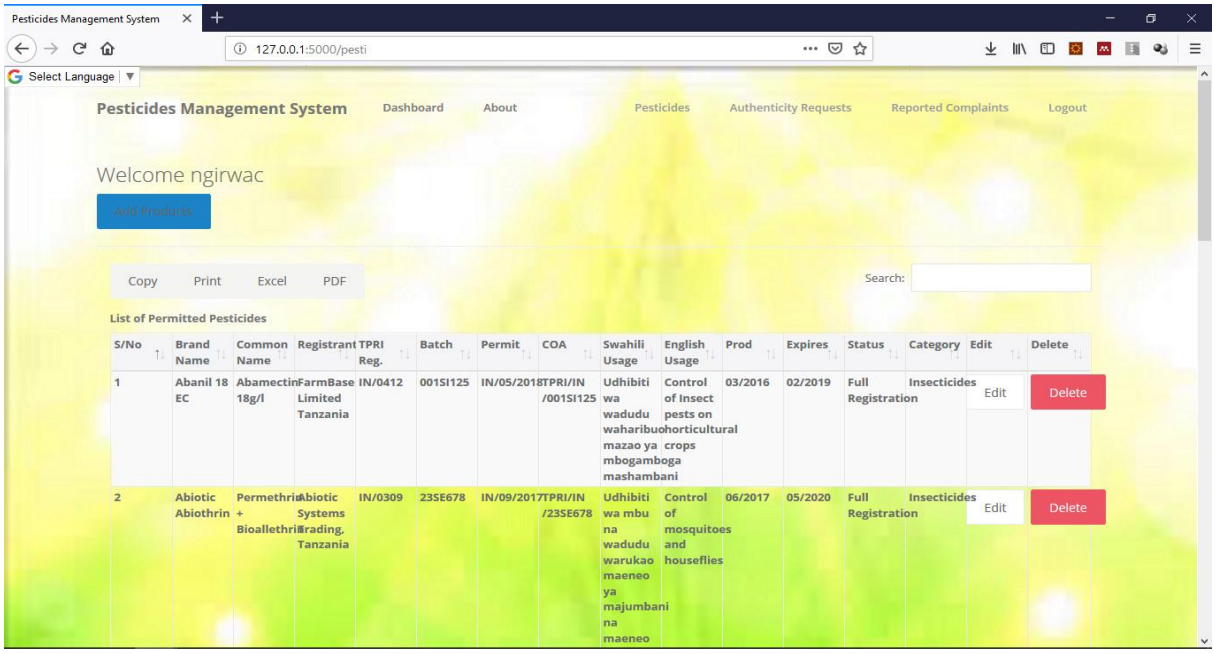

Figure 33: Authentic pesticides information

Figure 34 below, shows authenticity requests from the mobile application, where for each of the request the system stores coordinates which are later plotted to make a map. The registered user can as well copy, print authenticity requests report and download the report in either excel or pdf format for office use. When the requested product is not in the authentic database, its value of found is ‘0’ if it is the value is ‘1’. These values were then used to draw maps.

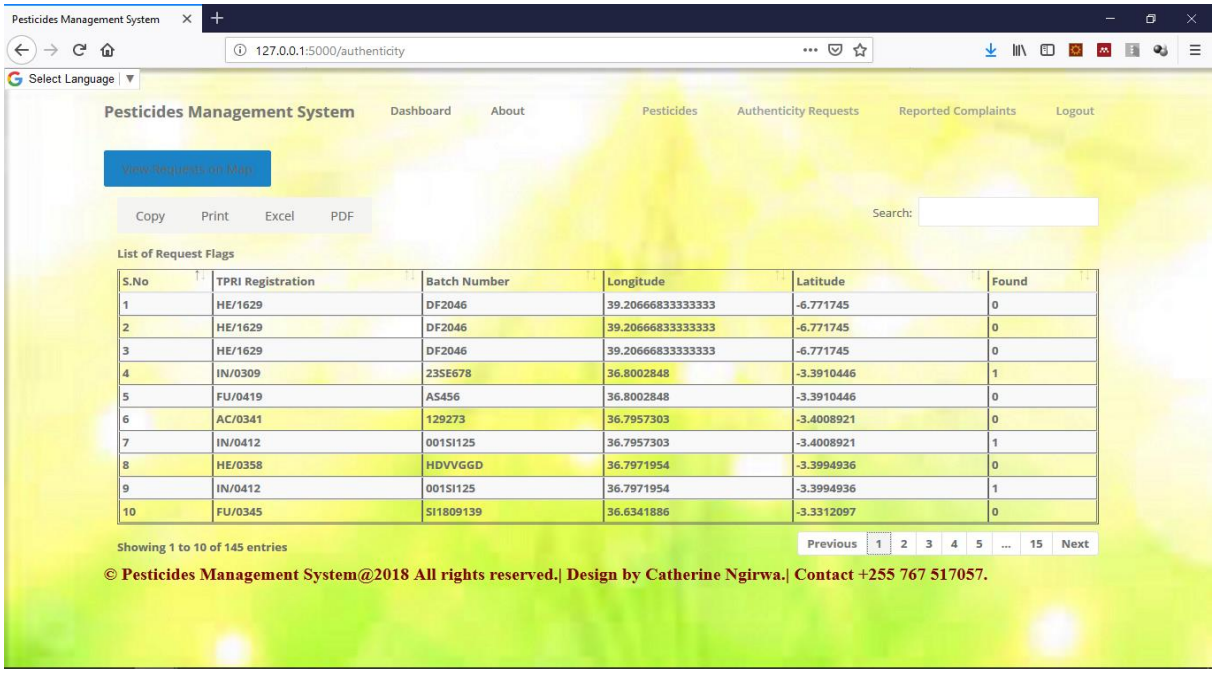

Figure 34: Authenticity requests from mobile application

Figure 35 below shows the map drawn from the authenticity request. Where the red markers are the requests with found ‘0’ (means the requested information aren’t in the database). This map aimed at assisting the pesticides regulatory authority to know threat areas for inspection purposes.

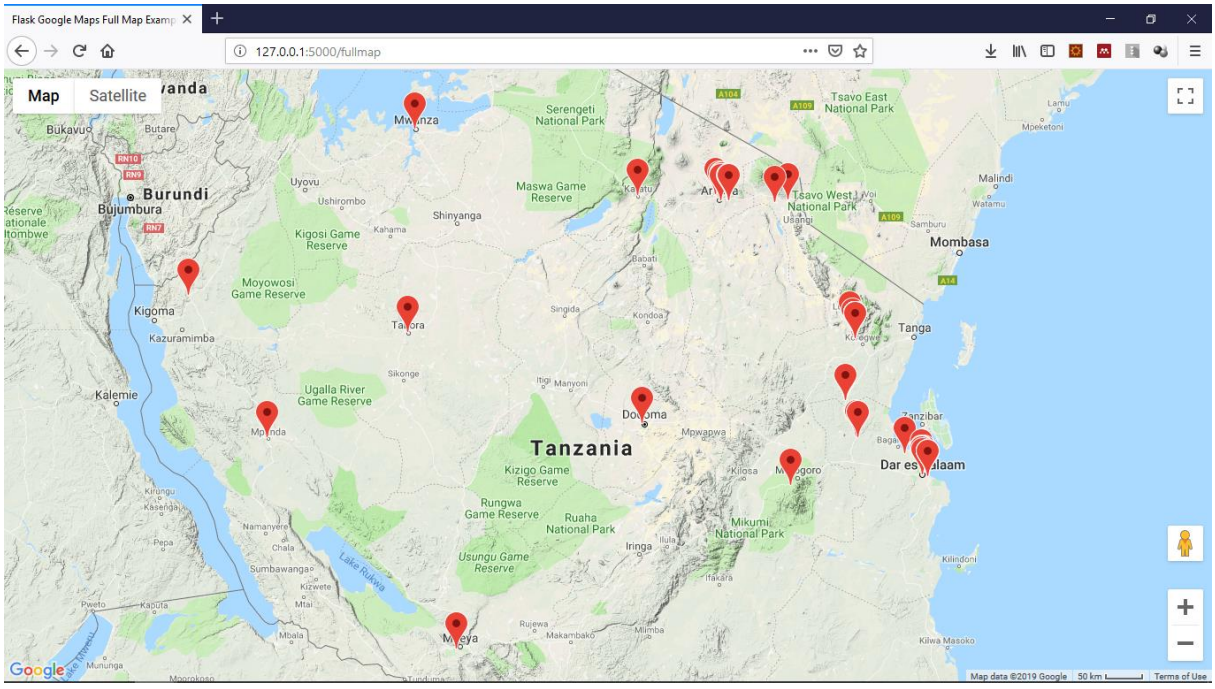

Figure 35: Map showing location of non-authentic pesticides

The reported complaints are as well recorded for the regulatory authority to act on them as shown in Fig. 36 below.

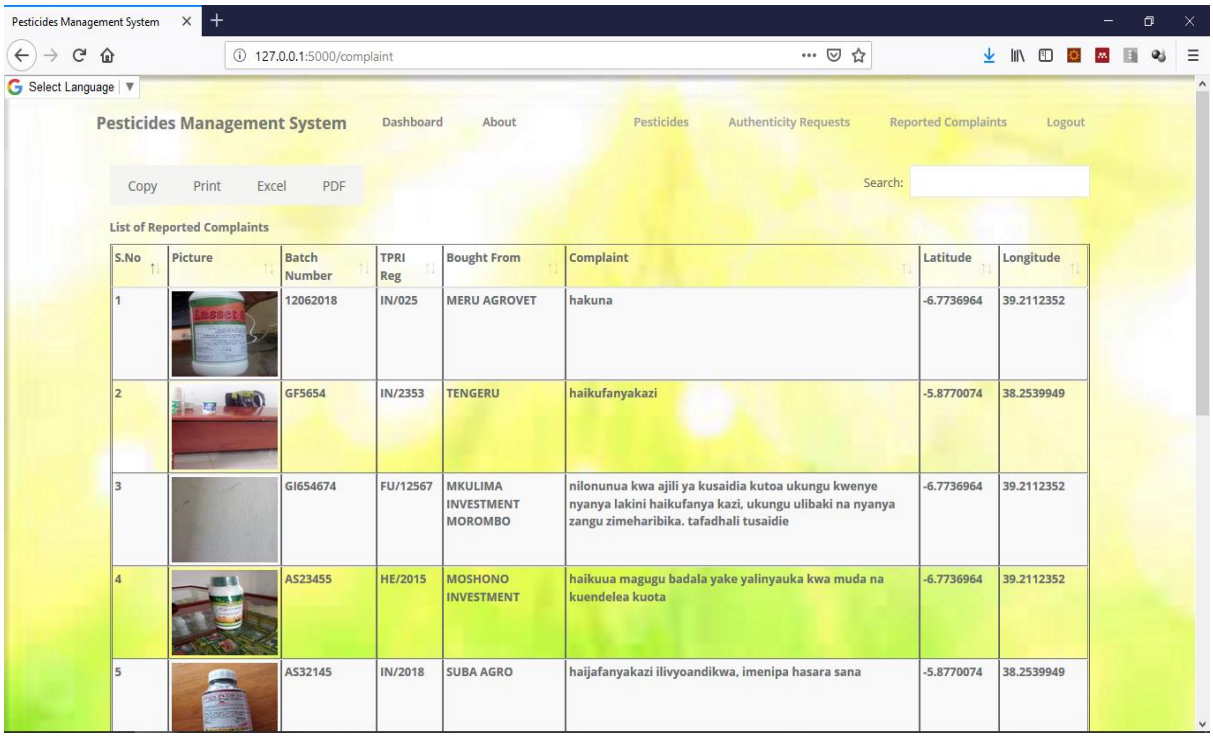

Figure 36: Complaints report

4.4 System Preliminary Test Results and Discussion

This section starts by describing the preliminary test participants groups. It then gives the findings obtained from the pre-test questionnaires to both groups. Furthermore the section presents results of actual testing and user comments gathered during the testing sessions as captured by the test moderator. Additionally it gives analysis obtained from the standard System Usability Scale (SUS) and the average SUS score for both groups. Finally, the section offers observations and recommendation for the next testing session.

4.4.1 Short Description of the Preliminary Test Participants

The preliminary test of the Pesticides Authenticity Verification System (PAVS) contains two main groups of participants. These groups are five staffs from TPRI and five farmers.

(i) Description of the Preliminary Test Participants-TPRI Staffs

The first group of participants was the TPRI staffs who are in one or another way dealing with pesticides quality control, health risks analysis and pesticides inspection.

First participant was the pesticides inspector with experience of more than 20 years in the field having a background in chemistry and laboratory technology. The participant showed interest, got overwhelmed when heard of the ICT tool to help them in managing their work, yet very inexperienced and reluctant in using it.

Second participant was the pesticides inspector with 23 years' experience in pesticides inspection and quality control, having a strong background in chemistry. The participant showed interest in the technology and ready to learn using it. Also seemed lack of experience in using work related information systems.

Third participant was the laboratory technologist with a strong background in chemistry and working experience of 6 years in laboratory efficiency testing of pesticides products and preparation of the testing analysis reports. The participant looked overwhelmed and very interested in using the tool.

Forth participant was the pesticides health impact analyst with strong background in biology and 3 years working experience in the field on analyzing pesticides health impact to the users also educating them on proper usage and handling of pesticides products. The participant seemed ready to learn.

Fifth participant was the pesticides inspector with 17 years working experience in the field with strong background in chemistry. The participant was very interested in using the tool despite being inexperienced of work related information system.

(ii) Description of the Preliminary Test Participants-Farmers

The second group of the involved participants was five farmers. First participant was the farmer of age group of 45-54, with 15 years' experience in buying and using pesticides products also having basic primary education, capable of reading and writing Swahili. The participant was very interested in using the tool despite being inexperienced with using smartphone.

Second participant was the farmer of age group of 24-34, with 10 years' experience in buying and using pesticides products also having a bachelor's degree in Education majoring agricultural technology, capable of reading and writing English and Swahili. The participant has experience in using smartphone also interested and ready to use the tool.

Third participant was the farmer in age group of 35-44, with 15 years' experience in buying and using pesticides products also having basic primary education, capable of reading and writing Swahili. The participant has no experience in using smartphone though seemed ready to use the product.

Forth participant was the farmer in age group of 18-24, with 6 years' experience in buying and using pesticides products also having secondary education, capable of reading and writing Swahili and English. The participant has experience in using smartphone and looks ready to learn how to use the tool.

Fifth participant was the farmer in age group of 54-64, with more than 25 years' experience in buying and using pesticides products and having basic primary education, capable of reading and writing Swahili. The participant has no experience in using smartphone and reluctant to use though was ready to learn in using the tool.

4.4.2 Pre-Test Questionnaires Results

(i) Pre-Test Questionnaires Results - TPRI Staffs

All of the five participants understood 4 out of 5 terminologies requested which are; pesticides, registered pesticides, permitted pesticides and problems reported.

All of the five participants aren't satisfied with the current means of storing and managing information at the institute which is paper based with grounds that technology way of handling information increases accessibility also new model is needed.

Portable Digital Format (PDF) is commonly used document format by all of the five participants in their daily activities of managing electronic documents in their personal computers.

All of the five participants agreed that being able to capture arise problems and respond to community of pesticides users through the applications is more useful, with reasons that; it's a new application at the institute (as they don't have any information system which they are currently using in managing their activities), increase of awareness and easily capturing of information, easily making a follow up through reported complaints for products which haven't worked as expected and the unregistered pesticides products which are in the market

Finally shows that four out of five participants enjoy using high technology products if available in their offices

(ii) Pre-Test Questionnaires Results - Farmers

All of the five participants understood only one out of five words, which is; reporting complaint. Others like; pesticide, quality pesticides, Tropical Pesticides Research Institute (TPRI) and batch number weren't understandable to them.

Four out of five participants aren't satisfied by the means they are currently using in authenticating quality of pesticides products. While only two of the participants were familiar in using camera in their phones, others use SMS, manages calls.

All of the five participants strongly agreed that using mobile phone in authenticating quality of pesticides products will be great. On the other hand, four out of five participants strongly agreed that they are happy in using gadgets and high technology products.

4.4.3 Results of Actual Testing and User Comments

(i) Results of Actual Testing and User Comments -TPRI Staffs

The first participant, spent 3 minutes trying to understand what the application is all about and how to get started. It took the participant longer than the scheduled time in accomplishing the three tasks of mobile application, though was done correctly. For the web application, it took about 4 minutes for the participant trying to understand how to get started then did the wrong action by trying to login instead of registering first, minor redouble in filling the register form. But finally, all the tasks were performed successfully and within the expected time.

The second participant spent less time in performing the mobile application tasks. On contrary to the first, this participant was able to perform well in the mobile application. But as for the previous one, the register form was a challenge. The participant suggested combination of the batch and TPRI registration numbers in requesting authenticity of the products.

For the third participant, was able to spend less time in performing the entire mobile and web application tasks correctly.

Nothing new captured for the fourth and fifth participants, with exception to the suggestion of providing a room for users to provide their contacts when reporting complaints or requesting authenticity.

(ii) Results of Actual Testing and User Comments from Farmers

The terms like; batch number, TPRI registration number, pesticides and quality pesticides weren't familiar with the participants then moderator had to explain the terms clearly to each of the participants well before the mobile application testing sessions.

The first participant spent 7 minutes trying to understand what the application is all about and how to get started. Then the participant was able to perform all of the three tasks of the mobile application correctly though spent more time.

The second participant spent less time in each of the tasks and performed correctly. On the other hand, participant advised educating people in understanding the information provided in the pesticides products so as to be able to use the tool. As for them the mostly checked information is the expiry date.

No new feature observed for the third and fourth participants, but for the fifth participant assistance was needed in accomplishing the tasks.

4.4.4 Post-Test Questionnaires

The System Usability Scale (SUS) that contained 10 standard statements with 4 responses for both groups of participants was used. Analysis of questionnaires was done as by (Mclellan, Muddimer and Peres, 2012), and coded as shown in Table 9 and 10 which presents farmers and TPRI staffs respectively. The results for regulatory authority's staffs is 71.5 and for farmers is 73; where for both groups the scale is above the average (68), hence the pesticides authenticity verification system perceived usable to its intended stakeholders.

Table 9: Coding of the SUS questionnaires for farmers

Question	Participant				
	P1	**P2**	**P3**	**P4**	**P5**
Q1	3	4	4	4	3
Q2	3	1	2	1	1
Q3	2	4	4	4	4
Q4	3	1	1	1	2
Q5	3	4	4	4	3
Q6	2	2	2	1	1
Q7	4	3	3	4	3
Q8	1	3	1	1	4
Q9	2	3	4	4	4
Q10	4	1	2	2	1
SUS score	**=52.5**	**=80**	**=77.5**	**=85**	**=70**
Average SUS score is 73					

Table 10: Coding of the SUS questionnaires for TPRI staffs

	Participant				
Question	**P1**	**P2**	**P3**	**P4**	**P5**
Q1	3	4	4	4	3
Q2	2	1	2	1	2
Q3	3	4	4	3	3
Q4	3	2	1	1	2
Q5	3	4	4	4	3
Q6	2	2	1	2	1
Q7	2	3	4	3	4
Q8	2	2	1	1	2
Q9	2	3	4	3	4
Q10	1	2	1	2	4
SUS score	**=60**	**=72.5**	**=85**	**=75**	**=65**
Average SUS score is 71.5					

4.4.5 Observations during the Preliminary Test

General observation is that all of the participants seemed interested in using the applications despite minor struggle in filling the needed information in the register form but the reply to the requests were clearly understood by the participants. It was also observed that comfortability and experience with technology products affected their performance in terms of time taken to complete tasks, errors in selection and easiness in navigation through the mobile and web applications.

In the mobile application all of the participants spent time in understanding the main page before getting started with the three main tasks and the performance was impressive. For farmers a brief understanding of the terms was important so that to make sure they are able to use the tool.

For the web application only the first participant struggled in discovering how to get started and finding the link to register, but after some minutes the participant eventually managed to register. But all of the remaining four participants managed to identify the register link immediately though they struggled with navigating in the register form but they did make it at last and managed to complete all of the tasks correctly.

4.4.6 Recommendations

(i) Opting for more visible links or buttons. This can be corrected by bolding the links or make it blinking to capture users' attention. Other option can be to having buttons for both new and returning users for popups to open when clicked.

(ii) Use of drop down menus to reduce text entered especially in complaints reporting. This can serve also need for the participant who suggested health impact option to be added. Example in the effect of user filling the complaint there can be a dropdown menu for selection by the users instead of them writing there.

(iii) Combination of the batch number with the TPRI registration number in requesting authenticity of the product. This combination shall eventually reveal the exact product and not several which might happen that the batch number collides between products as it is usually decided at the company.

(iv) Adding of option for user to fill in the contacts when requesting and reporting complaint as suggested by the participant. Since, this study concentrates in pesticides products which have no required standard or permit to be in the market, rather than personal information. As for this considered to be of less attention for now.

(v) To get user's concentration to the page, reducing amount words is very important. For the index page reduce to make it not too wordy. Making user friendly forms, by making them easily scrollable and not too spread out also adding hints in some of the options. A thorough understanding and twisting on the CSS and bootstrap file can make the work done.

(vi) Educating farmers on the standard terms used in the tool, this shall help them in using the tool while at the same time understands the product information displayed after authenticity request.

4.5 Final Testing of PAVS

The recommendations from the preliminary test were implemented in the pesticides authenticity verification system. The final test involved the same participants of the preliminary test and the same test protocol in Appendix 13 and 14. Even the mobile application was installed in android 8.0 and the web application used a laptop which was installed 2007-2015 copyrighted Tobii technology AB and the eye tracker is Tobii X2-60 Compact.

The result of the pre-test questionnaires was no difference between the two test phases, even performance in the testing sessions. But much improvement for the rating in the post-test questionnaire, where for regulatory authority's staffs SUS score is 79.5 and 75 for farmers this indicates that users' satisfaction level to the system has increased as well.

Table 11: Coding of the SUS questionnaires for farmers

Question	**Participant**				
	P1	**P2**	**P3**	**P4**	**P5**
Q1	4	3	4	4	4
Q2	2	2	1	2	1
Q3	3	4	4	3	3
Q4	2	1	2	1	1
Q5	4	4	3	4	4
Q6	1	2	1	1	2
Q7	3	4	3	3	4
Q8	2	2	2	2	1
Q9	3	4	3	4	3
Q10	2	1	2	2	1
SUS score	**=70**	**=77.5**	**=72.5**	**=75**	**=80**
Average SUS score is 75					

Table 12: Coding of the SUS questionnaires for TPRI staffs

Question	Participant				
	P1	**P2**	**P3**	**P4**	**P5**
Q1	4	3	4	3	4
Q2	1	2	1	1	2
Q3	3	4	4	4	4
Q4	1	2	2	1	1
Q5	4	3	4	4	4
Q6	2	1	1	2	1
Q7	4	4	4	4	3
Q8	1	2	1	1	1
Q9	3	4	4	3	4
Q10	2	1	2	1	2
SUS score	**=77.5**	**=75**	**=82.5**	**=82.5**	**=80**
Average SUS score is 79.5					

The web part assessment of user performance with the eye tracker was good. Participants performed all other tasks on time, with exception of the initial task which requires participant to discover what the application is all about and how to get started. The average time spent for all five participants is 2 minutes 30 seconds which is 30 seconds more than the benchmarked time which is 2 minutes.

In clear evaluation of the GazePlots of the index page for the web application as shown in Fig. 37 below. It shows that three participants concentrated in the login form and the remaining two concentrated in other parts of the index page before discovering the register link and be able to start. This describes problem for participants to clearly discover the register link and be able to register to the system.

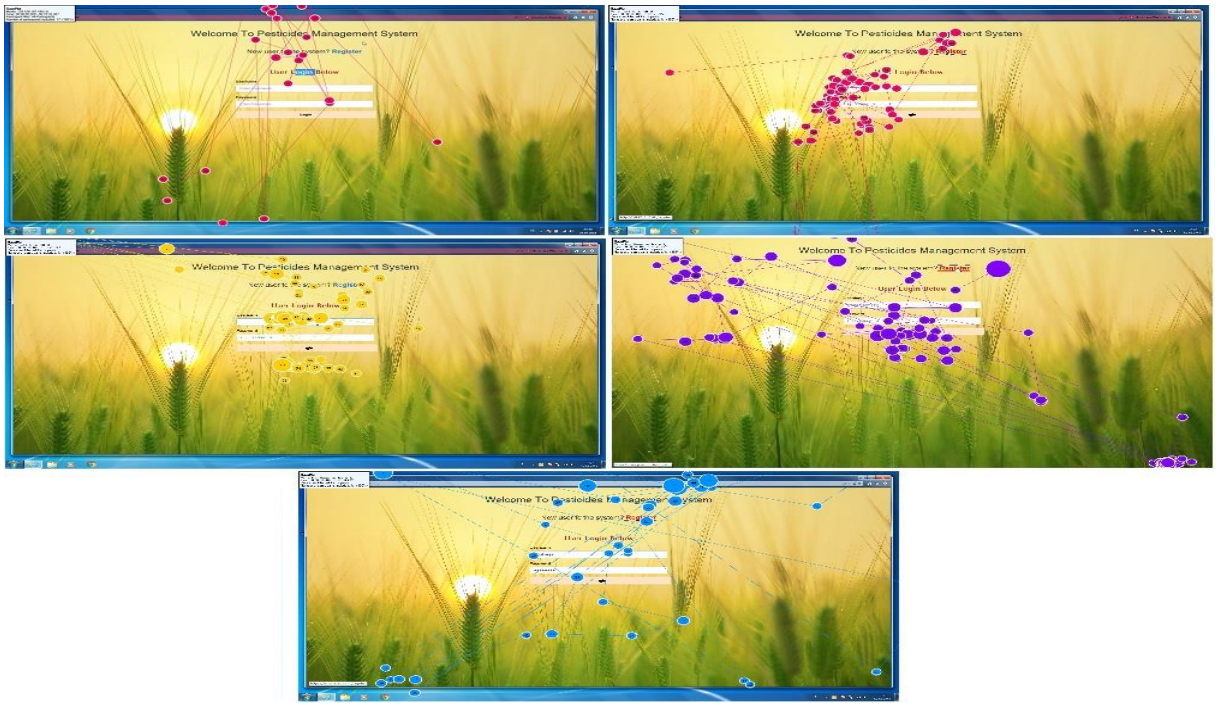

Figure 37: GazePlot snapshots for index pages for TPRI staffs

4.5.1 Gaze- Cued Retrospective Verbal Protocol (RVP)

All of the five participants of the web application were required to go through the recorded eye tracking test while verbalizing on what was going on their mind while doing the test. All of the participants' verbalization on what they were doing during the tests matched the eye movement data collected during the test. Quoting one of the participants verbalization "*The first thing I thought of when I set my eyes on the page was that the form there was for the new users, so I went directly and start thinking, what can I put in the credentials required to use the system. That's where I realized that wasn't the correct way for me*."

4.6 Conclusion

This chapter has successfully presented results from data collection in three groups of selected stakeholders as well as conclusion drawn from the findings. On the other hand the chapter presented results of the two phases of validation of the pesticides authenticity verification system and in both phases the system has proved positive results as the SUS score is above 68. Which means that target users have been satisfied by the services provided by the pesticides authenticity verification system provides.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion of the Study

Pesticides authenticity considered in this study is just one step to cleaning the pesticides market in Tanzania. The Tropical Pesticides Research Institute (TPRI) has been working in ensuring the market for authentic pesticides are nourished but having a backup of the developed pesticides authenticity verification system shall make their work a lot easier. As no need of guessing or planning inspection based on experience and records rather referring to the map and identify threat areas and work on the facts and not possibilities. On the other hand, the TPRI officers shall be able to solve customers' problems through the application and also manage information concerning authentic pesticides. For the inspection process no need of roaming around with printed papers for reference but just the mobile application part solves everything for them and their dear pesticides customers.

Therefore, the study presented here not only has helped solving the issue of authentic pesticides products, reporting of problems for products which haven't worked as expected and the pesticides use health tips. But the study has also helped in management of pesticides information. On the other hand, it has ease working on the reported complaints and locating counterfeits around Tanzania.

5.2 Recommendations

The study supports pesticides products authentication using mobile application. This means users with feature phones won't be able to enjoy the service. So as to make it viable we propose the Tanzanian government through TPRI to distribute smartphones to retail shops for users with no smartphones to use for products authentication during purchase.

For the mobile application; the reply message for authenticity check may contain image of the product for user to match with the real product which he/she is about to buy. In future, the study can still opt to work with the image processing for authenticity request functionality in the mobile application. But this will only be possible when there is restructuring of the labels, for batch and registration numbers to be closer (as for now no such requirement from TPRI to

suppliers/producers). The issue of image processing shall reduce the errors which can be made during entering of the information needed for authentication of the product.

An advance improvement in location access is as well proposed. Currently the captured location is saved by coordinates, which are then used to draw a map. TPRI staffs use the map to spot the threat areas. In forthcoming the study can be extended for the mobile application location to capture the name of the GSM tower.

In efforts to accommodate both mobile phone types, the study can be extended to include USSD codes so that even pesticides customers with featured phones could be able to enjoy the services provided currently by the mobile application. For location access functionality, there should be agreement with the telecommunication company to provide location service which is usually stored in their systems.

5.3 Research Contributions

This research has presented work which could be used with other researchers in products authenticity theoretically and practically.

For the mobile application it has been able to support pesticides authenticity check, complaints reporting and learning on the safety measures in using pesticides products. While on the other hand the mobile application could be used by inspectors to check products authenticity during the inspection processes. The web application contributes to pesticides information management, locating counterfeits in the market around Tanzania and also working on the reported complaints by pesticides users' allover Tanzania.

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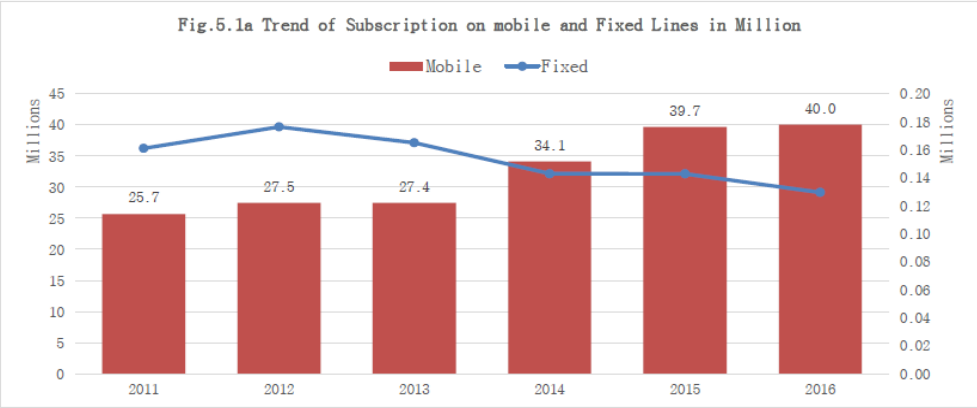
APPENDICES

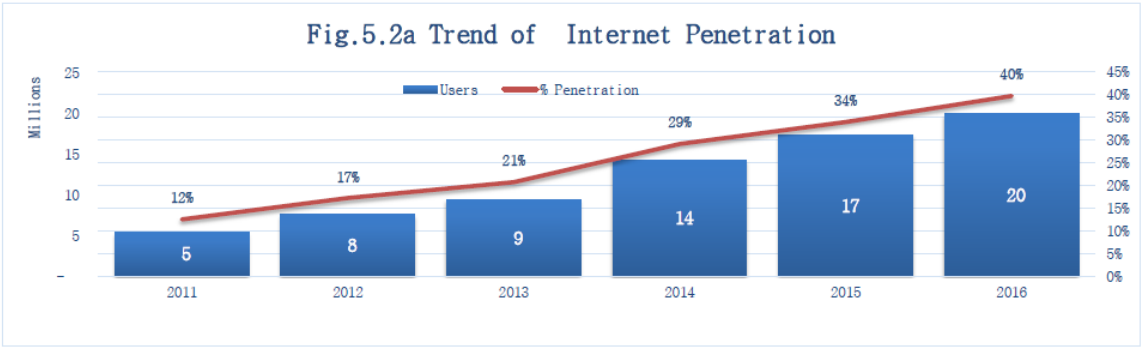
Appendix 1: Mobile Subscription and Tele density

Year	2011	2012	2013	2014	2015	2016
Fixed	161,063	176,367	164,999	142,950	142,819	129,597
Mobile	25,666,455	27,450,789	27,442,823	34,108,851	39,665,600	40,044,186
Total	25,827,518	27,627,156	27,607,822	34,251,801	39,808,419	40,173,783
Penetration	59%	61%	61%	71%	79%	80%

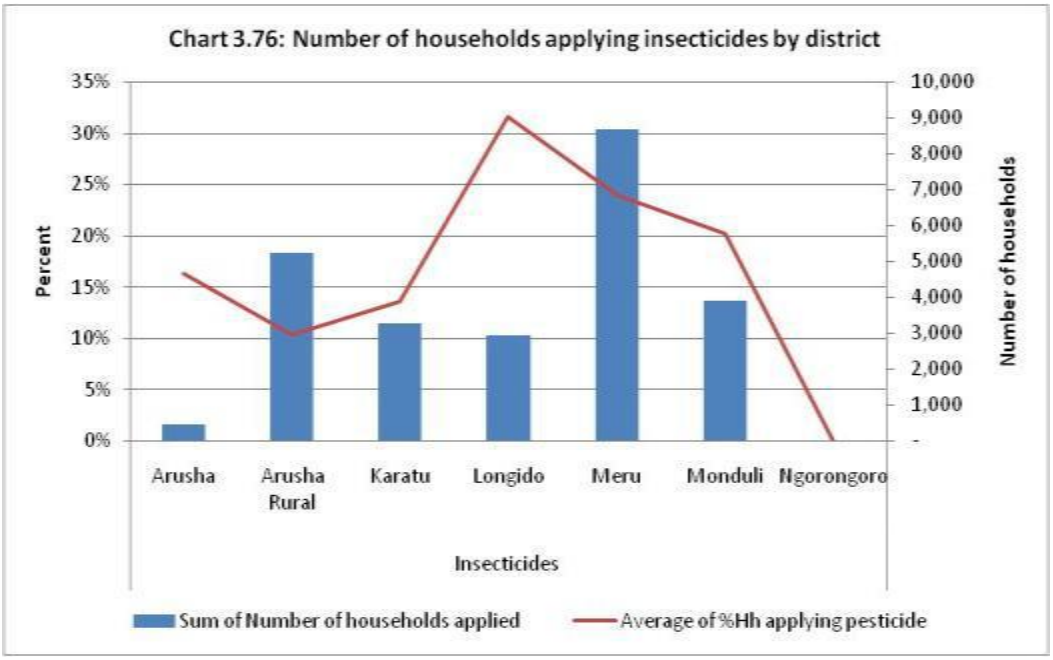


Appendix 2: Internet services penetration; users per technology type

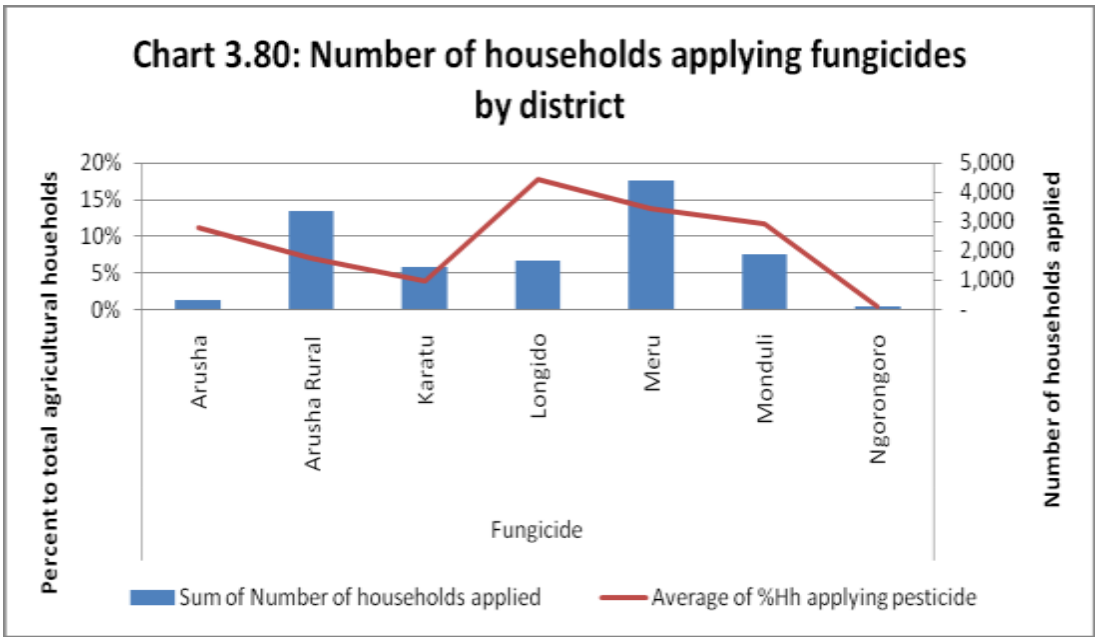
Type of Service	2011	2012	2013	2014	2015	2016
Fixed Wireless	968,088	777,461	1,056,940	1,913,082	662,882	1,218,693
Mobile Wireless	3,665,680	6,031,323	7,493,823	11,320,031	16,280,943	18,014,358
Fixed Wired	677,450	712,095	761,508	984,198	319,698	629,474
Total	5,311,218	7,520,878	9,312,272	14,217,311	17,263,523	19,862,525
Penetration	12%	17%	21%	29%	34%	40%



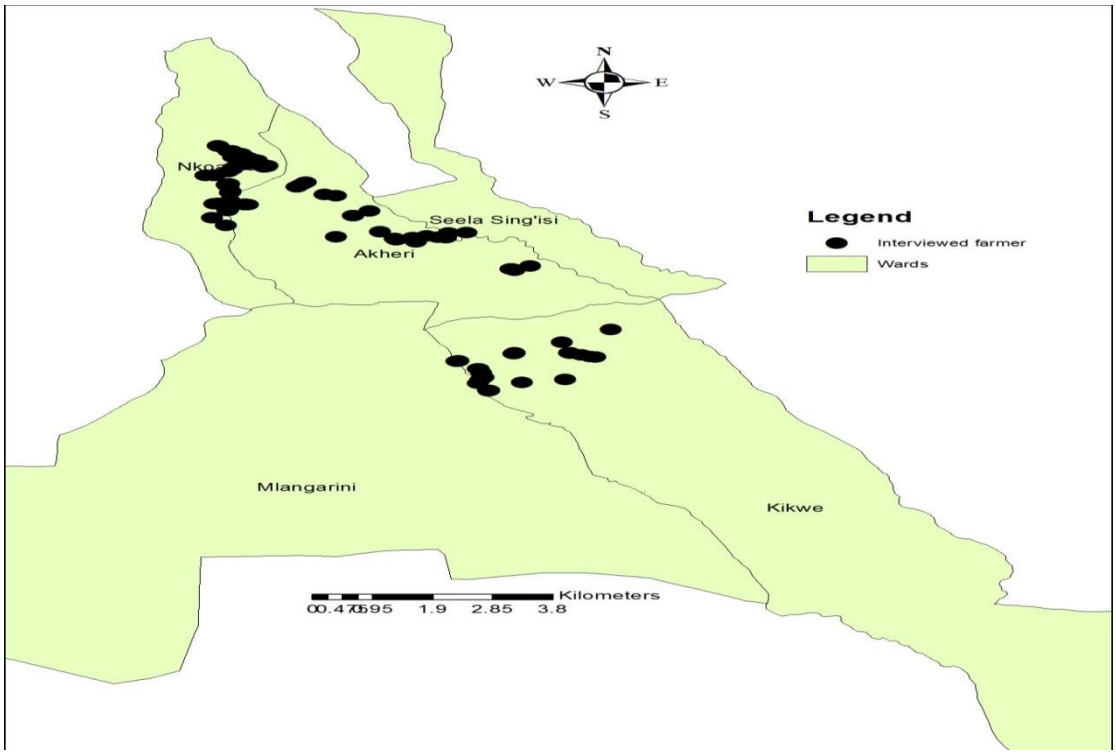
Appendix 3: Insecticides Use by District



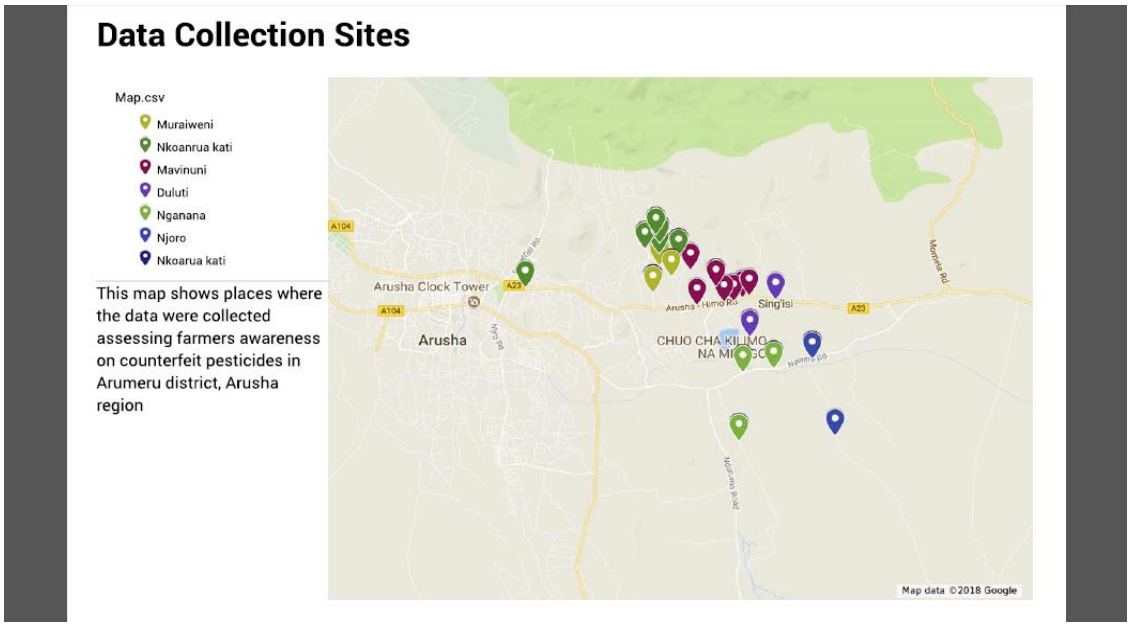
Appendix 4: Fungicides Use by District



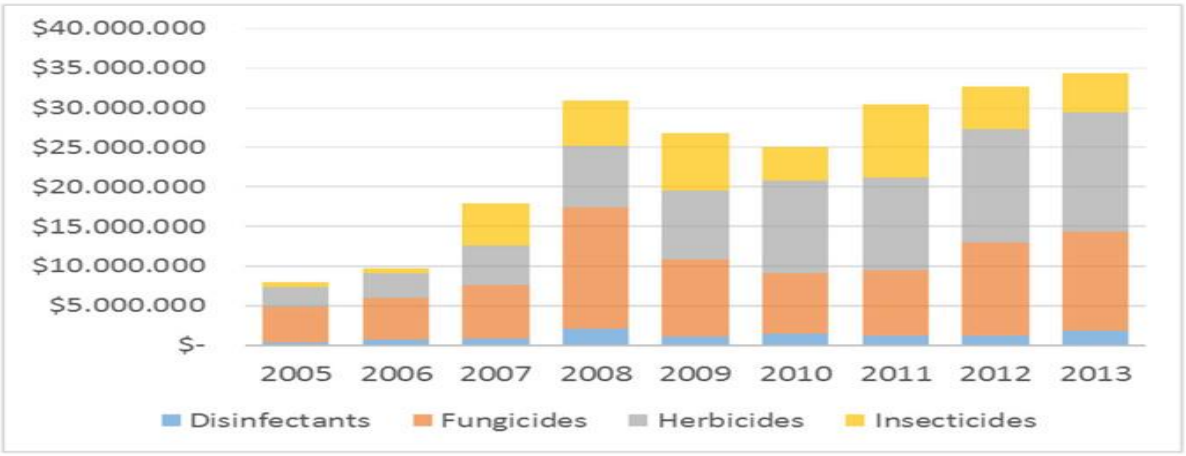
Appendix 5: Wards Involved in Data Collection



Appendix 6: Data Collection Sites per Hamlets



Appendix 7: Pesticides importation in Tanzania



Appendix 8: Persona; Farmer A

Farmer A

A Day in the life of Kheri, Volunteer in training farmers

Kheri finished his Diploma in Agriculture in 2015 at Karagwe University College of Agriculture (KARUCO). He is currently volunteering in educating farmers on modern farming techniques at his village; Chumbageni, Tanga. Decided to engage in farming activities, after inheriting a big farm from his father, Mr. Makanya. He has been using his smartphone in social media, job searching and applications and following weather forecasts.

Future Use: He would like to increase the use of internet to get more information about agro-inputs, trainings on how to safely use agro-chemicals for his health protection, he hopes for better ways of authenticating farming products during purchase as he can pass the idea to fellow farmers at the village. More tips in modern farming techniques and better markets for farming produce.

Characteristics of person: Kheri is a hardworking and committed person. He has many friends who are also farmers at the village, where he helps them with knowledge obtained from college about farming issues. He always tries to crack how he can improve his village through farming.

Preferences and Dislikes: He dislikes false hopes. He is interested in transferring knowledge to fellow farmers. He has a passion about farming. He likes systems that are easy to use, with many features, likes to test by implementing new farming tips.

Key goals in farming life: He would like to improve and updates farming knowledge. So he hopes to add more knowledge trough training.

Key goals in personal life: Sharing whatever information he surely knows it will be of help to many colleagues as possible, for development of farmers' lives in his village.

Learning interests: He would like to go for further education in agriculture.

Table 1: Fact Sheet of Kheri Makanya

Fact sheet of Kheri Makanya, farmer	
Features	**Descriptions**
Age	26
Job situation	Volunteer in farming education, farmer
Acceptance of change	Change agent
Level of general motivation	Mandatory
Languages (A1-C2)	English(B2), Swahili(C2)
Impairments	Vision (medium), cognition (high), mobility (high)
Assistive technology	None
Device types	Smartphone
Environment of use	outdoors
Online activities	e-mail, social media, web browsing, online search
Main activities	Learning agro-chemical use tips, products authentication
Availability learning environment	Training plan, farmer
Learning roles	Trainer

Appendix 9: Persona; Farmer B

Farmer B

A Day in the life of Bishangwayo, farmer

Bishangwayo finished his primary education 2014. As any other boy of his age at Chanika village in Karagwe, he is engaged in farming activities. Getting knowledge from parents and colleagues at the village. In order to make sure that he gets better farming produces, he has been using pesticides, having farming tips through various farming applications from his smartphone.

Future Use: He would like to have buying tips of various agro-inputs, training on how to safely use pesticides for his health protection, he hopes for better ways of authenticating pesticides products, training for modern farming techniques and better markets for his farming produce.

Characteristics of person: Bishangwayo is a hardworking and responsible person. He has many friends who are also farmers at the village, where they exchange the little knowledge they have about farming issues. He always listens and implements tips heard about farming hoping improvements in his farming produce.

Preferences and Dislikes: He dislikes farming applications that do not provide reliable information. He likes systems that are easy to use, with few features, likes listening more than talking and likes to test by implementing new farming tips.

Key goals in farming life: He would like to have more farming information from professionals, so that not just relying in tips from colleagues who sometimes aren't sure even on what they share.

Key goals in personal life: Sharing whatever information he surely knows it will be of help to many colleagues as possible, for development of farmers' lives in his village.

Learning interests: He would like to have training in modern farming especially in areas of land management and agro-inputs use.

Table 1: Fact Sheet of Bishangwayo Ponsian

Fact sheet of Bishangwayo Ponsian, farmer	
Features	**Descriptions**
Age	17
Job situation	Farmer
Acceptance of change	Follower
Level of general motivation	Mandatory
Languages	English (A2), Swahili (C2)
Impairments	Vision (high), cognition (medium), mobility (high)
Assistive technology	None
Device types	Smartphone
Environment of use	Outdoors
Online activities	social media, farming apps
Main activities	Learning agro-chemical use tips, products authentication
Availability learning environment	None
Learning roles	Farmer

Appendix 10: Persona; TPRI Staff

TPRI Staff

A Day in the life of Kurwa, scientist and inspector

Kurwa works as a scientist and a pesticides inspector at the Tropical Pesticides Research Institute (TPRI), experienced in the field since October, 2002. He is confident with his job as it allows him to be autonomy. His job requires him to travel different regions searching for pesticides retailers making sure they abide by the laws. Most of the time this becomes difficult as the inspection schedule is prepared based on experiences and not the real fact about the possibility of counterfeits pesticides. To increase accuracy in searching they usually prepare list of permitted and registered pesticides to use as reference during the inspection. As any other people of his level, Kurwa uses computer for managing office work.

Future Use: He would like to improve the efficiency in preparing the inspection schedule, also the inspection process in general. While preparing information concerning genuine products to be uploaded in the institute's website. Also Kurwa hopes for better education to pesticides sellers in retail shops.

Characteristics of person: He is a quiet man who concentrates in making his job efficiently and abide by deadlines. He has a university degree, which makes him hope for promotion at his job.

Preferences and Dislikes: He dislikes being doing routine works and working overtime. He enjoys preparing research proposals and learning new ideas. Also Kurwa, likes training new employees to make sure they catch up and enjoys work as well.

Key goals in professional life: Exchanging work ideas through meetings, as he believes that every human being is different. He initiated, Monday morning meeting, which they called "Morning Glory". For every worker to give his weekly plan, previous week challenges and achievements. Which has been a success for the institute.

Key goals in personal life: Earn more through research and training to pesticides users.

Learning interests: Always on job-training, as he likes learning new ideas and transferring what he have to others. So he likes having a tool to help him transfer it to many people as possible.

Table 1: Fact Sheet of Kurwa Makungu

Fact sheet of Kurwa Makungu, inspector	
Features	**Descriptions**
Age	46
Job situation	Employee, scientist, inspector, acting registrar
Employment status	Full time
Acceptance of change	Explorer
Level of general motivation	Mandatory
Languages	English (C2), Swahili (C2)
Impairments	Vision (high), cognition (medium), mobility (low)
Assistive technology	None
Device types	Smartphone, laptop and computers
Environment of use in TPRI	Indoors, outdoors
Online activities	social media, web browsing, online search
Main activities	Dedicated programs, Microsoft office, portable document format
Availability learning environment	Training plan
Learning roles in TPRI	Trainer

Appendix 11: User stories

A farmer's perspective

As a < farmer >,

I want < to authenticate pesticides during purchase, report problem with pesticides products that didn't work as expected, learn on the safety measures in use of pesticides products >,

So that < To be assured that the products are authentic, safely use pesticides products, to be able to know that my complaint have reached the right place >

A pesticides inspector's perspective

As a < pesticides inspector >,

I want < to have a reliable way to reach information about permitted pesticides products to users, educate pesticides users on safety measures in using pesticides products, locate counterfeits in the market >,

So that < to educate as many people as possible, to build community trust to the institute >

Appendix 12: Test Plan 1 for Mobile Application

The plan was prepared to be used for testing with farmers and the TPRI staffs. The plan is available in English and Swahili version. The Swahili version was used during the testing for easy understanding and communication with target users. Only English version was included in this dissertation for language uniformity.

Objective: The aim is for the participant to able to;

(i) Verify authenticity of pesticides products and have suggestions on the proper usage through the application

(ii) Send complaint to TPRI through the mobile application

(iii) Learn on the safety measures of using pesticides products

Participant Characteristics

The usability test of the Pesticides Authenticity Verification System will be done using 5 participants who expects to be farmers. Mixed adult age range, having pesticides buying

experience, similarly who knows how to read and write will be involved to validate the design based on the prepared usability objectives to be accomplished from the test.

The table below indicates in summary of participants' characteristics and desired mix (Rubin *et al.,* 2008).

Table 1: Participants Characteristics (Farmers)

Characteristic	**Number of participants**
Total number of participants	5
Age-groups	
18-24	1
25-34	1
35-44	1
45-54	1
55-64	1
Pesticides buying and using frequency and experience in using camera	
Rarely	1
Sometimes	2
Often	2
Gender	
Female	2
Male	3

Methodology: This usability testing process will be fairly summative, as it is expected to be conducted at the final stages of the development of the mobile application of the pesticides verification system, and the results will be used as suggestions for future study. All participants will be involved on all the core tasks which are; verify authenticity of pesticides products, report a problem raised due to the usage of the pesticides products and learning on safety measures in using pesticides products.

Chosen test design; within subject design

All of the participants will participate in all of the three main tasks of the mobile application since the tasks aren't very long. Considering the problem of transfer of learning, the

counterbalance technique (systematic way of varying tasks) will be used by varying the three tasks among participants. Will conduct up to 5 participants for 23 minutes usability study sessions. Using every 10 minutes of each session explaining the background information and post-test briefing to each participant. The remaining 13 minutes, participant will use to verify authenticity of the sample pesticides products prepared for the test, report a problem through the application and learn safety measures in using pesticides products

Session outline and timing

The session will comprise 23 minutes for each participant. Will use every 10 minutes of each session explaining the background information and post-test briefing. The sessions will take place in farmer's places in wards of Nkoanrua, Kikwe and Akheri.

Pre-test arrangements

The test moderator will have participants; fill out pre-test questionnaires.

Introduction to the session (5 minutes)

Expects to discuss about; participant experience with usability studies, importance of their involvement, moderator's role and protocol of the rest of the session.

Tasks (13 minutes)

Participant will start by verifying authenticity of the prepared sample pesticide product, learn on the safety measures of using pesticides and report complaint for products which haven't worked as expected.

Post-test debriefing (5 minutes)

Asking some questions to collect preferences and other qualitative data and if possible documenting and follow up on any problems in using the application.

Table 2: Task List

Task	Description	Material	Performance	Timing
Verify authenticity of the sample pesticide product	Sending batch number for pesticides authenticity request	Smartphone with internet, location and camera access	If within 4 minutes user has been successfully request and get reply on product authenticity	4 minutes
Report complaint for products which haven't worked as expected	Feed in the app details required about the product that has been of problem, then send the details to the web app	Smartphone with internet, location and camera access	If within 5 minutes the participant is able to feed in the details and get confirmation of receipt	5 minutes
Learn safety measures of using pesticides products	Browse in the app, and understand safety measures details provided	Smartphone with internet access	If within 4 minutes the applicant is able to browse and understand safety measures provided by the app	4 minutes

Test Environment, Equipment, and Logistics

This usability will be conducted preferably at pesticides shops or even in farms in wards of Nkoanrua, Kikwe and Akheri. Necessary equipment is a smartphone with internet, location and camera access. Participant will use an internet accessed android 4.0 and/or above smartphone.

Test Moderator Role

Moderator has to be near the participant at the chosen test environment based on the description in the plan, start by introducing the session and tasks appropriately also briefing about the whole session. Will take detailed notes and record the participant's comments.

Report Contents and Presentation

Provide a brief summary on the whole test document, including goals, methodology, logistics and participants characteristics also present findings based on the questions used in evaluating the product.

Give qualitative results and provide visuals of pages in the mobile app, that was used in specific questions.

Discuss the implication of the results and provide recommendations on future research If necessary, participants screening will be done based on the set characteristics. Below are the participants screening questions.

Participants screening questions (for farmers)

1. Fill in gender

   []Male

   [] Female {recruit: mix}

2. What is your age range?

   [] Below 18 years

   [] 18-24

   [] 25-34

   [] 35-44

   [] 45-54

   [] 55-64 {recruit: mixer at least one from each category}

3. Do you know how to read and write?

   [] Yes

   [] No {recruit only those who knows how to read and write}

4. Pesticides buying experience

   [] Rarely

   [] Sometimes

[] Often {recruit : mixer}

5. Experience with using smartphone and camera

[] Never

[] Rarely

[] Sometimes

[] Often {recruit : mixer}

Pre-test questionnaire for farmers

1. Does the participant understand terminologies?

{Pesticides, pesticides authenticity, complaints reporting, TPRI, batch number}

2. (value the product?) I think just using my normal ways of authenticating pesticides products is enough

….Yes; how?……..

….No; why not?……..

3. I use this features in my phone

….camera

…text messaging

…other, kindly specify……..

4. Being able to verify authenticity of pesticides using my phone would be useful to me (circle one answer, also give reason for your answer)

a. Strongly agree b. Agree c. Disagree d. Strongly disagree

Why?.....

5. In general I enjoy using gadgets, like cell phones and other high-tech products

a. Strongly agree b. Agree c. Disagree d. Strongly disagree

Post-test questionnaire for farmers

Measuring user satisfaction using SUS (ISO standard 9241)

For each statement, tick one box in a row, based on how you feel about the statement

Question	Scale			
	Strongly Disagree	Disagree	Agree	Strongly Agree
	1	2	3	4
I think that I would like to use this system frequently				
Found the system unnecessarily complex				
I thought the system was easy to use				
I think that I would need the support of a technical person to be able to use this system				
I found the various functions in this system were well integrated				
I thought there was too much inconsistency in this system				
I would imagine that most people would learn to use this system very quickly				
I found the system very cumbersome to use				
I felt very confident using the system				
I needed to learn a lot of things before I could get going with this system				

Appendix 13: Test Plan 2 for Mobile and Web Applications

Objective: TPRI staffs will test the whole system, starting with the mobile to web application. They will perform all testing objectives as farmers will do, then back to the web application. For the web application they will;

(i) Discover what the system for and how to get started in interacting with the system

(ii) Register to the system

(iii) Login and manage information of authentic pesticides products

(iv) View and print authenticity requests and reported complaints

Participant Characteristics

The user experience test will be done by preferably pesticides inspectors. Will use in usability study of the web part of the pesticides authenticity verification system based on the prepared objectives to be accomplished from the test.

The table 3 indicates in summary participants' characteristics and desired mix (Rubin *et al.*, 2008).

Table 1: Participants Characteristics

Characteristics	**Number of participants**
Total number of participants	5
Pesticides inspectors	5
Gender	
Female	2
Male	3

Methodology: This study will be fairly summative, as it is expected to be conducted at the final stages of the development of the web application of the pesticides authenticity verification system. Participants will fall into single group based on the core tasks which are; discover of what the product is all about and how to get started, register to the system, login and manage

information concerning authentic pesticides, view and print authenticity requests and the reported complaints.

Chosen test design; within subject design

Where all of the participants will participate in all of the five main tasks of the web application since the tasks isn't very long. Considering the problem of transfer of learning, the counterbalance technique will be used by varying the tasks among participants. Will conduct up to 5 individual 53 minutes usability study sessions each. Using every 20 minutes of each session explaining the background information and post-test briefing to each participant. The remaining 33 minutes, participants will use to perform the tasks.

Session outline and timing

The session will comprise 53 minutes for each participant. Will use every 10 minutes of each session explaining the background information and calibration of the eye tracker when the wweb application is about to be conducted. The participant will do all task within 33 minutes. Post-test briefing by using gaze-cued retrospective verbal protocol will be done for 10 minutes also record the feedback capture grid. The sessions will take place at TPRI offices in Ngaramtoni, Arusha- Tanzania.

Pre-test arrangements

Will have participants; review and understand that they have to start with the mobile then web application

Introduction to the session (10 minutes)

Expect to discuss about; participant experience with usability studies, importance of their involvement, moderator's role, protocol of the rest of the session.

Tasks for Mobile Application (13 minutes)

Participant will start by requesting authenticity of the product, report complaint for product which haven't worked as expected and learn on the safety measures in using pesticides products.

Tasks for Web Application (20 minutes)

Participant will start by discovering what the system for and how to get started in interacting with the system, register to the system, login and manage information concerning authentic pesticides information also view and print authenticity requests and reported complaint.

Post-test debriefing (10 minutes)

Replay session so as to have more information using gaze-cued RVP. Asking some questions to collect preferences and other qualitative data and if possible documenting and follow up on any problems in using the application. Lastly filling the Likert scale.

Table 2: Task List for Mobile and Web Application

Task	Material	Performance	Timing
Verify authenticity of the sample pesticide product	Sending batch number for authenticity request	Smartphone with internet, location and camera access	If within 4 minutes user has been successfully request and get response on product authenticity
Report complaint for products which haven't worked as expected	Feed and send the app details required for product that has been of problem	Smartphone with internet, location and camera access	If within 5 minutes the participant is able to feed in the details and get receipt alert
Learn safety measures of using pesticides products	Browse in the app, understand safety measure provided	Smartphone with internet access	If within 4 minutes the applicant is able to browse and understand safety measures provided
Discover what the system for, benefits, how to get started in interacting with the system	Load and understand the home page of the web application	Internet accessed PC with set mobile eye tracking equipment	If within 2 minutes a participant has been able to discover what the system is for and how to get started in interacting with it
Register to the system	User clicks register link to access the form for registration	Internet accessed PC with set mobile eye tracking equipment	If within 4 minutes a participant has been able to register and login to the system
Login and manage information concerning authentic pesticides	Login, add, edit, delete and print pesticides information	Internet accessed PC with set mobile eye tracking equipment	If within 10 minutes user has been successfully login and manage pesticides information
View and print lists of authenticity requests and reported complaints		Internet accessed PC with set mobile eye tracking equipment	If within 4 minutes the participant has been able to view and print lists of authenticity requests and reported complaints

Test Environment, Equipment, and Logistics

This study should be conducted preferably at the TPRI offices in Ngaramtoni Arusha-Tanzania. Necessary equipment is an internet accessed personal computer with mobile eye tracking equipment. Participant will use an internet accessed personal computer with Firefox version 59.0.1 and above or Google chrome version 65.0.3325.181 and above. With an eye tracker to capture user activities during the test session.

Test Moderator Role

Moderator will be near the participant at the prepared room for conducting the test. Will start by introducing the session and tasks appropriately also briefing about the whole session. Also take detailed notes and record the participants' behavior and comments. After completion of the test, the moderator will take the recorded clip by the eye tracker and show it to the participant for gaze-cued RVP.

Pre-Test Questionnaire for TPRI Staffs

1. Does the participant understand terminologies? (Pesticides, registered pesticides, permitted pesticides, authenticity request, problems reported)
2. (value the product?) I think just using my normal ways of paper based is enough

   ….Yes; how?……..

   ….No; why not?……...……..
3. I use this function in my PC

   ….Portable Document Files (PDF)

   …Work related information systems

   …others, kindly specify……..
4. Being able to respond to customer problems, manage permitted pesticides through this system would be useful to me (circle one answer, also give reason for your answer)

   a. Strongly agree b. Agree c. Disagree d. Strongly disagree

   Why?.....

5. In general I enjoy using PC and other high-tech products

   a. Strongly agree b. Agree c. Disagree d. Strongly disagree

Post-test questionnaire for TPRI Staffs

Measuring user satisfaction using SUS (ISO standard 9241)

For each statement, tick one box in a row, based on how you feel about the statement

Question	Scale			
	Strongly Disagree	Disagree	Agree	Strongly Agree
	1	2	3	4
I think that I would like to use this system frequently				
Found the system unnecessarily complex				
I thought the system was easy to use				
I think that I would need the support of a technical person to be able to use this system				
I found the various functions in this system were well integrated				
I thought there was too much inconsistency in this system				
I would imagine that most people would learn to use this system very quickly				
I found the system very cumbersome to use				
I felt very confident using the system				
I needed to learn a lot of things before I could get going with this system				

Appendix 14: Interview Questions for TPRI

1. What are the TPRI functions in regard to pesticides management?
2. Requests elaboration of each TPRI function in detail
3. What are the registrants' registration procedures?
4. How are the pesticides registrants managed by the TPRI?
5. How many registrants which are currently registered by the TPRI?
6. What are the pesticides products registration procedures?
7. What criteria are used in categorization of pesticides products?
8. What are the types and /or categories of pesticides products currently registered by the TPRI?
9. How does the quality of pesticides products controlled by the TPRI once manufactured and/ or imported?
10. How often is the quality of pesticides products reviewed by the TPRI? Per batch or once in product lifetime?
11. If not often, why?
12. What does the procedures indicates (requires)?
13. What is contained in details given to the manufacturer as a go ahead in production of pesticides products?
14. How are the pesticides products details stored by the TPRI?(paper /electronic)
15. Are there any other products details that are shared by the suppliers / registrants to TPRI?
16. If there are, how are those details shared? Any electronic system that links TPRI with pesticides suppliers / registrants?
17. Which information is shared by the suppliers / registrants for imported pesticides?

18. Any data that shows the mostly used categories of pesticides. (Request the documents contained the data).

19. Are most used pesticides imported or manufactured in the country?

20. How great is the magnitude of counterfeits in the areas you're inspecting (**hint**: in terms of quantity, also request the documents for review)?

21. How do you store information concerning the inspection?

22. Are those information used in predicting which areas are to be inspected more often?

23. If yes, has the approach being of help in reducing the magnitude of counterfeits in the market?

24. If no, why? What do you suggest?

25. How do you verify authenticity of the products during inspection (**hint**: method(s) which is used)?

26. How can you rate the effectiveness of the method(s) used in verification? (Very Effective, Capable and Effective, Somewhat Effective, Needs Development, Unsatisfactory)

27. What are the driving factors makes you inspect certain area or shops (**hint**: any indicators)?

28. What are the challenges faced during inspection?

29. How do you overcome the challenges?

30. Is there any initiative which is done by TPRI in educating the registered retailers on how they should verify authenticity of pesticides products before buying so as to make sure that they sell authentic products?

31. If there is, how has it be effective in reducing counterfeits in the market?

32. What is the initiative done by TPRI to educate other pesticides stakeholders (eg. farmers) in reducing counterfeits?

33. Are there any electronic devices that assist inspectors, during inspection?

34. Or any electronic system that is involved, during inspection?

35. Does the inspection team possess mobile phones for work purposes?

36. How is it used in pesticides management, especially during the inspection purposes?

37. What do you think of the solution which uses mobile phones to authenticate pesticides products?

Appendix 15: Interview Questions for Pesticides Registrants/Formulators/Importers

1. What categories of pesticides products do you produce?
2. What is the distribution channel of the pesticides products you produce to end users?
3. What are the required procedures for registration of pesticides products and/ or registrants?
4. How do you store the details of products produced? Any electronic system?
5. What information is contained in the barcode of your products? (are those information stored in the e-system?, for how long the company keep those information before destroying them?)
6. What are the regular products details shared to the TPRI during or after registration? Any means (e-system) which is used in sharing those details.
7. How often are those details shared to the TPRI?
8. How often does the quality of pesticides products controlled within the plant once manufactured?
9. How often is the quality of pesticides products reviewed by the TPRI? Per batch or once in product lifetime?
10. If not often, why?
11. What does the procedures indicates (requires)?
12. What makes manufacturers produce counterfeits pesticides?
13. What challenges do you face concerning counterfeits?
14. Have your products being counterfeited?
15. What are the actions which have been taken so far in combating counterfeits?
16. Do you (as manufacturer) do any control of your products once in the market?
17. What do you think of the solution which uses mobile phones to authenticate pesticides products?

Appendix 16: Questionnaire for Farmers

This is the questionnaire which was prepared for farmers. The questionnaire was in English and Swahili version. The Swahili version was used during the data collection for easy understanding and communication with target users. But, only English version was included in this dissertation for language uniformity.

Introduction

I am Catherine Cleophace Ngirwa, a Masters student in Information and Communication Science and Engineering at The Nelson Mandela African Institution of Science and Technology in Arusha Tanzania. I am currently doing a research titled "A Mobile based System for Pesticides Authenticity Verification: A Case of Tanzanian Market". Aim of this questionnaire is to identify awareness of users of pesticides in authenticating products during purchase. Thanks for your time to be part of this research.

(Check [✓] the appropriate box(es))

Section A: Demographic Information

1. District……
2. Ward……..
3. Village…….
4. Gender…….
5. Age……...
6. Do you know how to read and write?

   Yes ☐

   No ☐

7. Do you use pesticides?

   Never ☐

   Rarely ☐

Sometimes ☐

Often ☐

Always ☐

8. Which type of pesticides do you commonly use?

Acaricides ☐

Fungicides ☐

Herbicides ☐

Insecticides ☐

9. Where do you buy pesticides?

Shops ☐

Colleagues ☐

10. Who goes to buy?

Adult ☐

Child ☐

11. If adult, you know how to read or write?

Yes ☐

No ☐

12. Have you heard of the counterfeits pesticides?

Yes ☐

No ☐

13. Have you by any chance bought one?

Yes ☐

No ☐

Don't know ☐

14. If yes in 13 above, which type?

Acaricides ☐

Fungicides ☐

Herbicides ☐

Insecticides ☐

15. Did you report the problem?

Yes ☐

No ☐

16. Which reporting method did you use to report?

Mobile ☐

Phone ☐

Letter ☐

Physically to the shop/office ☐

17. How do you rate the follow up after reporting?

Very Dissatisfied ☐

Dissatisfied ☐

No Opinion ☐

Satisfied ☐

Very Satisfied ☐

18. What do you check to verify authenticity of products during purchase?

Brand ☐

Type Ingredients ☐

Expiry Date ☐

Nothing ☐

19. How do you rate your method of authenticating pesticides products?

Very Effective ☐

Capable and Effective ☐

Needs Development ☐

Unsatisfactory ☐

20. Do you face challenges in authenticating the products during purchase?

Yes ☐

No ☐

21. If yes in 20 above, what challenges?

Understanding product ☐

Differentiating between genuine and non-genuine ☐

Other ☐ Specify…….

22. How do you know the products usage and storage details?

Product Descriptions ☐

Sellers' Tips ☐

Experience ☐

23. When the product is at home do you still check its validity before using again?

Never ☐

Rarely ☐

Sometimes ☐

Often ☐

Always ☐

24. Do you possess mobile phone?

Yes ☐

No ☐

25. What type of mobile phone do you possess?

Featured ☐

Smartphone ☐

26. What basic functionalities and/or applications contained in your mobile phone which you are conversant with?

SMS Service ☐

Call Service ☐

Camera ☐

Social Media e.g. WhatsApp, Facebook ☐

27. Do you use mobile phone to acquire farming services and / or information?

Yes ☐

No ☐

28. How do you acquire those farming information?

Social Media ☐

Installed Applications ☐

Browsing ☐

Forums ☐

SMS ☐

29. Which farming information and/or tips you have been able to acquire through mobile phone? Land Management ☐

Pests and Animal Diseases Management ☐

Agro-inputs usage ☐

Markets ☐

Financial Support ☐

Other ☐ Specify……

30. A mobile phone to be used for authentication of pesticides products during purchase, what is your opinion?

Strongly Disagree ☐

Disagree ☐

Neutral ☐

Agree ☐

Strongly Agree ☐

RESEARCH OUTPUTS

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An ICT Based Solution for Pesticides Authenticity Verification: A Case of Tanzania

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ABSTRACT

Pesticides authenticity is important for human health and environmental protection also economic progress of users, dealers and the government benefits through levies. In order to ensure that authentic pesticides are sold in Tanzania, laws have been enacted and government bodies given mandate to enforce these laws. Despite the efforts, counterfeits are found in markets. Companies that spend a lot in research so as to produce authentic pesticides products end up losing hope as no substantial return in investment. This study targets on an ICT based solution for pesticides authenticity verification in the market which is a case study of Arusha region. In order to prove the need for the solution, literature review has been done and presentation of data gathered from the identified three groups of pesticides stakeholders, which are regulatory authority, registrants/formulators/importers and users preferably farmers all from Arusha region. The findings from the collected data reveals that, despite high awareness on availability of counterfeit pesticides among respondents, still most of them declared to have been buying counterfeits. Hence, there is a need of more reliable ICT based solution to help pesticides users in authenticity verification of products during purchase.

Keywords: ICT, pesticides, authentic pesticides, counterfeit pesticides, ODK

INTRODUCTION

Information and Communication Technology (ICT), plays a great role in human life, as it has been a catalyst of information management in different sectors. It is also been used as a tool for providing education opportunities to underserved who are geographically dispersed through teleconferencing technologies and increased students' performance by facilitating teaching and learning (Tinio, 2002; Vitanova et al., 2015). In business, through e-commerce ICT has been able to cater many customers in shorter time and in effective manner while increasing competitive edge of a particular business (Carnoy, 2005). ICT has correspondingly been identified to improve the quality and efficiency of healthcare systems and workers and facilitate information and knowledge flow of agriculture in rural areas (Idowu et al., 2003; Lwoga et al., 2010).

"Pesticides are chemical substances used to kill, repel or control certain forms of plants or animal lives that are considered to be pests" (U.S. (NIEHS), 2016). They have varieties of applications based on the user intentions. Roughly 85 percent of pesticides currently used in the world are devoted to agricultural sector, and the remaining percent for sanitary measures (Yáñez et al., 2002).

Product authenticity refers to; originality, quality commitment and credibility, heritage and style persistence, scarceness, sacredness and purity (Liao and Ma, 2009). As this study is concerned, pesticides authenticity would

refer to quality commitment and credibility of the pesticides products. In ensuring that authentic pesticides products are sold in Tanzanian market, laws have been enacted and government bodies given mandate to enforce them. Among the regulations that govern commercial distribution of pesticides are; the Pesticides Control Regulations Act No.18 of 1979 section 41(8), which states that *"Every person who for commercial purposes or disposal in any way for use by the public imports, manufactures, formulates or compound any pesticide shall register that pesticide in accordance with the Act and these Regulations"* (Tropical Pesticides Research Institute, 1984). Despite these regulations, Lahr described information published by AGENDA for Environment and Responsible Development reported that, about 40 percent of pesticides sold in 2012 in Tanzania, were substandard (Lahr et al., 2016). The work of (Singh et al., 2015), described substandard (counterfeit) pesticides are those which are not registered, having low/incorrect active ingredients, trademark infringed or sometimes misbranded. Going further Singh, Smita and Panchal, described that among the identified reasons of using these substandard pesticides in India, is lack of awareness and not being able to differentiate genuine from non-genuine pesticides.

The magnitude of counterfeits pesticides is great also worldwide. Europe pesticide business estimated to lose about $260-$370 million U.S. dollars, also counterfeit pesticides in China and India believed to comprise about 30-20 percent of the whole pesticides in the market respectively (Fishel, 2009). Additionally, Fishel discusses the problems caused by counterfeit pesticides which includes; problems to the health of customers and farmers, harm to the environment and economic damage to people and governments. From literature review, the need of a reliable ICT based solution for authenticity verification of pesticides has been revealed.

Additional to the literature review, this paper presents results from data collection which involved three categories of pesticides stakeholders in Arusha Tanzania; pesticides regulatory authority, pesticides registrants/formulators/importers and pesticides users preferably farmers. From the regulatory authority, this study aimed at understanding their functions and responsibilities in regard to pesticides management, quality control and how often it is done also the procedures, regular sharing of information with registrants/formulators/importers, if there is any electronic system for management of pesticides products and dealers, inspection process and challenges facing during the inspection. Similarly from the pesticides registrants/formulators/importers aimed at understanding their means of storing and sharing information about the products, status on counterfeited of their products, actions which have been taken so far in combating counterfeits, also their views in the use of ICT based solution for pesticides authenticity verification. From pesticides user's questionnaires were used to collect information on awareness and status of counterfeits pesticides, means which they use in reporting problem arise when products don't work as expected. On the other hand, their views on efficiency of the authenticity methods and their view on ICT based solution for pesticides authenticity verification.

The organization of this paper is as follows; section one presents brief introduction of the study and the stakeholders. Section two presents background information on similar studies done in developing countries. Section three describes methodology used in gathering the needed information from various identified groups of stakeholders. Section four is the results from gathered information. Section five describes the proposed solution. Section six is conclusion.

BACKGROUND

On the other hand, different ICT approaches and methods have been suggested in developing countries and others even implemented towards combating counterfeits. The suggested methods for product authentication includes the cloud technology, mobile and syndication technologies, rapid alert systems, coded stickers, website seals and cyber warning and all of these can be a success by conducting authentication and verification related activities, which involves; organizations and stakeholders collaborations as well as public awareness campaigns (Isah, 2012).

The following are ICT efforts which have been done by different stakeholders in combating counterfeit pesticides in various developing countries which includes Greece, Taiwan, Kenya, Uganda and Tanzania.

Starting with the Microsoft Access managed database proposed in **Greece** (Vassiliadou et al., 2011). It provides information on the recommended and genuine pesticides and information on how to use them. It facilitates communication between the regulatory authority and potential users and dealers of the pesticides.

Also the regulatory information system was proposed in **Taiwan** (Fei, 2014). The system covers the registration, quality regulation also establishment and evaluation of maximum residue limits and field monitoring of pesticide residues. It also, provides information to users of the services concerning how to use pesticides products.

On the other hand there is a Short Message Service (SMS) system for pesticides products authenticity verification in **Kenya** (Syngenta, 2011). The Kenya Plant Health Inspectorate has established this simple SMS

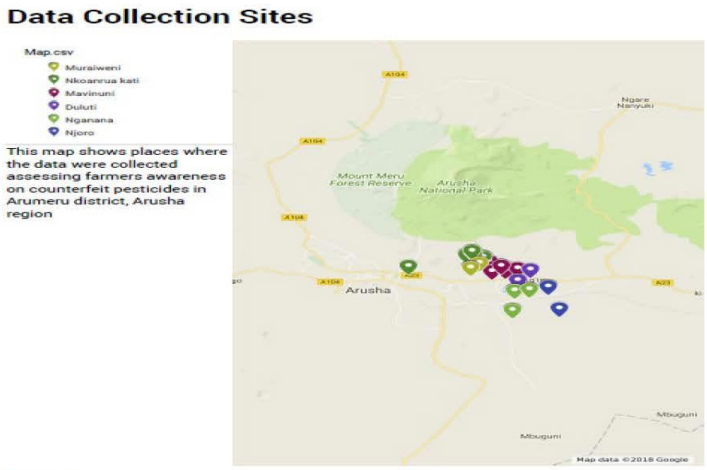

Figure 1. Data Collection Sites

system that allows farmers to check the authenticity of agro inputs – seeds, fertilizer, chemicals by sending text that contains dealer's license number and gets an SMS confirming the status of the product.

Similarly in **Uganda**, the electronic pesticides authenticity verification system uses SMS was implemented (Ashour et al., 2015). It provides access for user to send the authentication code found after scratch off the product label and receives back an SMS confirming the authenticity of the product. Only products with valid scratch code, considered authentic.

In **Tanzania**, an ICT model to combat counterfeits agro-inputs was proposed (Shao and Edward, 2014). The proposed model requires communication between the regulatory authority and the manufacturers on agreed code to be kept on the products then update the database server for customer to authenticate during purchase through SMS. Similarly to the one in Uganda, only products with valid scratch code, considered authentic.

METHODOLOGY

This section presents the methods used in collecting the needed information from pesticides stakeholders, description of the study area, sample size and sampling technique used. Implementation methods and design decisions of the proposed solution is out of the coverage of this paper.

Methods

Mixed methods to data collection were used, which is a combination of qualitative and quantitative methods of data collection similarly the results should be analyzed both qualitatively and quantitatively (Tashakkori and Teddle, 1998; Tashakkori and Teddlie, 2010). From qualitative methods, interviews were used and for quantitative methods, questionnaires were used to gather the needed information from the pesticides stakeholders. Different groups of pesticides stakeholders were identified including the targeted information from each group as described in section one. The involved pesticides stakeholders in this study includes; pesticides regulatory authority in Tanzania, pesticides registrants/formulators/importers and pesticides users preferably farmers. This is due to the fact that there has been a spectacular increase in need and importation of agricultural pesticides (Lahr et al., 2016; Ngowi, 2002).

Description of the Study Area

This is a case study of Arusha region located at 3.3869° S, 36.6830° E coordinates. The whole process of data collection took place from January to March, 2018. The study involved three groups of pesticides stakeholders, which are pesticides regulatory authority, pesticides registrants/formulators/importers and pesticides users preferably farmers. Staffs from pesticides regulatory authority were involved in interviews. Staffs from randomly selected six companies which fall in category of pesticides registrants/formulators/importers involved in interviews as well. Random selection was chosen as way to give all companies equal chance to participate in the study (Denscombe, 2014; Meng, 2013). The study also involved farmers with pesticides buying experiences from six hamlets (see **Figure 1**); Mariweni, Nkoanrua kati, Mavinuni, Duluti, Nganana and Njoro which are in wards of Akheri, Kikwe and Nkoanrua in answering prepared questionnaires.

Sample Size and Sampling Techniques

Staffs from pesticides regulatory authority and the six randomly selected companies were interviewed based on availability. Likewise, a total of 170 farmers from Arumeru district, which comprise a total of 49,292 households that are involved in agriculture, it is also the leading district in pesticides use were involved (The United Republic of Tanzania, 2012). Questionnaires prepared in Open Data Kit (ODK), since it is a mobile, faster and reliable means of collecting needed information from target audience (Hartung et al., 2010). Findings from interviews were prepared and the analysis for questionnaires were done using excel.

FINDINGS FROM DATA COLLECTION

Pesticides Regulatory Authority

Their responsibilities in regard to pesticides management is concerned with registration of pesticides products and registrants/formulators/importers, issuing of pesticides importation permit, regular quality control of pesticides products which are imported or formulated to be used in the country. Also the authority is responsible for inspection of the products once in the market, making sure that they are registered and of the expected quality. Nevertheless it is responsible for inspection on regulations abidance by the registrants/formulators/importers and the retail sellers of pesticides. Basically, the regulatory authority identifies products by batch numbers. This is due to the fact that, in case the particular product has been identified and/or to not being working as expected then all of the products in that batch has to be written off from the market.

Despite, the efforts and procedures to ensure that the products are of the expected quality, still during inspection processes which are conducted by the regulatory authority's inspectors, products which are not registered, sometimes trademark infringed or those registered but that particular batch does not have the required permits are found in the market.

Among the initiatives done by the regulatory authority so as to reduce counterfeits in the market includes educating and issuing certificates to shops sellers which started in early 2005 [on how to read and understand products labels so they could identify counterfeits]. The knowledge has been of help in reducing counterfeits but still there are sellers who haven't been complied. Who takes advantage that pesticides users don't have the knowledge that (sellers) have and sell counterfeits.

Midst the identified challenges faced by the inspection team is the scarcity of resources especially money to reach more areas. Inspection handling issues are done on paper based, which makes difficulties in organization of the required information at real time.

Pesticides Registrants/Formulators/Importers

These are the registered agents for importing, formulating or even distributing particular pesticides products in Tanzania. Interviews conducted with six random selected companies. The findings were that 4 among 6 interviewed companies didn't have any electronic system to store basic information about the products either manufacturing and/or importations. Nevertheless, even those having electronic systems still the exchange of information with the pesticides regulatory authority is conducted on paper based. These companies declared to have been receiving reports of counterfeits from their sales representatives around regions and have been reporting to authorities about the problems without any follow-up or promising response. Respondents seconded the idea of an ICT based solution for pesticides authenticity verification, quote from one of the respondents "*That idea shall work, just make sure that the displaying information to the users are more detailed for user to be able of distinguishing counterfeited from genuine*"

Pesticides Users

The following are the findings analyzed from 170 questionnaires in Arumeru district. Where the information presented in **Table 1**, includes; pesticides users' awareness on counterfeits, sources of information on counterfeits, status on whether respondents have been victims of counterfeits or not, reporting complaints for products which haven't worked as expected, pesticides verification methods in use, rating of the pesticides verification methods in use and pesticides user's views on ICT based solution for products authentication.

From Table 1

There is high *awareness in availability of counterfeits* pesticides among respondents, where 85.88% are aware.

Furthermore it was of interest knowing the *sources of information* for which the respondents who declared to be aware of availability of counterfeits heard the information. Respondents were allowed to choose more than one source of information. The results shows that despite radio, television, newspapers and social media being among the sources which people have heard of counterfeits, 61.18% of all respondents identified other sources as one of

Table 1. Presents Analyzed Results from Questionnaires

REQUIREMENT	TYPE OF RESPONSES	NUMBER OF RESPONSES (n)	PERCENTAGE (%)
1. Awareness of counterfeit pesticides	Yes	146	85.88%
	No	24	14.12%
	Total	**170**	**100%**
2. Sources of information on counterfeits	Television	33	19.41%
	Radio	95	55.88%
	Newspaper	31	18.24%
	Social Media	9	5.26%
	Other Sources	109	61.18%
	Total (multiple selection for 146 respondents)		
3. Bought counterfeits	Yes	116	79.45%
	No	28	19.18%
	Don't Know	2	1.37%
	Total	**146**	**100%**
4. Reporting complaints for products which didn't perform as expected	Yes	31	26.72%
	No	85	73.28%
	Total	**116**	**100%**
5. Pesticides verification methods in use	Brand	106	62.35%
	Expiry date	154	90.59%
	Type ingredients	78	45.88%
	Nothing	6	3.53%
	Total (multiple selection for 170 respondents)		
6. Rating of the pesticides verification methods in use	Very effective	1	0.59%
	Capable and effective	60	35.29%
	Somewhat effective	60	35.29%
	Needs development	43	25.29%
	Unsatisfactory	6	3.54%
	Total	**170**	**100%**
7. Views on ICT based solution	Strongly agree	39	22.94%
	Agree	91	53.53%
	Neutral	16	9.41%
	Disagree	24	14.12%
	Total	**170**	**100%**

the most chosen among five sources of information they heard of counterfeits. These other sources were mentioned as, hearing from fellows and/or personal experience in using counterfeit pesticides.

Besides, the table presents the percentage of respondents in regard to *status of been or not buying counterfeit pesticides* for the respondents who declared to be aware of counterfeits availability. From the results, 79.45% of respondents have bought counterfeit pesticides and the rest not.

Going further checking whether there were any efforts of *reporting the incidents* for those respondents who claimed to have been bought counterfeits, it show that 73.28% of the respondents who bought counterfeit pesticides didn't report the incidents. Among the mentioned reasons of not reporting is, not knowing the proper channel to follow in reporting the incidents. For those reported to the shops where they bought the products claimed that sellers blamed them (users) not to properly follow the usage and storage instructions as per product descriptions.

It felt similarly of important to understand current practice of users in authenticating pesticides products during purchase, also users were allowed to select more than one method. Where 91% of all respondent selected expiry date as one of the four most used authenticity verification method, followed by those checking brand, type ingredients and those who checks nothing just trusts the pesticides sellers on what is the best product to use for their needs. Respondents' ratings of the *effectiveness of methods which are in use for authenticity verification of pesticides products* were collected, where more than 60% were not satisfied by the methods currently in use.

As this research targets on ICT based solution for pesticides authenticity verification during purchase, respondents opinions were collected concerning the matter. From the responses, more than 70% of the respondents seconded the idea.

PROPOSED SOLUTION

From the data collection it is clear that most of pesticides users are aware of availability of counterfeits from different sources, despite high awareness they still declared to fall into buying counterfeits and they don't have a clear channel to report their misfortune. Hence, this research study targets on development of a mobile application

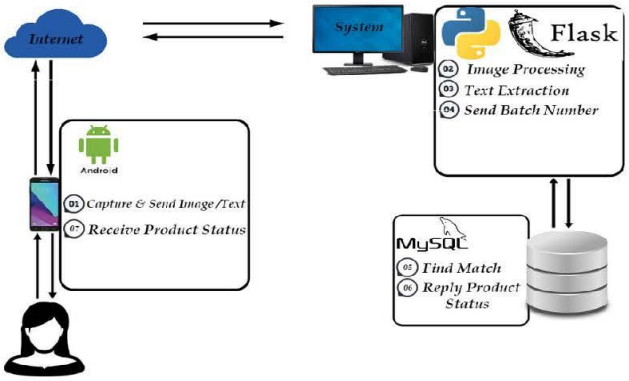

Figure 2. Research Framework

Figure 3. Map for Locating Counterfeits

that shall provide the service of pesticides products authenticity verification also reporting problems/complaints for products which haven't worked as expected.

The choice of a mobile application is due to the development of telecommunications market in Africa, where 60 percent of the population has mobile phone coverage and the growing rate increases by 49 percent annually. In Tanzania the penetration is approximately 80 percent and those using mobile internet services are 40 percent of them (Aker and Mbiti, 2011; Tanzania Communication Regulatory Authority, 2017).

The proposed solution as shown in **Figure 2**, expects to work by providing two options in pesticides authenticity verification requests, as described below.

First option is to capture image of the part of the product which contains batch number and send it to the system. The image is received by the python flask application and being processed and texts are extracted, then from the extracted text batch number is sent to the MySQL server for matching.

Second option in authenticity request is that the batch number is entered and sent to the system, then to the MySQL database for matching.

For both options (image and text), just in case the match is found, the system replies the found product information, like; batch number, product registration number, name of the product, manufacturer and registrant of the product, production and expiry dates of the particular product. Aiming for the requester to match the replied product information with the information found in the actual product to be bought. In case the match isn't found in the MySQL database then the system replies the alert message for user not to purchase the product as it is not authentic.

Similarly for both options (image and text), mobile application captures the longitude and latitude of the requester in the background. So just in case the match isn't found in the database they are used to create a map with red markers (as sample shown in **Figure 3**). This map would help the regulatory authority in identifying threat areas and act accordingly.

On the other hand the mobile application will have a complaint reporting service to users. Where information like; product image, batch number, registration number, source of product and harm which the user has encountered are to be filled and sent to the server for the regulatory authority to work immediately on them.

The MySQL database expects to contain updated information about pesticides products. The information is to be managed by the inspectors at the regulatory authority. As soon as the pesticide product has been undergone laboratory analysis and found that has the expected quality, then the product information is to be updated to be accessed by the pesticides users through mobile application. Also the regulatory authority inspectors will be able to manage details of the authenticity requests and the reported complaints.

CONCLUSION

As far as this study is concerned it is evident from literature and the reported findings, that there is a need for an ICT based solution for pesticides authenticity verification. Through the proposed solution pesticides customers will have a chance to check authenticity of the pesticides product and report complaints for products which haven't worked as expected.

It is clear that this study will serve as a link between other pesticides stakeholders and the regulatory authority and hence brings a solid foundation for pesticides authenticity in Tanzanian market.

In future this study can be extended to accommodate USSD codes so that even pesticides users with featured phones would be able to utilize the authenticity check service by entering direct the batch number to get reply on the product status through SMS (Short Message Service), on whether the product is authentic or not.

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Title: Validation of the Pesticides Authenticity Verification System Involving Target Groups in Tanzania

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Abstract

The Tanzanian Government has been struggling to make sure that it provides a good environment to different pesticides stakeholders. These efforts rely from strong policies to enforcement of amended laws by the Government and its bodies. The efforts have been well implemented with proper utilization of Information and Communication Technologies (ICT) in various government sectors.

This research presents an ICT tool for the lagging behind pesticides industry in Tanzania.

Prior to design and coding of the mobile based system for pesticides authenticity verification, selected stakeholders were involved in understanding the current situation in the industry. The findings from data collection, shows that industries have been stressed in finding ways of putting barriers to counterfeits for their sake without any promising positive results. On the other hand, pesticides regulatory authority concentrates on inspection and quality control, but counterfeits are found in the markets. Pesticides customers remain to lose. Neither any means of authenticating the products during purchase is available, nor is any proper channel of reporting complaints for products which have not worked as expected.

A pesticides authenticity verification system was developed and its validation provided positive results regarding usability. The SUS score in the preliminary and final testing phases was above average. This reflects users' satisfaction in using the system, despite minor challenges in understanding some terms which are to be fixed later in the study.

Keywords: Pesticides, Usability, User Experience, Validation, SUS, gaze-cued RVP

1.0 Introduction of the whole project

Pesticides are chemical substances for controlling pests and vectors of diseases. They are used in agriculture both pre- and post-harvest and also in sanitary measures against vectors of diseases. Since its applications touches various aspects of human life, its authenticity becomes of great concern among stakeholders (U.S(NIEHS), 2016; Wittmer, Scheidegger, Bader, Singer, & Stamm, 2011; Yáñez et al., 2002).

Increase in needs and market increase of pesticides causes problems to pesticides stakeholders, as people are trying to maneuver in selling products without following proper procedures set by the government. These unchecked products cause problems to human and environmental health and economic loss to stakeholders (Lahr, Buij, Katagira, & Valk, 2016; Tropical Pesticides Research Institute, 1984). On the one hand most of them are sub-standards. On the other hand, the government misses taxes for those meeting standards, but without required permits to be sold in the country.

Earlier findings from the data collection stage of this research (Ngirwa & Ally, 2018) report, that despite the efforts done by the pesticides regulatory authority in Tanzania, counterfeits are still in the market. For the side of pesticides customers, their awareness concerning availability of counterfeits is high but still most of them fall into buying counterfeits. The methods which they are using were also identified which included those checking expiry dates, brands, type ingredients and those who just trust the sellers on advising which product is the best to use.

Currently there is no ICT tool available for use by pesticides customers to authenticate pesticides products during purchase.

The purpose of this study was to link pesticides buyers with the pesticides regulatory authority by facilitating information, which the authority has to provide to pesticides buyers if required. Currently the regulatory authority communicates information regarding authentic pesticides in printed papers to inspect against counterfeits.

The developed system contains two main parts, a mobile application and a web application.

The developed mobile application is for pesticides buyers to check the authenticity of the needed product, report complaints about products which have not been working as expected and to also learn about safety measures in using pesticides products. The mobile application can also be of help to pesticides inspectors during the inspection process. Instead of walking around with printed papers, as is current practice, it is now possible to verify authenticity of pesticides, using the mobile application.

The web application provides access to a database with information on authentic pesticides. Registered users are able to view authenticity requests and location of requests through a map. The map is populated with information, using the location captured during products authenticity requests from the mobile application. Users are also able to view and print reported complaints for further management and inspection procedures.

This paper presents validation results of the mobile based system for pesticides authenticity verification, which was conducted in two testing phases.

The organization of this paper is as follows; the first section gives an introduction of the study and outlines expected achievements. Section two gives a background on the usability and user experience also the main system functionalities with screenshots, section three explains methodologies which have been used in achieving the objectives. Section four discusses the results and section five provides an outlook from the study.

2.0 Background information

Information systems are designed products that involve interaction between human beings and machines, which impact people, organizations and society in general (Hevner, March, Park, & Ram, 2004). Design puts more emphasis on the functional nature of what is to be produced, not only the look; it includes all aspects of user experience and web design. It also takes usability and accessibility into account (Horton, Quesenbery, & Gustafson, 2013; Mehalik & Schunn, 2006).

The International Standards organization (ISO, 1998) defined usability as the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction. The product (whether a web system, or mobile) should not make people think more than they should, as people have limited mental capability. Design of a usable product is possible by involving users from the beginning, which can be termed as user-centred design or human-centred design (Krug, 2014; Rubin, Chisnell, & Spool, 2008).

On the other hand, The International Standards Organization (ISO, 2010) defined human-centred design as an approach to systems design and development that aims to make interactive systems more usable by focusing on the use of the system and by applying human factors as well as usability knowledge and techniques. Accessibility is one of the qualities of usability, as it is not possible to say a product is usable while not accessible. Other qualities from ISO definition are;

efficiency, effectiveness and satisfaction to the targeted users (ISO, 2010; Krug, 2014; Rubin et al., 2008).

By definition, user experience refers to the attitude when a user interacts with a product, facility or environment (Bevan, Carter, & Harker, 2015). It can be altered by expectations, psychological state, context in which the system runs and characteristics of an interactive system (Ardito, Buono, Costabile, De Angeli, & Lanzilotti, 2008; Vaananen-Vainio-Mattila, Roto, & Hassenzahl, 2008).

Particularly usability testing is suggested so as to increase value of the software product. Usability test are performed with one person at a time trying to use the product, figuring out what it is and performing some tasks in the target environment (Rubin et al., 2008). It should be iterative, so that problems identified in one test are corrected and used in improving the system for the next test. Usability testing involves actual system users. (Battleson, Booth, & Weintrop, 2001).

Notably, usability testing can be performed using different methods at different stages of the system development, as indicated in different literature (Battleson et al., 2001; Hom, 1998; Petrie & Bevan, 2009; Rubin et al., 2008). Based on time and cost criteria, pesticides authenticity verification system's usability testing was done in two phases. In each of the testing phases two groups of users were involved, pesticides users, preferably farmers and staff from the pesticides regulatory authority.

A test model was developed (see figure 1).

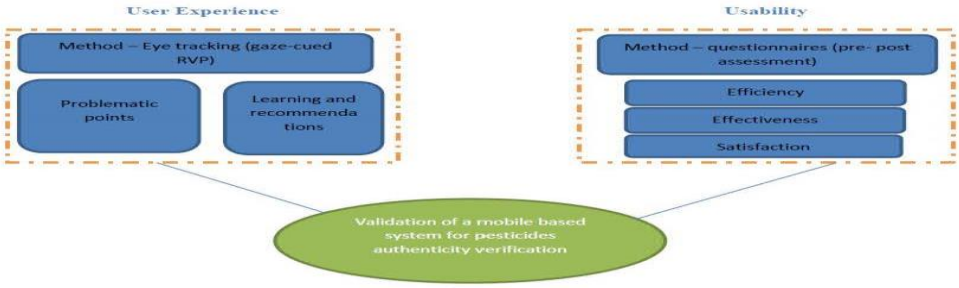


Figure 1: Test model (Source: amended from Moebs, 2011)

The test model in **figure 1** presents combination of user experience and usability methods in validation of the pesticides authenticity verification system. Where in user experience eye tracking method was used and analyzed by gaze-cued RVP. Aiming at identifying problematic points, check respondent's learning and gather recommendations for future improvements of the system. On the usability, questionnaires both pre and post assessments were chosen, aiming at measuring efficiency, effectiveness and satisfaction of the developed system to its users.

In the first testing phase (preliminary test) only usability has been tested, using questionnaires (both pre and post assessments). The objective of the test was to measure usability, using the System Usability Scale (SUS) and to gather recommendations from participants. In addition, the SUS reflects users' satisfaction with the product (Mclellan, Muddimer, & Peres, 2012).

The second testing phase aimed at validation of the system by measuring usability and user experience of the system. This has been done after implementation of the gathered recommendations and identified problematic points from the preliminary test. Usability methods applied were questionnaires (both pre and post assessments) and the eye tracking in both testing phases.

The mobile application was tested with farmers and regulatory authority staff. The web application was tested only with regulatory authority staff, as they are the ones responsible for managing pesticides information and are therefore the target users of the tested web application. For user experience testing eye tracking software was used to test the web application in the final testing phase.

According to Nielsen (2012), the number of participants in a usability test should be 5, for single group usability test. The pesticides authenticity verification system involves two groups. Due to that, the number of participants in each of the testing phase of the pesticides authenticity verification system involved a total of 10 participants, 5 from each target user group.

2.1 Pesticides Authenticity Verification System Main Functionalities

The developed system for verifying authenticity of pesticides in the market named Pesticides Authenticity Verification System (PAVS) contains two main parts the mobile application and web application. This section shall explain screenshots and explanations of main functionalities provided by the PAVS to its users.

2.1.1 Mobile Application Part of Pesticides Authenticity Verification System

The developed mobile application part of PAVS provides the following services; pesticides authenticity verification, complaints reporting for products which haven't worked as expected and safety measures in using pesticides products. As the target users of the mobile application are farmers, the Tanzania national language which is Swahili was used in all of the functionalities of it, for better and simple understanding and usage of the application.

For requesting authenticity of the pesticides product to be bought user clicks the 'Uliza Ubora' meaning 'Ask quality' button in the home page shown in **figure 2**, then the corresponding page which is **figure 3** opens. It requires user to input registration number of the product and the batch number. Thereafter, when user clicks 'Bofya kuuliza ubora' meaning 'Click to check authenticity' then the dialog confirming the status of the product pop ups. If the product is authentic the dialog that contains information of authentic pesticide for user to match with the real product he/she is about to buy as in **figure 4** opens. But if the product is not in authentic database the alarm message that the product is not authentic appears to the user as in **figure 5** opens.

Reporting the complaint for products which haven't worked as expected, user has to click 'Ripoti tatizo' meaning 'Report a problem' button in the main page, then the page for user to fill in the details concerning the product to be reported opens as in **figure 6.** Where user has to take a picture of the product, then fill in the batch number, product registration number, a place where the product was bought and the problem raised and then user clicks 'Bofya kutuma taarifa' meaning 'Click to send information' and the reply dialog appears if the complaint received successfully, if not the toast that requests user to try again appears. The failure may usually be caused by the problem in internet connection.

When user clicks on 'Matumizi sahihi ya viuatilifu' meaning 'Proper usage of pesticides', **figure 7** opens. This is a swipe dialog, where there are different tips for user to consider during usage of pesticides.

Figure 2: Main page

Figure 3: Authenticity request page

Figure 4: Positive reply dialog

Figure 5: Negative reply dialog

Figure 6: Complaint reporting page

Figure 7: Safety measures

2.1.2 Web Application Part of Pesticides Authenticity Verification System

The developed web application part of the PAVS receives, records and processes information and requests from the mobile application. The web application allows users to register, manage information concerning authentic pesticides and views and prints authenticity requests and map showing the location of the requests. Also registered user views and print reported complaints. The target users of the web application part are staffs at the pesticides regulatory authority.

Figure 8 shows the page which allows user to add, edit, delete, search and print information concerning any authentic pesticides that user would like. The system allows user to copy files to clipboard, print directly from the system, transfer files to excel or pdf for both authentic pesticides information, authenticity requests and the reported complaints. **Figure 9** shows authenticity requests from the mobile application, where for each of the request the system capture the location and only for those which their value of found is 0 they are plotted by red markers (as shown in **figure 10**). This map aimed at assisting the pesticides regulatory authority to know threat areas for inspection purposes. The reported complaints are as well recorded for the regulatory authority to act on them as shown in **figure 11**.

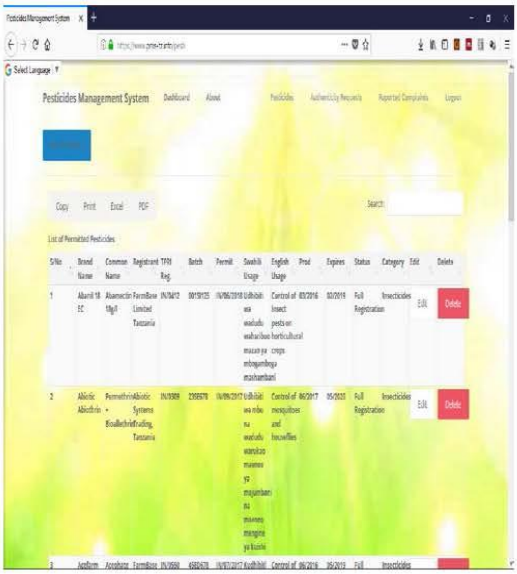


Figure 8: Authentic pesticides information

Figure 9: Authenticity requests from mobile application

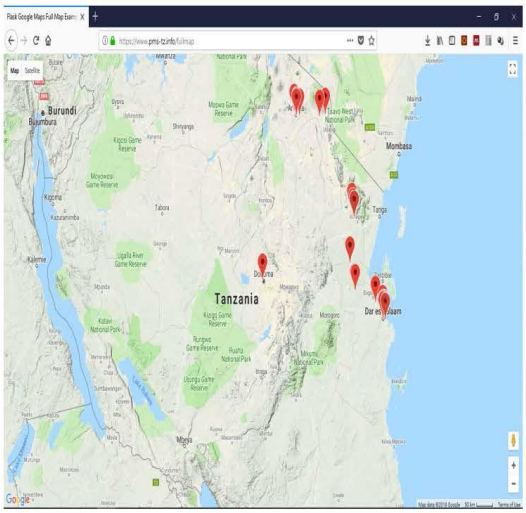


Figure 10: Map showing location of non-authentic pesticides (Ngirwa & Ally, 2018).

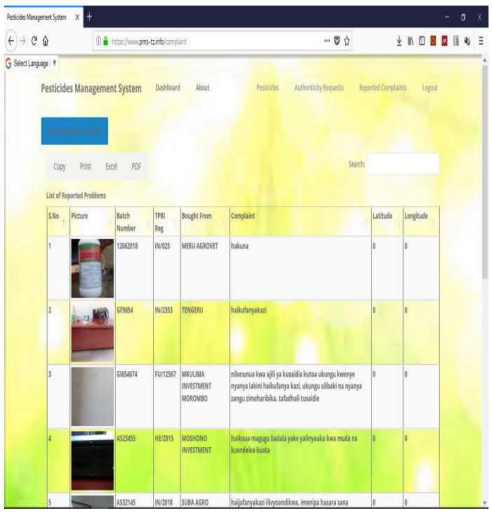


Figure 11: Complaints report

2.2 Description of the Study Participants

The preliminary and final testing phases for the mobile and web applications for pesticides authenticity verification involved two user groups. A total of 10 participants were involved in each of the testing phases. The first group involved 5 staffs from pesticides regulatory authority in Ngaramtoni, Arusha and Dar es Salaam regional office, which were tested with both mobile and web applications. The second group involved 5 mixed age group farmers with pesticides buying experience from the ward of Kikwe in Arumeru district, Arusha region. They were tested only with the mobile application. The mobile application was installed in an Android 8.0 smartphone and the web application launched in Internet Explorer 11. In the final testing phase a laptop with a Tobii X2-60 Compact eye-tracker.

3.0 Methodology

3.1 Methodology for the Preliminary and Final Test

In order to measure usability of the developed mobile and web applications, questionnaires method (both pre and post) were prepared to be answered before and after the test respectively.

The main goals for the preliminary test were to measure usability of the product and gather user comments, make recommendations and prioritize them accordingly.

The final testing goal was to discover design problems using eye tracking in the web part of the system by combining with gaze-cued Retrospective Verbal Protocol (RVP). The choice of gaze-cued RVP is to increase efficiency in a testing session, while not disturbing participants during the test (Bojko & Krug, 2013). Also usability was measured in both mobile and web applications in this testing phase.

Sessions for each participant started with answering the pre-test questionnaire. Then for the mobile application, a participant is expected to request authenticity of the product by providing the batch number and then get a reply on the status of the product within 4 minutes. For reporting a complaint the user has to be able to take a picture of the product, then provide a batch number, a pesticides regulatory authority registration number, name of the place where the product was bought and the complaints; it also gets a reply on delivery success within 5 minutes. For safety measures it is important that the information provided in the image slider is understandable by the participant within 4 minutes.

For the web, it is expected that the participant would be able to understand what the application is all about in 2 minutes and how to get started. Registration should take about 4 minutes, then login and being able to add, edit and delete details of permitted pesticides within 10 minutes. Similarly the participant should be able to navigate and view lists of authenticity requests and the reported complaints within 4 minutes. After mobile and web testing the participant should answer the post-test questionnaire.

3.2 Short Description of the Preliminary and Final Test Participants

3.2.1 Description of the Regulatory Authority Staff

The first group of participants was the pesticides regulatory authority staffs who deals with pesticides quality control, health risks analysis and pesticides inspection.

First participant was a pesticides inspector, with experience of more than 20 years in the field and a background in chemistry and laboratory technology. The participant showed interest, got overwhelmed when heard of the ICT tool to help them in managing his work, and turned out to be very inexperienced and reluctant in using it.

Second participant was a pesticides inspector with 23years experience in pesticides inspection and quality control, having a strong background in chemistry. The participant showed interest in the technology, was ready to learn using it, but also showed a lack of experience in using work related information systems.

Third participant was a laboratory technologist with a strong background in chemistry and working experience of 6 years in laboratory efficiency testing of pesticides products and preparation of the testing analysis reports. The participant looked overwhelmed, but very interested in using the tool.

Fourth participant was a pesticides health impact analyst with a strong background in biology and 3 years of working experience in the field of analyzing pesticides' health impact to users. The participant is also educating pesticide users on proper usage and handling of pesticides products. The participant seemed ready to learn.

Fifth participant was a pesticides inspector with 17years working experience in the field with strong background in chemistry. The participant was very interested in using the tool despite being inexperienced of work related information system.

3.1.2 Description of the Farmers

The second group of the involved participants was 5 farmers.

First participant was a farmer in the age group of 45-54 years, with 15 years of experience in buying and using pesticides products, with basic primary education, capable of reading and writing in Swahili. The participant was very interested in using the tool, despite being inexperienced with using a smartphone.

Second participant was a farmer in the age group of 24-34 years, with 10 years of experience in buying and using pesticides products, with a Bachelor in Education, with a major in agricultural technology, capable of reading and writing in English and Swahili. The participant has experience in using smartphone and was interested and ready to use the tool.

Third participant was a farmer in the age group of 35-44 years, with 15 years of experience in buying and using pesticides products, with basic primary education, capable of reading and writing in Swahili. The participant has no experience in using a smartphone, though seemed ready to use the product.

Fourth participant was a farmer in age group of 18-24 years, with 6 years of experience in buying and using pesticides products, with a secondary education, capable of reading and writing in

Swahili and English. The participant has experience in using a smartphone and looks ready to learn how to use the tool.

Fifth participant was a farmer in the age group of 54-64 years, with more than 25 years of experience in buying and using pesticides products, with basic primary education, capable of reading and writing Swahili. The participant has no experience in using smartphone and reluctant to use though was ready to learn in using the tool.

4. Preliminary Test Results

4.1 Pre-Test Questionnaires Results for Regulatory Authority Staff

All five participants understood 4 out of 5 terminologies requested, including pesticides, registered pesticides, permitted pesticides and problems reported.

All five participants were not satisfied with the current means of storing and managing information at the institute, which is paper based. Using technology to handle information increases accessibility. Participants expressed that a model is needed.

PDF is a document format commonly used by all of the five participants.

All five participants agreed that being able to capture problems as they arise and to respond to the community of pesticides users through the applications, is more useful that the current situation. Reasons for the perceived usefulness are that it is a new application at the institute, it increases awareness and easily capturing of information. It makes a follow up easy through reported complaints for products which have not worked as expected and the unregistered pesticides products which are in the market.

Finally it showed that four out of five participants enjoy using technology products, if available in their offices.

4.2 Pre-Test Questionnaires Results for Farmers

All of the five participants understood only one out of five words, which is reporting complaint. Others like pesticide, quality pesticides, pesticides regulatory authority and batch number were not understood by them.

Four out of five participants were not satisfied by the means they are currently using in authenticating the quality of pesticides products. While only two of the participants were familiar in using camera in their phones, others use SMS, manages calls.

All of the five participants strongly agreed that using a mobile phone in authenticating the quality of pesticides products will be an advantage. Four out of five participants strongly agreed that they are happy in using gadgets and technology products.

Result of Actual Testing and User Comments

4.3 Regulatory Authority Staff

First participant, spent 3 minutes trying to understand what the application is all about and how to get started. It took the participant longer than the scheduled time in accomplishing the three tasks of mobile application, though was done correctly. For the web application, it took about 4 minutes for the participant trying to understand how to get started then did the wrong action by trying to login instead of registering first, minor redouble in filling the register form. But finally all the tasks were performed successfully and within the expected time.

Second participant spent less time in performing the mobile application tasks. On contrary to the first, this participant was able to perform well in the mobile application. But as for the previous one, the register form was a challenge. The participant suggested combination of the batch and TPRI registration numbers in requesting authenticity of the products.

For the third participant, was able to spend less time in performing the entire mobile and web application tasks correctly.

Nothing new captured for the forth and the fifth participants, with exception to the suggestion of providing a room for users to provide their contacts when reporting complaints or requesting authenticity.

4.4 Farmers

Terms like; batch number, pesticides regulatory authority, pesticides regulatory authority product registration number, pesticides and quality pesticides weren't familiar with the participants. The moderator had to explain the terms clearly to each of the participants well before the mobile application testing sessions.

First participant spent 7 minutes trying to understand what the application is all about and how to get started. Then the participant was able to perform all of the three tasks of the mobile application correctly though spent more time.

Second participant spent less time in each of the tasks and performed correctly. On the other hand participant advised educating people in understanding the information provided in the

pesticides products so as to be able to use the tool. As for them the mostly checked information is the expiry date.

No new feature observed for the third and fourth participants, but for the fifth participant assistance was needed in accomplishing the tasks.

4.5 Post-Test Questionnaire

The SUS that contained 10 standard statements with 4 responses for both groups of participants was used. The results for regulatory authority's staffs is 71.5 and for farmers is 73; where for both groups the scale is above average (68), hence the pesticides authenticity verification system perceived usable and acceptable to its intended stakeholders.

4.6 Observations from the Preliminary Test

General observation is that all of the participants seemed interested in using the system. Despite minor struggle in filling the needed information in the register form but the reply to the requests were clearly understood by the participants. It was also observed that comfortability and experience with technology products affected their performance in terms of time taken to complete tasks, errors in selection and easiness in navigation through the mobile and web applications.

In the mobile application all of the participants spent time in understanding the main page before getting started with the three main tasks and the performance was impressive. For farmers a brief understanding of the terms was important so as to make sure they are able to use the tool.

For the web application only the first participant struggled in discovering the link to register, but after some minutes the participant eventually managed to perform. But all of the participants struggled with navigating in the register form though they did make it at last.

4.7 Recommendations from the Preliminary Test

1. **More visible links or buttons.**

   This can be corrected by bolding the links or having buttons for both new and returning users.

2. **Use of drop down menus to reduce text entered especially in complaints reporting.**
   This can serve also as a need for the participant who suggested health impact option to be added. For example if the user is filing a complaint, there can be a dropdown menu for selection by the users instead of them typing everything themselves.
3. **Combination of the batch number with the pesticides regulatory authority product registration number in requesting authenticity of the product.** This combination shall eventually reveal the exact product and not several which might happen that the batch number collides between products as it is usually decided at the company.
4. **Adding of option for user to fill in the contacts when requesting and reporting complaint as suggested by the participant.** Basically, this study concentrates in pesticides products which have no required standard or permit to be in the market, rather than personal information. As for this thought to be of less consideration for now.
5. **To get user's concentration on the page,** reducing amount words is very important. For the index page reduce to make it not too wordy.
6. **Making user friendly forms, by making them easily scrollable and not too spread out**, also adding hints in some of the options. A thorough understanding and twisting on the CSS and bootstrap file can fix this.
7. **Educating farmers on the standard terms used in the tool.** This shall help them in using the tool comfortably. Results from the preliminary testing phase shows that, farmers have their own way of calling pesticides. Most of them named pesticides as **poison**. Therefore there is a need of educating them on the standard terms used in the tool.

4.8 Final Testing

The recommendations from the preliminary test were implemented in the pesticides authenticity verification system and the amended system was tested with the same participants from the preliminary test.

The results from the pre-test questionnaires were no different between the two tests, even the performance in the testing sessions was equivalent. But much improvement showed for the rating

in the post-test questionnaire. Of the regulatory authority's staffs 79.5 and 75 of the farmers indicate that they are more satisfied with the software.

Furthermore, web part assessment of user performance with the eye tracker was good. Participants performed all other tasks on time, with exception of the initial task, which requires participant to discover what the application is all about and how to get started. The average time spent for all five participants of the web part of the system is 2 minutes 30 seconds, which is 30 seconds more than the benchmarked time, which is 2 minutes.

The gaze-plots screenshots attached in appendix 1, show that three participants concentrated in the login form and the remaining two concentrated in other parts of the index page, before discovering the register link and be able to start. This indicates there is a problem for participants to clearly discover the register link and to be able to get started as new users to the system.

5. Discussion

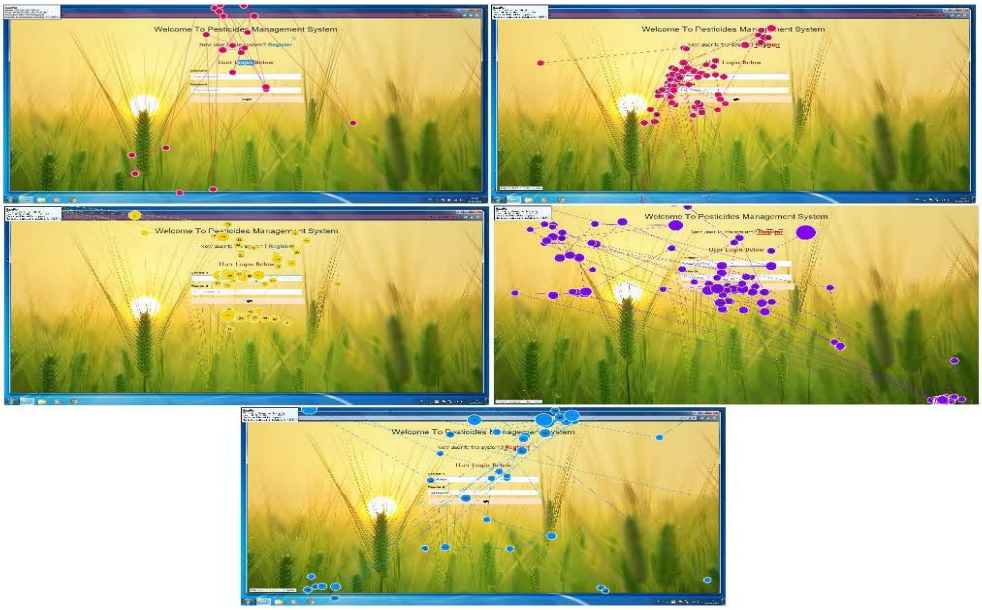
The validation phases of the pesticides authenticity verification system has been of success as the SUS score is above the average score. This proves the acceptability of the system to its intended stakeholders. Despite good rating of the system, there was a challenge in maintaining the same participants for the final testing phase. This caused a longer duration for the test arrangements and test completion, which took longer than expected. All preliminary test participants returned for the final testing phase.

6. Conclusion and Outlook

All in all the developed pesticides authenticity verification system has been a success, which is evidenced by the increase in SUS score from preliminary to final testing phase. Adoption of this system by the pesticides regulatory authority in Tanzania promises relief to other pesticides stakeholders within the country.

In the future the reply message when user requests authenticity can contain an image of the product for users to match with the real product in front of them. Also authenticity request can be changed from text entering to image processing. This shall help in minimizing errors during entering of the batch number and pesticides product registration number.

Appendix 1: GazePlots for five participants



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THE NELSON MANDELA AFRICAN INSTITUTION OF SCIENCE AND TECHNOLOGY (NM-AIST)

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Research Title: A Mobile based System for Pesticides Authenticity Verification: A case of Tanzanian Market

Introduction

Pesticides authenticity plays a great role to human health and environmental protection also economic progress of users, dealers and the government benefits through levies. In order to ensure that authentic pesticides are sold in Tanzania, laws have been enacted and government bodies given mandate to enforce these laws. Despite the efforts, counterfeits are found in markets. Companies that spend a lot in research so as to come up with authentic pesticides products end up losing hope as there is no substantial return in investment.

This study targets on an ICT based solution for pesticides authenticity verification in the market which is a case study of Arusha region. In order to prove the need for the solution, literature review has been done and presentation of data gathered from the identified three groups of pesticides stakeholders, which are pesticides regulatory authority, pesticides registrants/formulators/importers and pesticides users preferably farmers.

The findings from the collected data show that despite high awareness on availability of counterfeits among users, still most of them declared to have been buying counterfeits. Hence, there is a need of more reliable ICT based solution to help pesticides users in authenticity verification of products during purchase. Also provides a room for users to report complaints for products which haven't performed as expected.

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Objectives

- **General Objective:** To develop a mobile based system for pesticides authenticity verification
- **Specific Objectives:**
  - To identify and analyze requirements for the mobile based system for pesticides authenticity verification
  - Design and coding of a mobile based system for pesticides authenticity verification
  - Validation of a mobile based system for pesticides authenticity verification

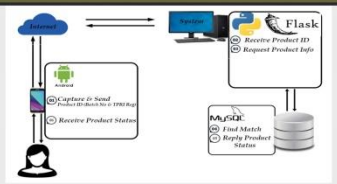

Figure 1: *Research Framework*

System Functionalities

- **The pesticides authenticity verification system comprises two parts,** which is the mobile and web application
- **Mobile application part:** supports products authenticity verification, complaint reporting and tips on the safety measures in using pesticides products
- **Web application part:** supports pesticides information management and maps showing location of products which haven't found match in the database (counterfeits pesticides)

Figure 2: *Main page*

Figure 3: *"Uliza Ubora" page*

Figure 4*: When the requested product info is found*

Figure 5: *When requested product info not found*

Figure 6: *"Ripoti Tatizo" page*

Future work:

This study presented a solution which is based on mobile application, so only pesticides user with smartphones are able to utilize the services provided. But in future, the system can interact with USSD codes so as to support accessibility for users-having featured phones. By doing this the market for authentic pesticides will be nourished for the betterment of pesticides stakeholders in Tanzanian market.