DETERMINING THE UPTAKE OF ICT, GIS, RS, AND 4IR TECHNOLOGIES IN IMPROVING FOOD SECURITY IN THE AGRICULTURAL SECTOR IN GAUTENG PROVINCE, SOUTH AFRICA

by

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DECLARATION

I, Khathutshelo Mafenya (Student Number: 51100983), declare that this thesis has been written solely by me and that it has not been submitted, in whole or in part, in a previous degree application. The work presented is entirely mine, except were stated otherwise by reference or acknowledgments.

04/12/2023

Signature **Date**

DEDICATION

I dedicate this research to my wife Nomsa Mafenya and my children, Zwivhuya, and Khano for putting up with my stress and encouraging me during my research period.

This research is also dedicated to my late father, Simon Mafenya, and mother, Selina Mafhenya, they took good care of me and encouraged me to work hard in school.

I would like to thank my brother Micheal Mafhenya and my nephew Mashudu Mafhenya for their continuous support during the research process.

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ABSTRACT

Food insecurity has long been a problem in South Africa, with 6.5 million people (11% of the population) suffering from hunger in 2019. South Africa should, due to rising demands for food in urban areas, notably in Gauteng, the most populated province, enhance its efforts for food production. The aim of the study was to evaluate the uptake of ICT, GIS, RS, and 4IR technologies by the agricultural sector in improving food security in the Gauteng province of South Africa. The study objectives were to investigate the uptake of ICT, GIS, RS, and 4IR technologies by agricultural support divisions in government, assess and map the uptake of these technologies by smallholder and commercial farmers, assess the implementation of GIS and RS in local farms including available government support, as well as to assess and map underlying conditions that promote or discourage the uptake of these technologies in Gauteng. The literature review underscores the transformative impact of advanced technologies, such as ICT, GIS, RS, and 4IR, on agriculture, significantly enhancing productivity and sustainability. Precision farming, AI, robotics, UAVs, IoT, and big data have transformed agricultural practices, enabling efficient resource management and improved yields. Nevertheless, poverty and inadequate resources hinder the adoption of technology by smallholder farmers in South Africa. There is a digital divide between commercial and smallholder farmers in terms of the uptake of ICT, GIS, RS, and other 4IR technologies. Food security and agricultural productivity can be improved in Gauteng Province through the adoption of these digital technologies. A mixed methods approach, through a concurrent triangulation data collection design, was employed in the study. This means both qualitative and quantitative data were collected and analysed simultaneously. The study was conducted through a cross-sectional survey of N=150 farmers, N=60 GDARD personnel, and face-to-face interviewing of N=26 DALRRD personnel as well as researcher observations of N=6 farms. Research findings show that many commercial farmers have adopted 4IR technologies, although the uptake by smallholder farmers remains low. Results suggest that the high 4IR adoption by commercial farmers can be attributed to affordability, whereas low uptake by smallholder farmers can be due to a lack of funds and level of education. It is recommended that DALRRD and GDARD do not neglect smallholder farms and provide advanced ICT, GIS, RS, and 4IR training to smallholder and commercial farmers. This research work only focused on the Gauteng province so future research work could focus on adapting and improving the methods presented in this study for investigating the uptake of these technologies in other provinces to better understand the general status quo for the whole country.

Keywords: GIS, ICT, RS, 4IR, Food security, Farmers, GDARD and DA

LIST OF ABBREVIATIONS AND ACRONYMS

GIS – Geographic Information System

RS – Remote Sensing

ICT – Information Communication Technology

4IR – Fourth Industrial Revolution

VETS - Veterinarians

GDARD – Gauteng Department of Agriculture and Rural Development

GDARDE – Gauteng Department of Agriculture, Rural Development and Environment

DALRRD – Department of Agriculture, Land Reform, and Rural Development

GAPA – Gauteng Agriculture Potential Atlas

IoT – Internet of Things

GNSS - Global Navigation Satellite System

MSS - Multispectral Scanner System

AI - Artificial Intelligence

PA - Precision Agriculture

GPS- Global Positioning System

MMR - mixed-method research

UN – United Nations

Kernel Density Estimation (KDE)

CASP - Comprehensive Agricultural Support Programme

AgriBEE – Broad-Based Black Economic Empowerment

IFSNP - Integrated Food Security and Nutrition Program

IFSS - Integrated Food Security Strategy

TMR - Transformation, Modernization, and Re-industrialization

AWS - Amazon Web Services

WSNs - Wireless Sensor Networks

UAVs - Unmanned Aerial Vehicles

SaaS - Software as a Service

PaaS - Platform as a Service

IaaS - Infrastructure as a Service

WEF - World Economic Forum

PDA - Personal Digital Assistant

NIST - National Institute of Standard and Technology

CC - cloud computing

StatsSA - Statistics South Africa

TER - Township Economic Revitalization

Leaf area index (LAI)

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CHAPTER 1: INTRODUCTION

1.1. Background

Food security is a global challenge with predictions indicating that by 2050, farming will have to feed 9 billion people, meaning that the demand for food would have increased by 60 % (Breene, 2016). The United Nations (UN) aim is to end hunger by 2030. Through its Sustainable Development Goal 2: Zero Hunger, its objective is to promote sustainable agriculture and ensure food security (National Geographic Society, 2023). This issue makes food security a priority for all countries regardless of whether a country is developed or still developing (Breene, 2016). The South African constitution explicitly articulates the right of every citizen to have access to water, food, and social security. It is in this context that the South African National Department of Agriculture, Land Reform & Rural Development (DALRRD) was given a mandate to, among others, make sure that opportunities are created to inspire South Africans to participate in agriculture to help improve food security in the country. To this extent, the DALRRD has introduced a set of initiatives that are intended to enhance food security in South Africa (Du Toit, 2011). These programs include, inter alia, (A). Comprehensive Agricultural Support Program (CASP), (B). Agricultural Broad-Based Black Economic Empowerment (AgriBEE), (C) Integrated Food Security and Nutrition Program (IFSNP), (D) Small Holder Farmer Evaluation.

Moreover, a comprehensive agricultural support program (CASP) was launched in 2004 to encourage agricultural production among previously disadvantaged communities. One of the main objectives of the CASP program is to provide post-settlement assistance. The program includes six pillars of nonfinancial support for smallholder farmers and cooperatives: agricultural extension, research and development, information dissemination, market access, capacity building, and infrastructure access, to enhance sustainability and commercial viability for land reform beneficiaries and emerging farmers. Agricultural Broad-Based Black Economic Empowerment (AgriBEE) is a framework used for sectoral Black Economic Empowerment aimed at supporting Black South Africans to actively participate in the agricultural sector as owners, consumers, professionals, managers, and skilled employees through deliberate and systematic support. To address the imbalances of the past, it offers a wide range of social and economic benefits.

The adoption of smart farming practices and Fourth Industrial Revolution (4IR) technologies can assist in ensuring the successful implementation of the above-mentioned programs at national and provincial levels. For example, in the CASP program, technology can help to improve advisory services and access to information, improve farming efficiency, and link farmers to the market. This program will lead to efficient and sustainable ways of farming, enabling farmers to produce more food and increase profits. When this research was conducted, the Gauteng Department of Agriculture and Rural Development (GDARD) changed its name to the Gauteng Department of Agriculture, Rural Development and Environment (GDARDE). For consistency with the referred literature cited in this research work, the name GDARD will be used throughout the study as was applicable during data collection. GDARD, like other provincial agriculture departments, has the mandate to implement programs such as CASP, AgriBEE, IFSNP, and Integrated Food Security Strategy (IFSS) as well as to ensure that residents in the Gauteng province are aware of the services that the organisation provides. In GDARD, the agricultural branch consists of three directorates who are responsible for developing and supporting farmers to improve food security; advising farmers on new technologies that can assist in improving agriculture; and lastly, assisting farmers with Agro-processing, pricing, and marketing their products (Mayathula-Khoza, 2010).

Collett (2014) explains that agricultural land protection plays a key role in ensuring food security in South Africa. Land with high agriculture potential makes up only about 3% of the country's surface. For the remainder, there is a lot of pressure from many stakeholders to utilise high-potential agricultural land for non-agriculture uses and other developments. Although Geographic information systems (GIS) have enabled researchers to demarcate this land, they lament its lack of incorporation into national planning.

With the advent of the 4IR, Gauteng province can benefit by leveraging some of its technologies in the farming sector to improve food production. This study focused on assessing the uptake of smart farming technologies by local Gauteng farmers. Technological innovations that were considered in this study that could be adopted by Gauteng crop and livestock farmers include UAVs, the Internet of Things (IoT), Artificial Intelligence (AI), Big Data, robotics, and the application of geospatial sciences such as Remote Sensing (RS) and Geographic Information Systems (GIS).

1.2 Problem Statement

Food insecurity has long been a problem in South Africa, with 6.5 million people (11% of the population) suffering from hunger in 2019, as reported by Statistics South Africa (2019). South Africa, owing to the increasing demand for food in expanding urban areas such as those in Gauteng, should increase food production to address the local demand. The ICT, GIS, remote sensing, and 4IR technologies can assist farmers in improving food production in the Gauteng Province. This issue can be addressed through improved crop management and site-specific precision agriculture. The uptake of these technologies has the potential to reduce the importing of agricultural products such as wheat, rice, beans, corn, and soya. These technologies will also assist in analyzing what can be cultivated where and during which season.

A significant information gap exists in Gauteng's agricultural sector regarding ICT, GIS, RS, and 4IR adoption and impact, which inhibits effective policy development. By assessing current technology use, identifying barriers, and exploring integration pathways, this study seeks to bridge this information gap. Study innovation lies in its systematic exploration and application of ICT, GIS, RS, and 4IR technologies in Gauteng's agricultural sector, as well as its tailor-made approach to identify and address barriers preventing their broader adoption. By investigating these technologies innovatively and sustainably, the research aims to provide strategic insights and practical recommendations.

1.3. Research Questions, Aim, and Objectives

1.3.1 Research Aim and Objectives

The purpose of this research was to evaluate the uptake of ICT, GIS, RS, and 4IR technologies by the agricultural sector in improving food security in the Gauteng province of South Africa. The objectives of the study were to:

a) investigate the uptake of ICT, GIS, RS, and 4IR technologies by agricultural support divisions in government

b) assess and map the uptake of ICT and 4IR technologies by smallholder farmers.

c) assess and map the uptake of ICT and 4IR technologies by commercial farmers.

d) assess the implementation of GIS and RS in local farms including support.

e) and to assess and map the underlying conditions that promote or discourage the uptake of ICT, GIS, RS, and 4IR in Gauteng.

1.3.2. Research Questions

The main research question to be addressed in the study is: “What significant role ICT, GIS, RS, and 4IR technologies can play in the agricultural sector to improve food security within Gauteng?”

To find out how ICT, GIS, RS, and 4IR Technologies can influence food production in Gauteng province and to collect more information about the research problem, this study will seek out answers to the following questions:

a) How is the uptake of ICT and GIS by the government agriculture department in Gauteng, do they have a GIS section, how functional is it in terms of personnel, software, and hardware, and are these departments and their people GIS-enabled?

b) How is the uptake of ICT and 4IR technologies by smallholder farmers?

c) How is the uptake of ICT and 4IR technologies by commercial farmers?

d) How can the implementation of GIS and RS in local farms improve the harvest, is there GIS and RS support that feeds the farmer even if he does not do the analysis himself? For example, are there people who model drought using GIS and RS and inform farmers in Gauteng?

e) What are the underlying conditions that promote or discourage the uptake of ICT, GIS, RS, and 4IR in Gauteng?

1.4. Significance of the proposed research

Research in South Africa over the last decade or two has enhanced the knowledge of ICT, GIS, and Remote Sensing (RS) that can be used as tools to improve food security through agriculture. However, with the advent of the Fourth Industrial Revolution (4IR) technologies available, there is a need to investigate how recent ICT, GIS, RS, and 4IR technologies can grow our economy through improved food security. This study contributes to the knowledge base of the agricultural sector by evaluating the uptake of these technologies and how they can improve food security in the Gauteng province.

This research work has explored, defined, mapped, and provided insights into the technologies currently being used in the Gauteng province and how newer 4IR technologies can be used in the agricultural sector. In particular, the study focused on the use of GIS in improving food security, the significance of survey applications and crowdsourcing to collect agricultural information, the use of satellite imagery to amplify agriculture, e-government direct services, Gauteng e-agriculture, the use of UAVs in agriculture to improve food security, the importance of ICT in agriculture, Big Data, and data analytics in agriculture. The study provided insights on how to use crowdsourcing, UAVs, AI, the internet of things, smart farming, robots, etc, and how to improve the collection of agricultural information, assist in mapping, spraying, and monitoring crops to improve food security, and further assess how can these technologies assist in reducing theft at the farms, and lastly improve productivity in smallholder and commercial farms.

Findings from this study could potentially benefit communities/societies of Gauteng as agriculture plays a vital role in fighting food insecurity, increasing job opportunities, and growing the local economy in general. In Venda, there is a saying “Lupfumo luma vuni,”, meaning there are riches in the soil. The study developed guidelines, which could potentially be implemented by GDARD as one of the key agricultural stakeholders with a mandate to ensure food security through agriculture in the Gauteng province. The study has also documented knowledge of available smart farming tools that can be adopted by farmers and extension officers to improve yield. Mapping and understanding the distribution of the areas with uptake, partial uptake, and no uptake in Gauteng province, could assist the extension officers in developing their approaches in assisting and educating farmers.

GIS, ICT, and Remote Sensing service providers can also benefit from this study by identifying the gaps that require their expertise in the Gauteng province. In essence, service providers can develop solutions and present them to farmers, farming organizations, and government agriculture departments. This study lays a benchmark for similar studies in other SA provinces.

1.5. Study area

The study area is Gauteng, as indicated in Figure 1.1. Gauteng means “Home of Gold” in the Sotho language and is one of the nine provinces of South Africa. In terms of the area size, Gauteng is the smallest province in the country covering 1.40 % of the land area, with 19.70% of the South African population residing in Gauteng (Statistics South Africa, 2014). The map below indicates where Gauteng Province is located South Africa.

Agriculture contributed 2.47% to the gross domestic product of South Africa in 2021, and industry and services, 24.50% and 63.02 %, respectively (O'Neill, 2023). According to Statistics South Africa (2021), the Western Cape province were the biggest the contributors to revenues in 2021 in terms of agricultural and related services (19.50% of the industry's total) at R74.9 billion, followed by Free State (R51,1 billion), Gauteng (R46.4 billion or 12.0%) and Northwest (R45.7 billion or 11.80%). According to Alexander (2021), finance, real estate, and business services make up almost a quarter of Gauteng’s economy, followed by general government services (19%) and manufacturing (14%), while agriculture, forestry, and fishing contribute the least (0.50%).

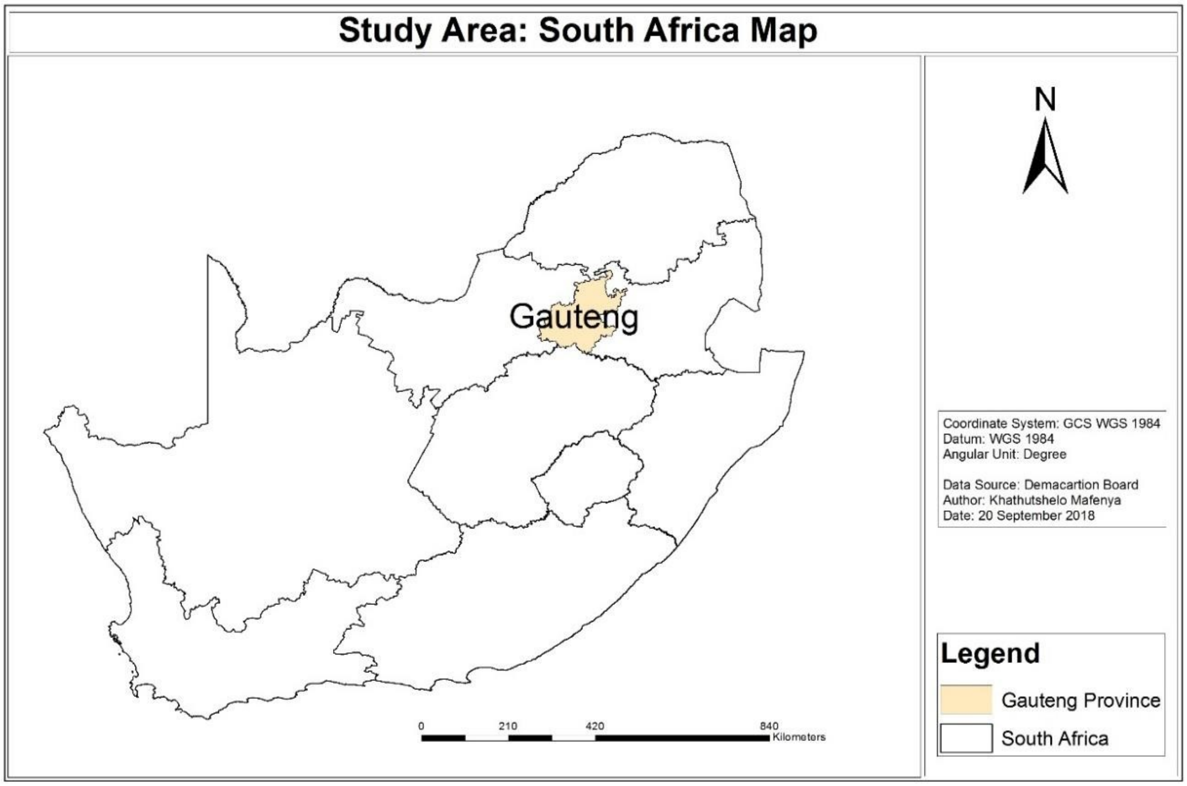


Figure 1.1: South African Map (Data source; Demarcation Board).

Gauteng province was chosen as the study area because it is small but hosts a big population that is still rapidly growing. Following the census 2022 results, Gauteng has become the most populated province in South Africa, passed Kwazulu-Natal. This research work investigates how available technologies can improve food production to sustain this fast-growing population (Statistics South Africa, 2023).

According to Statistics South Africa (2023), Gauteng has the highest population (15 million), while the Northern Cape has the smallest (1.3 million). In all, Gauteng, KwaZulu-Natal, and the Western Cape account for 56% of the country's population. Gauteng has three metropolitan municipalities and two district municipalities (Statistics South Africa, 2019), refer to the map in Figure 1.2.

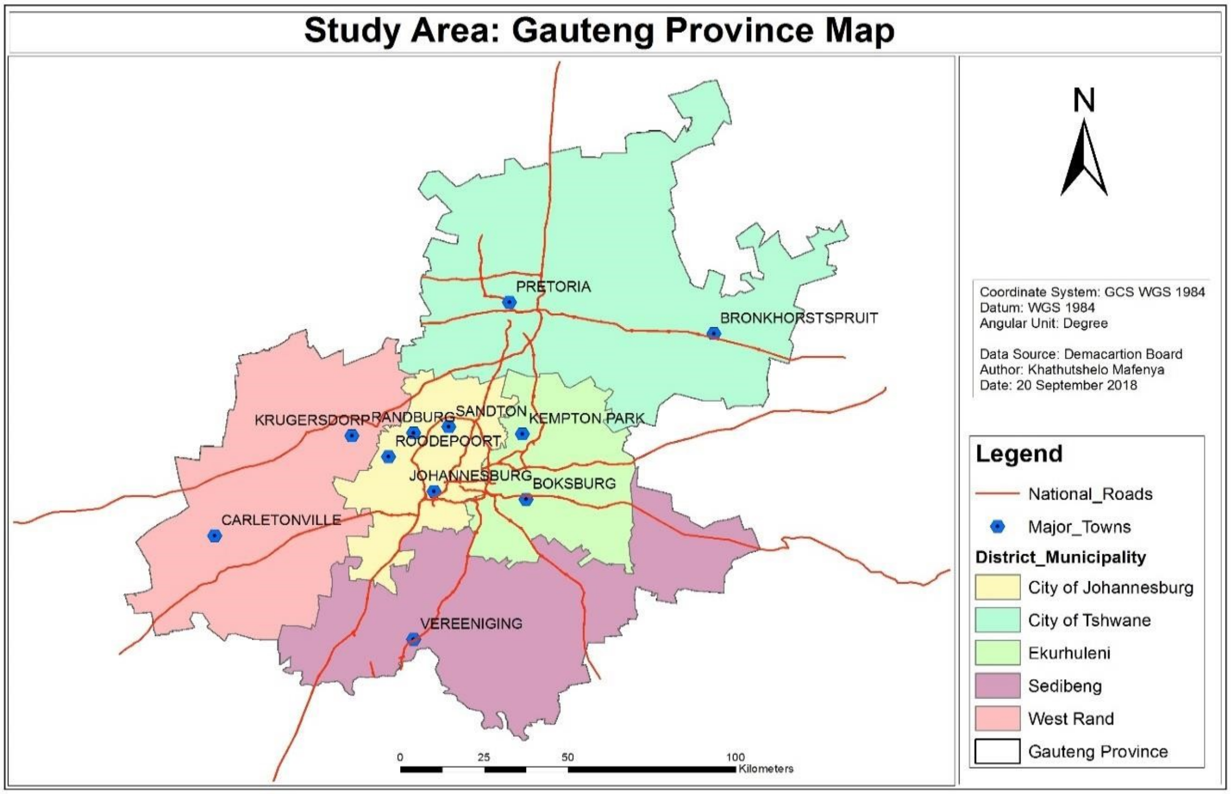


Figure 1.2: Gauteng Province Map (Data source; Demarcation Board)

According to GDARD (2016), Gauteng's agriculture and food industry has undergone major structural changes. A variety of factors have contributed to these changes, such as in-migration and urbanisation, resulting in Gauteng, the smallest province, being the most populated, a host to 25% of the country's population. Gauteng introduced the Agri-parks program, a one-stop destination for farmers in the agri-food value chain.

Agricultural parks are the continuation of agriculture hubs that emphasise the importance of agricultural development zones aimed at achieving volume, increased competitiveness, and sustainability while making judicious use of limited resources, and contributing to the economic growth of Gauteng. Figure 1.3. shows the location of Agriculture hubs (parks) in Gauteng (GDARD, 2016).

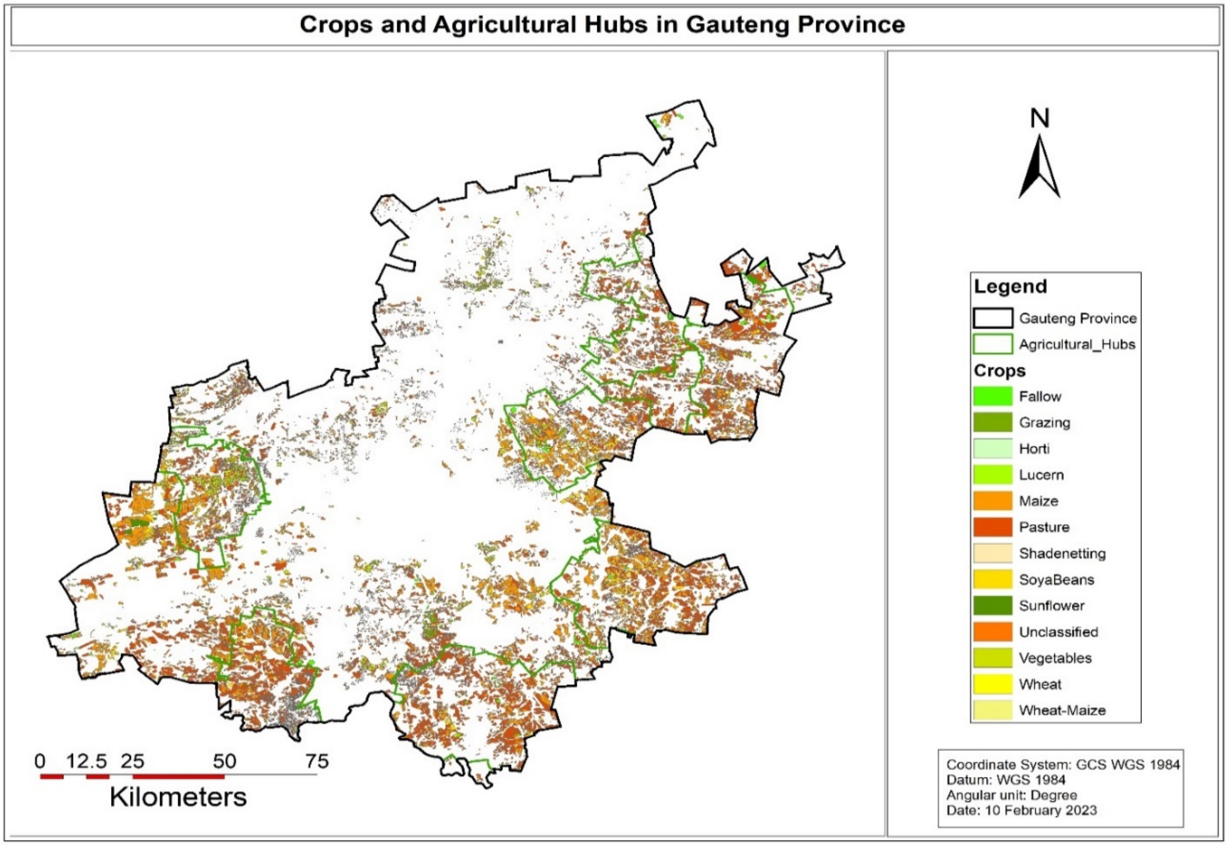


Figure 1.3: Map for Crops and Agriculture hubs in Gauteng province (Data source; GDARD).

Gauteng Agri parks form the backbone of the Transformation, Modernisation, and Re-industrialisation (TMR) pillars. Since these Agri parks are in urban and peri-urban areas, they have a strong economic link with the townships nearby. Agri parks are part of the Township Economic Revitalisation (TER) program. Investments in modern technology such as Hydroponics Vertical Chambers at Westonaria Agri Park have prioritised innovative and modern technology, thus attracting a greater number of young people to agriculture (GDARD, 2016).

Figure 1.4 shows that the livestock commodity value chain contributes 59% to agricultural output in Gauteng Province. Gauteng Agri Parks prioritise high-value vegetables over the horticulture value chain. At the Mega-Agri Park, grain is given priority within the Sedibeng District Municipality (GDARD, 2016). Most of the province's agriculture is devoted to vegetable production. Southern sectors of the province are devoted to commercial agriculture (part of South Africa's maize triangle), while areas near Bronkhorstspruit (east) and Heidelberg (south) are devoted to cotton, groundnuts, and sorghum production (Global African Network, 2021). The South African Poultry

Association (2021) reports that Gauteng has the highest percentage of laying hens (26.60%) in the country. A quarter of the country's eggs are produced in Gauteng, as well as 9.60% of its broilers (South African Poultry Association, 2021).

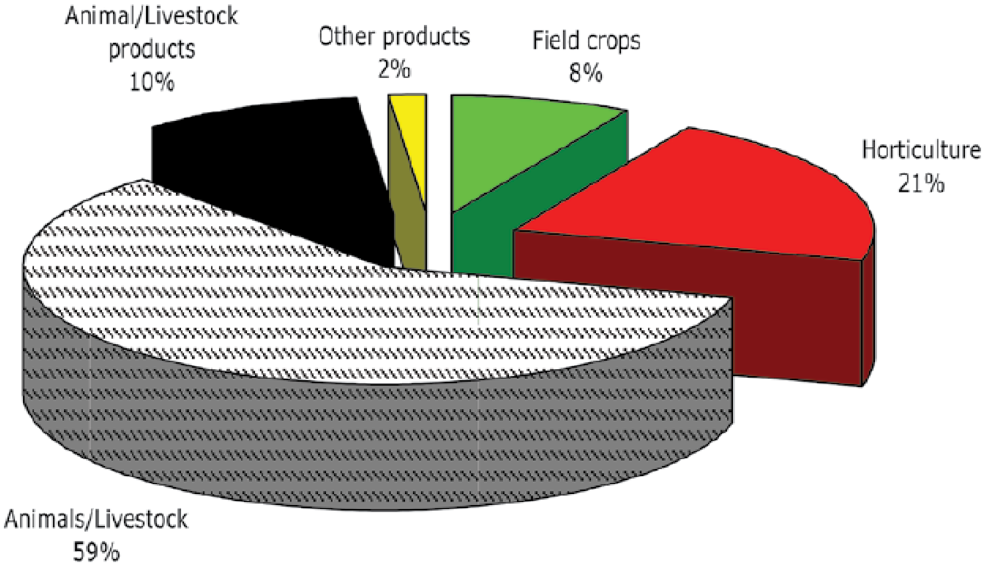


Figure 1.4. Gauteng agricultural outputs.

Gauteng province produces 11% of the country's pigs (DALRRD, 2023). Despite not having much milk production, it has 32% of the country's milk processors and 22% of its producer-distributors (Milk Producers’ Organization, 2023). Maize (4%) and soybeans (4%) are the two major crops (DALRRD, 2023). Despite accounting for only 4.86% of South Africa's agricultural production and 6% of all High Potential Agricultural Land (HPAL), Gauteng produces almost 25% of the country's eggs (GDARD, 2019).

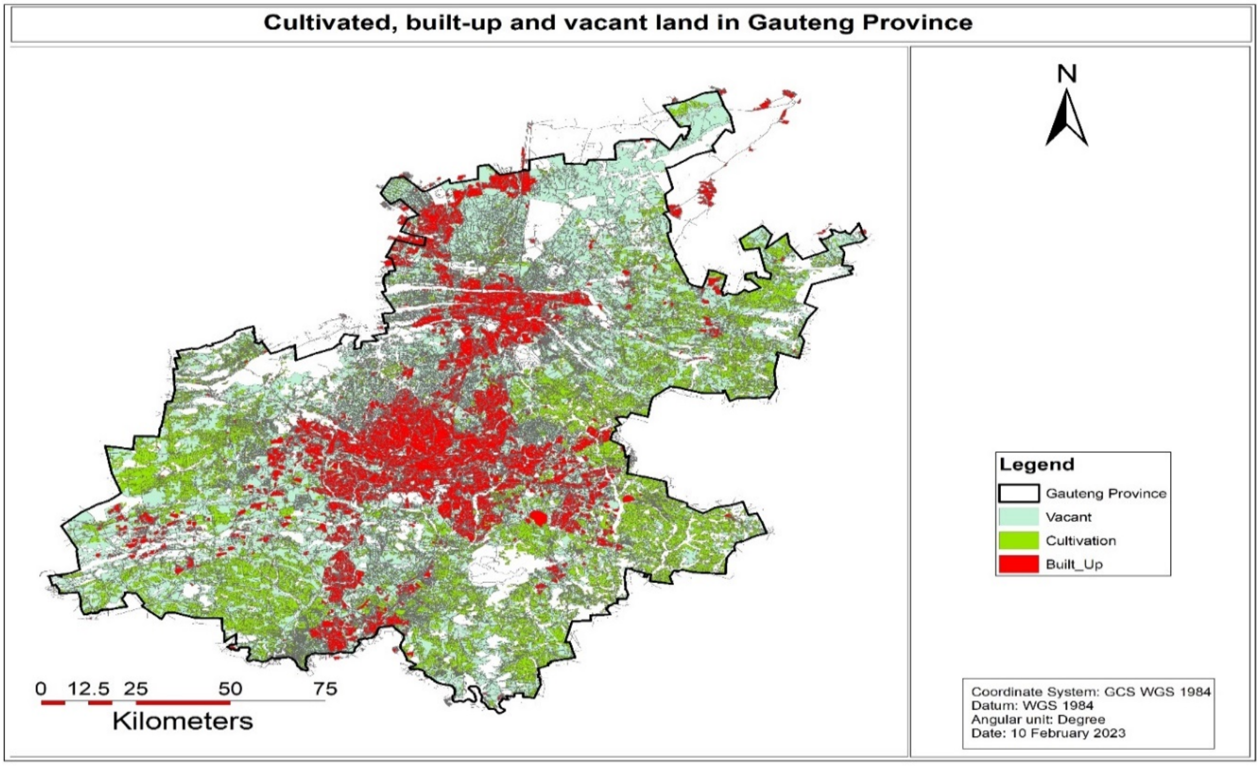


Figure 1.5: Map showing cultivated, built-up, and vacant land in Gauteng Province.

Gauteng has a total surface area of 1.818 million hectares. The term "cultivation" refers to all cultivated fields, whether they are rain-fed or irrigated. In addition, it includes seasonal and annual crops, as well as pastures planted for grazing. A total of 21.40% of the Gauteng province's land area is cultivated (GDARD, 2019). Approximately 3% of the country's arable land is in Gauteng (Statistics South Africa, 2020). A built-up area has been transformed permanently and is no longer suitable for farming. There is a total area of 334 224 ha built-up areas, including roads, railways, and mines, representing 18.40% of the total provincial land area (GDARD, 2019).

According GDARD (2019), vacant land, for purposes of GAPA, is defined as all open areas, excluding: (i) all buildings, roads, railway lines, and mines (built-up); (ii) wetlands buffered according to legal requirements (NEMA Act); (iii) rivers and riparian zones buffered according to legal requirements (NEMA Act); (iv) surface water – natural and built; (v) ridges (steep places with protected vegetation); (vi) Gauteng Conservation Plan (CPlan) Critical Biodiversity Areas (CBAs); (vii) designated protected areas at the National and Provincial level and (viii) existing cultivated areas. In Gauteng province, vacant land accounts for 60.20% of the total land area.

The Gauteng Conservation Plan Version 3.3 was produced by Gauteng Nature Conservation, a component of the Gauteng Department of Agriculture and Rural Development (GDARD). In C-Plan 3.3 Critical Biodiversity Areas consisting of irreplaceable, important, and protected areas are all integrated into one layer (Compaan and Pfab, 2011). Gauteng Conservation Plan is an essential tool for implementing NEMBA's national biodiversity mandate in Gauteng. According to the plan, areas must be conserved to ensure the survival of a representative and sustainable sample of the province's biodiversity, converted land uses need to be avoided, land uses incompatible with biodiversity need to be avoided, and special management measures must be taken to protect and maintain biodiversity (Pfab et al., 2017).

There are 1 250 smallholder farmers in Gauteng Province on the DALRRD farmers register. This is a database of all South African farmers. Smallholder farmers are shown in Figure 1.6. There are 53 commercial farmers registered on the farmer register. As a result of the Census of Commercial Agriculture 2017, Gauteng is at the bottom of the list of provinces with farms (5.70%), including farmers who are registered and not. The amount of commercial agricultural land is 0.80%, and the number of commercial agricultural employees is 4.80% (Statistics South Africa, 2020).

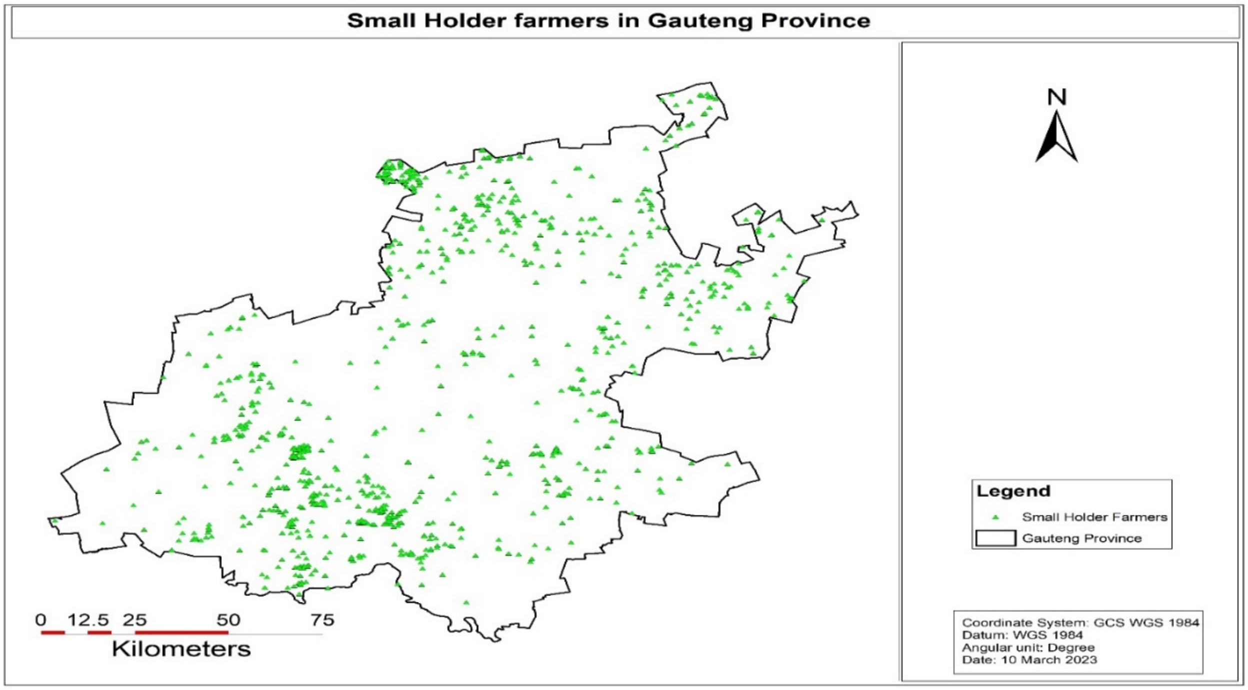


Figure 1.6: Map showing the location of smallholder farmers registered on the farmer register (Data Source: DALRRD).

1.7. Conclusion

This Chapter presented the background, problem statement, study aims and objectives, research questions, significance of conducting the research, and study area. A detailed literature review on the uptake of ICT, GIS, RS, and 4IR technologies in improving food security in the agricultural sector by both developed and developing countries will be discussed in Chapter 2. Also, in Chapter 2, the theoretical framework for this study will be discussed.

1.8. Chapter Outline

Chapter 1 of the thesis contains the introduction, background and theoretical framework of the study, problem statement, research aim and research question, the study area, feasibility, and significance of the research.

Chapter 2 discusses the context and background of the study through a literature review.

In Chapter 3, This chapter discussed the research methodology and its application to the study. It covers the research approach, research design, and sampling procedures employed. Additionally, it provided details on the instruments used for data collection and analysis. Finally, the chapter addressed the study's limitations and ethical considerations.

In Chapter 4, This chapter presents the findings from the data collected through survey questionnaires, interviews, and observations. The participants included farmers from the Gauteng province and officials from GDARD and DALRRD. The researcher presented, analyzed, and interpreted both quantitative and qualitative findings, aligning them with the study's objectives.

In Chapter 5, This chapter provides a summary of research findings, conclusions, and recommendations. GDARD and DALRRD officials have modern tools but lack sufficient mobile data, suggesting the need for robust tablets and an integrated system. Commercial farmers embrace 4IR due to affordability, contrasting with smallholders facing financial and educational barriers. Recommendations include adopting integrated systems, promoting technology, and supporting smallholders, with a call for future research in other provinces.

CHAPTER 2: LITERATURE REVIEW

2.1. Introduction

The current state of Remote Sensing (RS), Geographic Information Systems (GIS), Information and Communications Technologies (ICT), and the Fourth Industrial Revolution (4IR) uptake by farmers in developed, developing countries, Africa, and South Africa will be discussed in this chapter.

2.2. The role of ICT, GIS, 4IR, and Remote Sensing technologies in Agriculture and other sectors

In this section, the following terms will be described and their application in agriculture; the Fourth Industrial Revolution, Information Communication Technology, Geographic Information Technology, and Remote Sensing. Further explanations of 4IR technologies will be provided in this section. These technologies include smart agriculture, precision agriculture, the Internet of Things, unnamed aerial vehicles, artificial intelligence, big data, vertical farming, cloud computing, and cyber security.

2.2.1 The Fourth Industrial Revolution technologies

"Revolution" refers to a sudden and radical change in society. New technologies and new ways of seeing the world have driven revolutions throughout history, resulting in radical changes in social structures and economic systems (Schwab, 2016). Industrial revolution (IR) refers to a time when technological progress has led to dramatic and tremendous changes in people's lives and countries' economies (Olaitan, et al., 2021). Then Tripathi & Gupta (2021) defined 4IR as the transformation to novel systems, which bring together the physical and digital technologies to an increasingly interconnected population of active users.

Schwab (2016), points out that our way of living changed dramatically after the transition from foraging to farming around 10 000 years ago, enabled by the domestication of animals. In the agrarian revolution, animals and humans worked together to produce, transport, and communicate. Food production improved little by little, spurring the growth of the population and enabling the settlement of larger populations. Eventually, this led to urbanisation and the rise of cities. During the second half of the 18th century, a series of industrial revolutions followed the agrarian revolution.

As a result, muscle power gave way to mechanical power, evolving into what is known as the fourth industrial revolution, where cognitive power is augmenting human production.

2.2.1.1 First to Fourth Industrial Revolution

Worldwide, there have been three major industrial revolutions (Olaitan, et al., 2021). In Schwab (2017)'s view, the First Industrial Revolution (1760–1840) introduced mechanical production, which was sparked by the steam engine and the construction of railways. One of its key applications was automating the textile industry and moving production from homes to factories. Thirty years later, the second industrial revolution (late nineteenth century–early twentieth century) began, which led to mass production (Sung, 2014). A conveyor belt was introduced in conjunction with the distribution of electricity. The third revolution began in the 1960s. It is sometimes referred to as the computer revolution or digital revolution since it was sparked by semiconductors, mainframe computing in the 1960s, personal computing in the 1970s, and the internet in the 1990s (Schwab, 2016). The accumulated computational base was the catalyst for the informatisation of society and the development of information technologies (Schwab, 2017). As a result of electronics and information technology, production started to be automated (Sung, 2014).

We are in the early stages of the Fourth Industrial Revolution now (Olaitan, et al., 2021). The Fourth Industrial Revolution began at the beginning of the new millennium (Olaitan, et al., 2021) Schwab (2016) describes the digital, physical, and biological worlds as interconnected by using terms such as "industry 4.0," "smart industry," "smart factory," and "smart manufacturing." Figure 2.1 demonstrated the evolution from the 1st to the 4th Industrial revolutions and how each evolution impacted the agriculture sector.

Ayentimi (2020) notes that past industrial revolutions have typically led to greater growth and economic development in developed economies than in less developed or developing economies. In developed countries, 4IR technologies are at an advanced stage, and their wave is now spreading to developing countries (Olaitan et al., 2021). Schwab (2016) suggests that developing countries will be able to provide more products and services with the application of emerging technologies under 4IR. This is known as the digitalisation of production (Schroeder, 2016). According to Adendorff and Collier (2015), artificial intelligence has the potential to reduce the cost of goods and services, which would ease people's lives.

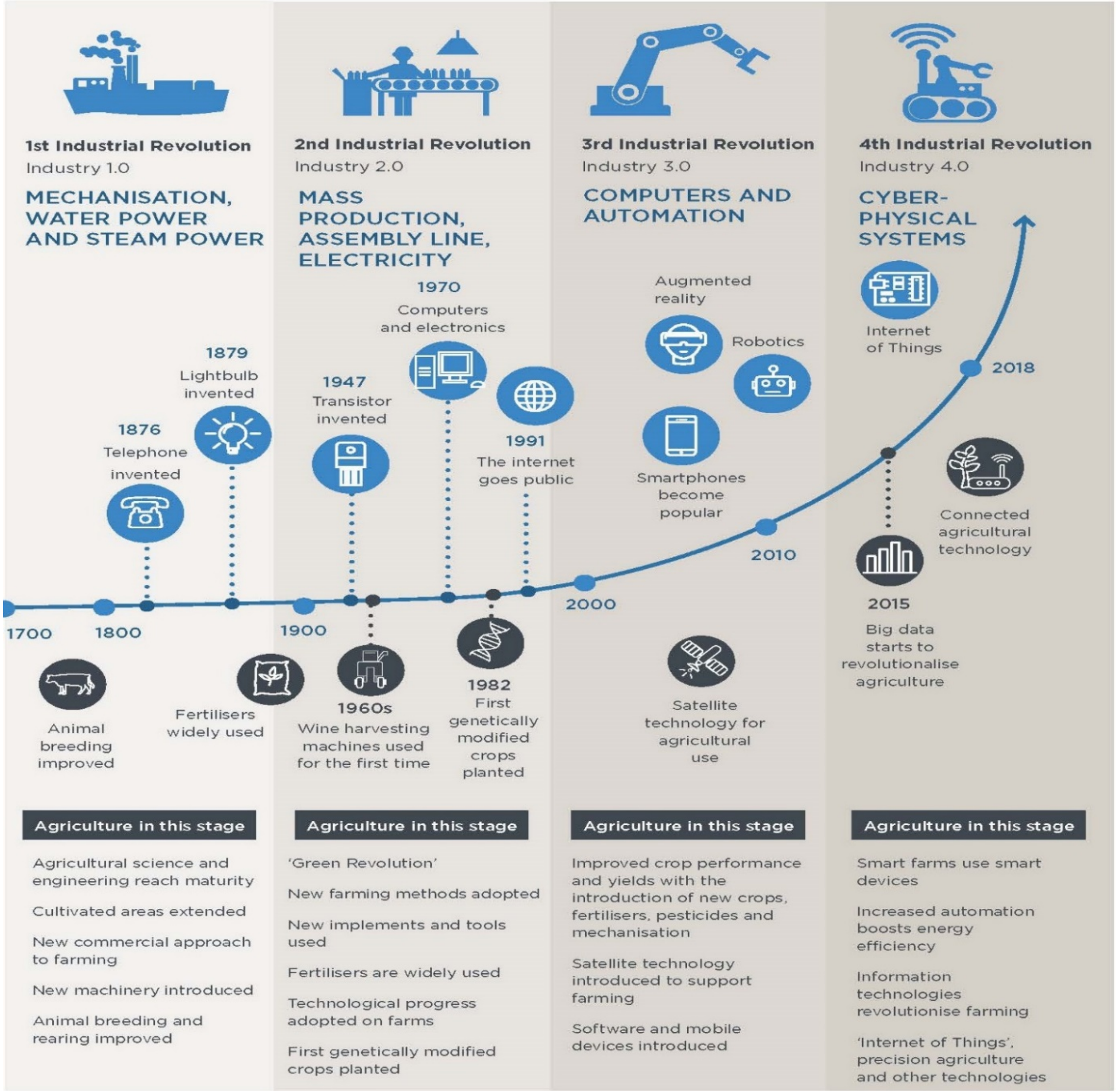


Figure: 2.1. Evolutions from the 1st to the 4th Industrial Revolutions (WCDoA/USB, 2017).

Cunningham (2018) asserts that 4IR is one of the most influential forces in shaping the modern world, radically reforming the way people live, businesses, and the industrial sector. Digitally ready countries have the potential to achieve unprecedented levels of economic prosperity. Amongst the predicted benefits of the 4IR are the stimulation of human-machine relationships, machine-machine relationships, the enhancement of economic growth, and the opening of new markets (Adendorff and Collier 2015). In the context of new technologies, the nature of work and human relations at work will change, allowing for the emergence of new talent and skills.

FAO (2017) suggests that the dawn of a new era in agriculture is fast approaching because of dramatic advances in technology. The use of ICTs in agriculture has grown significantly over the past decade. Precision agriculture, cloud computing, AI, robotics, and big data analysis have all revolutionised agriculture in combination with the Internet of Things, cloud computing, and enhanced analytics. The advances in technology are bringing agriculture to a tipping point for a new era. In recent years, agriculture has benefited significantly from the use of ICTs. Technologies such as the Internet of Things, cloud computing, advanced analytics, precision agriculture, as well as artificial intelligence, robotics, and big data analytics, have revolutionised agriculture.

2.2.1.2 Smart industries, smart factories, and smart cities

Smart industries integrate IoT's ubiquitous sensing capabilities with industrial infrastructure to automate a wide variety of industrial operations (Kaur et al.,2015). Additionally, Breivold (2017) emphasised that smart industry will be achieved by embedding connectivity into industrial products, leveraging the Cloud and Internet of Things (IoT) to leverage intelligence and actionable knowledge for machines, integrating products, and adding value-added services.

Smart factories are defined as flexible production systems that rely on connected processes and digital technologies, which can learn from and adapt to new conditions in real-time to autonomously drive production processes (Burke et al., 2017). According to Hughes (2017), smart manufacturing is another term used in defining the area of digital manufacturing. The term describes a set of manufacturing practices that combines data with digital technology to manage and control manufacturing processes (Mittal et al., 2019). By implementing advanced industrial digital technologies, people have access to better information about manufacturing processes and operations.

With this level of information, manufacturing processes are improved, issues are diagnosed faster, and challenges are overcome in a relatively short period (Ahuett-Garza and Kurfess, 2018). This method constitutes a new approach to lean manufacturing, with people empowered with insights that lead to optimising productivity and enhancing flexibility (Angel, 2015).

The term "Smart City" first appeared in the 1990s. Following that, the focus was on the impact of Information and Communication Technologies on modern infrastructure within cities (Alawadhi et al., 2012). In smart cities, information, and communication technologies, including mobile networks, are extensively used to improve the quality of life for citizens in a sustainable way (GMSA, 2013). In a smart city, data is collected from intelligently connected infrastructures, people, and vehicles and shared across them, generating new insights, and enabling ubiquitous services that enable citizens to move around more easily, explore public services, improve the efficiency of city operations and security, fuel economic activity, and provide resilience to natural disasters (GMSA, 2013).

2.2.1.3 Smart Agriculture

According to Reddy et al. (2021), smart farming is the application of advanced technologies to increase the quality and quantity of agricultural products to increase the nutritional value of food. In smart farming, technology such as the Internet of Things (IoT) is used to replace traditional agricultural practices with modern ones. In the 21st century, farmers have access to smart phones, global positioning systems (GPS), Internet of Things technologies, and other data management gadgets. Data-driven and data-enabled farming processes are becoming increasingly data-driven as more advanced machines and sensors are integrated into farms.

In smart agriculture, AI, and the internet of things are used to maintain a cyber-physical farm (Bacco et al., 2019). Farmers can use the tools provided by smart agriculture (shown in Figure. 2.2.) to tackle several challenges related to farm productivity, environmental impact, crop losses, and sustainable farming. Smart agriculture enables the monitoring of various aspects of crop production, including soil characteristics, soil moisture, and climate factors. Internet of Things (IoT) technology has enabled remote sensors, such as robots, ground sensors, and drones, to be linked with each other and to be controlled automatically via the Internet (AlMetwally et al., 2020). Precision farming is mainly concerned with improving spatial management to enhance crop yields on the one hand and reduce the misuse of fertilizer and pesticides on the other hand (Amato et al., 2015; El-zeiny et al., 2017).

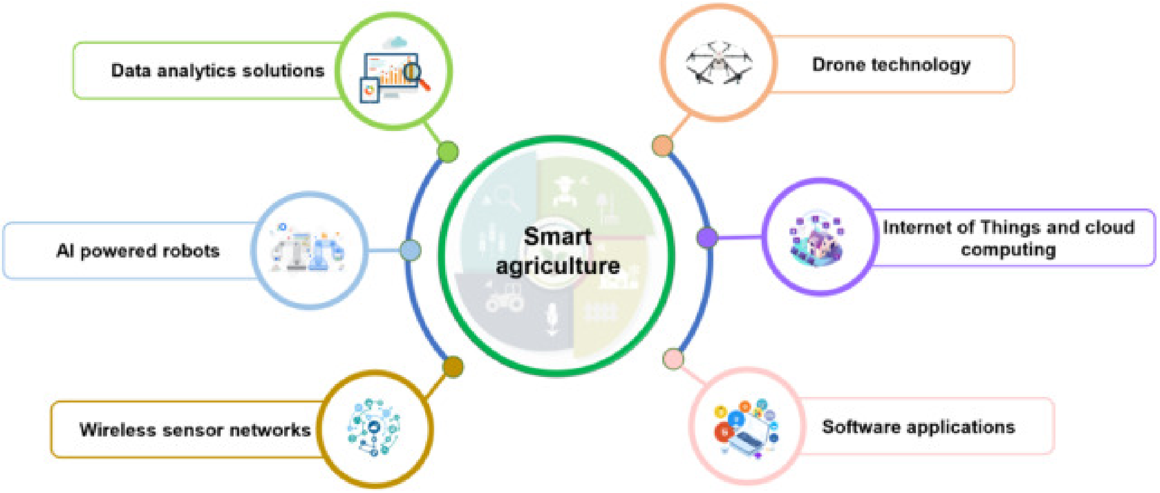


Figure: 2.2 The concept of “Smart Agriculture (Abbasi, 2022).

2.2.1.4 Precision Agriculture

Technologies such as smartphones, tablets, in-field sensors, UAVs, and satellites are widely used in agriculture. Through them, livestock and crops can be monitored remotely, the soil biophysical and biochemical constituents assessed and analysed remotely, water usage managed better. With the implementation of enhanced analytics, affordable devices, and innovative apps, the digitisation of farming is further enhanced. Precision agriculture research has allowed many types of sensors, as well as many farm management systems, to be used to record agronomically relevant parameters. Furthermore, digitalisation improves farmer working conditions while reducing environmental impacts in agriculture (Antić, 2018).

Several agricultural solutions were and are developed owing to the widespread use of digital technologies, including remote soil measurements, improved water management, and the monitoring of livestock and crops. Devices, analytics, and apps are facilitating the digitalisation of agriculture.

A recent example of precision agriculture research is the development of diverse sensors that farmers can use to live agriculturally relevant parameters similarly to manage their farms. Moreover, digitalisation reduces the impact of agriculture on the environment as well as assisting farmers to work more efficiently (Ozdogan et al., 2017).

2.2.1.5 Internet of things (IoT)

In agriculture, IoT refers to a type of network in which physical components relate to the internet through agricultural information perception equipment under specific protocols to exchange information and exchange communication. IoT has brought new developments to agricultural production. The result is not only an increase in agricultural output, but improvements in product quality, reduced labour costs, higher farmer incomes, and the advancement of agricultural intelligence. Agricultural IoT is being optimised in developed countries thanks to the development of information technology. Based on monitoring and intelligent management, artificial intelligence (AI) can be implemented to improve the utilisation of sensor data. Planters can enhance their planting experience and conduct precise crop management with agricultural IoT coupled with expert systems (Liu, 2016).

Farmers can use IoT systems made up of Wireless Sensor Networks (WSNs) to connect remotely to farms and monitor and control farm operations regardless of their location or time. Farms can be monitored by UAVs equipped with hyperspectral cameras, and monotonous jobs can be completed by autonomous robots. The acquired data can be evaluated using data analytics techniques and computer programs to assist farmers in making decisions. Furthermore, advanced technology can be used to monitor and analyse a range of environmental elements, such as weed control, crop yield status, water management, soil conditions, irrigation scheduling, herbicides, and insecticides, and ecologically managed agriculture, to name a few (Gacar et al., 2017).

It is illustrated in Figure 2.3 that IoT is divided into six layers: perception (hardware devices), network (communications), middleware (device management and interoperability), service (cloud computing), application (data integration and analytics), and end-user interface (end-user interface). The physical layer of IoT devices in the agricultural domain collects data related to pH value, temperature, water level, humidity, leaf color, fresh leaf weight, etc. (Shi et al., 2016).

These data are transmitted through the network layer, whose design depends on the size, location, and type of farming method of the field. Due to their low energy consumption and good transmission range, ZigBee, LoRa, and Sigfox are widely used in outdoor fields (Shi et al., 2016).

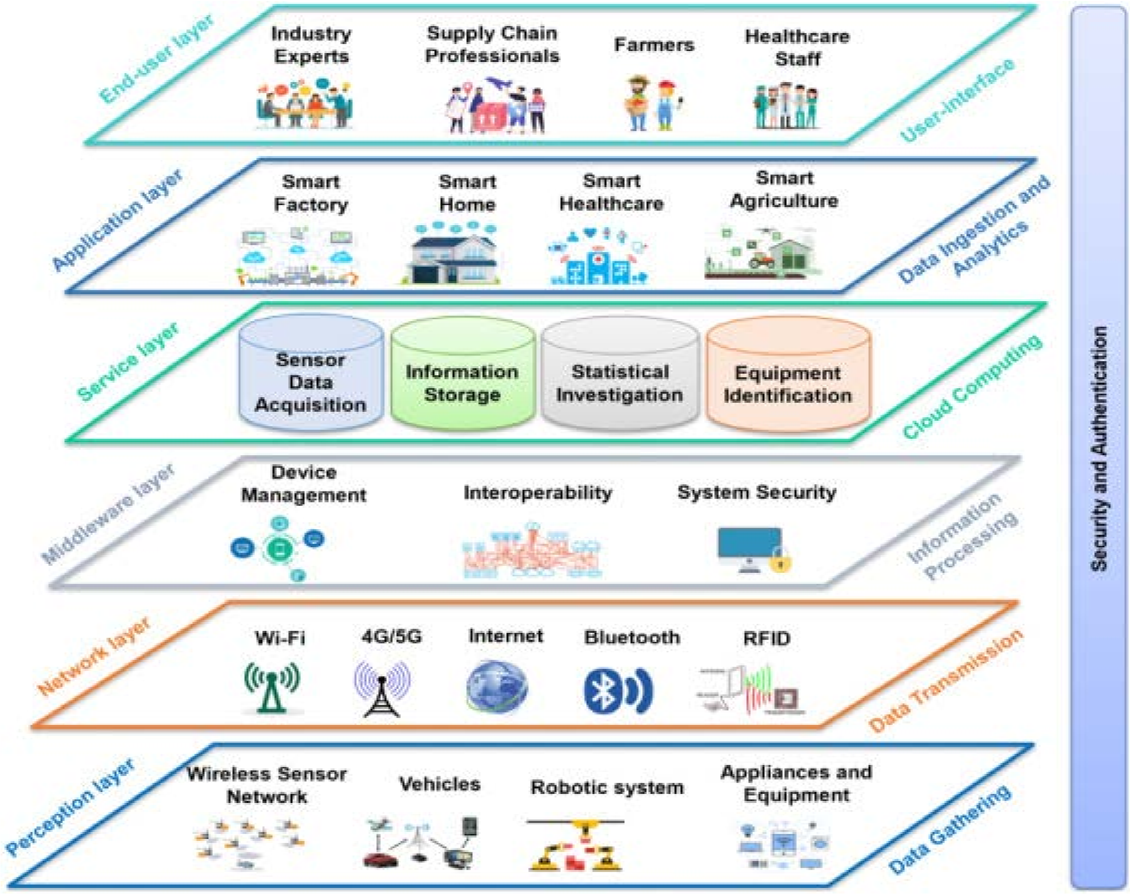


Figure 2.3. Six-layered architecture of the Internet of Things (Saemaldahr, 2020).

Due to its short transmission range, Bluetooth is only used in indoor farms despite being a secure technology. As a result of its high costs and high energy consumption, Wi-Fi is not a promising technology for agricultural applications (Abbasi et al., 2022). Agricultural systems are increasingly using Radio Frequency Identification (RFID) and Near Field Communication (NFC) technologies to track agricultural products (Tzounis, 2017).

For periodic monitoring of environmental and soil parameters, General Packet Radio Services (GPRS) or mobile telecommunications technology (2G, 3G, and 4G) are used. Additionally, Hyper Text Transfer Protocol (HTTP), World Wide Web (WWW), and Simple Mail Transfer Protocol (SMTP) are mostly used in agricultural scenarios. Furthermore, HYDRA and SMEPP Middleware provide context-aware functionality and system security to agricultural systems (Kour and Arora, 2020). In the service layer, cloud computing techniques are used to store data. A smart application built using this data is then used by farmers, agriculture experts, and supply chain professionals to increase farm monitoring capacity and productivity (Abbasi et al., 2022).

2.2.1.6 Unmanned aerial vehicles

UAVs or Aerial robots are aircraft that do not have human pilots. The technology used to fly (wing structure) and the amount of autonomy of UAVs differ (Del Cerro et al., 2021). UAVs include fixed-wing (planes), single-rotor (helicopters), hybrid (vertical takeoff and landing), and multirotor UAVs (draft ones). There are many types of UAVs (multi-rotor technology), the most used being quadrotors (four rotors) and hex copters (six rotors). Due to their mechanical simplicity, they have become increasingly popular in agriculture over helicopters, which rely on complicated plate control mechanisms (Patel et al., 2013). Agricultural UAVs are equipped with sensors (vision, infrared, multispectral, and hyperspectral cameras, among others) that allow farmers to investigate dynamic changes in crops that are not visible from the ground (Sylvester, 2017). Farmers can use this information to determine crop diseases, nutrient deficiencies, and water levels, among others. Farmers can use this information to plan possible remedies (irrigation, fertilization, weed control) (Abbasi et al., 2022).

UAVs, according to Anthony et al. (2014), can give farmers real-time data, allowing them to make better decisions regarding the inputs they use on their farms. Drone footage can provide precise crop loss estimations. UAVs were proposed by Michez et al. (2016) as a possible tool for measuring more accurately the damage caused by wildlife to crops and the accompanying compensation expenses. Stehr (2015) states that UAVs have a higher resolution than satellite or manned aircraft images of a field, and they can monitor a field every week throughout the growing season as opposed to satellite which has a delay of a week or two before being able to view the images.

The use of drone technology is currently changing the face of agriculture, helping businesses meet today's changing needs, such as crop monitoring, planting, livestock management, crop spraying, irrigation mapping, and more (Africa Surveyors News, 2020). There are unique benefits of using agricultural UAVs in agriculture, including the ability to detect problems early and manage crops with specific cameras for detecting pests (Reinecke and Prinsloo, 2017). In Figure 2.3, you can see a crop-spraying DJI drone (the AGRAS MG-1P model) taking its first legal flight in South Africa, a critical milestone that could revolutionise farming in the country (Farming portal, 2019).

Figure 2.4 Crop-spraying UAVs (Farming portal, 2019)

2.2.1.7 Artificial intelligence (AI)

Artificial intelligence is defined by Kaplan and Haenleim (2019) as the ability of a system to understand external data, learn from the data, and apply that learning to accomplish specific goals. In other words, AI gives machines or robots the capacity to make appropriate and intelligent decisions independently (Toor, 2017). Adendorff and Collier (2015) contend that machines and products will be able to interact independently of people due to the vast amount of data they can collect and store.

In agriculture, machine-learning tasks can be used to increase food production, analyse images to identify weeds and crops, and automate harvesting and pest detection (Trice, 2017). It has nevertheless been questioned whether these technologies are sustainable due to concerns related to soil depletion, which would prevent subsistence farmers from using these areas. Therefore, AI benefits would be limited due to the complex infrastructure issues created by this. Using artificial intelligence in the future may be able to improve yields and quality by monitoring soil quality (Gwagwa et al., 2021).

For almost two decades now, agricultural robots (non-AI) have been used for milking. The use of agricultural robots (non-AI) for milking has been around for almost two decades. Agriculture AI robots, however, are relatively new. Several agricultural robots are used to scout crops, control weeds and pests, harvest foods, spray them with insecticide, prune the trees, milk the animals, phenotype the animals, and sort them (Shamshiri et al. 2018). Many AI robots are still being developed in testing facilities, research projects, and labs. It is rare for commercial-scale robots to perform their functions faster than their human counterparts (for example, weeding and picking robots) (Shamshiri et al., 2018).

Robots such as UAVs, and autonomous tractors are also using the technology. UAVs are being used to spray pesticides, herbicides, and water on fields. In addition, they are used to take aerial photographs of the farm and its surroundings. With UAVs, you can gain valuable insight and map your farm in a way that would not be possible otherwise. Self-driving tractors can make farming more productive since farmers can perform other activities on the farm while the tractors plow. Despite this, self-driving tractors are still in their infancy and have not yet been deployed commercially. It is necessary to consider several safety and security factors before incorporating self-driving vehicles (Ryan, 2022). Software, apps, and recommendation systems have also been integrated with AI. By using image recognition, farmers can determine the health of plants and crops and determine how they should proceed (Ryan, 2019).

2.2.1.8 Big data and big data analytics

The European Commission (2016) defines Big Data as a variety of types of data originating from a variety of sources, such as people, machines, or sensors. There are many types of data: satellite imagery, climate information, videos, digital pictures, and transition records. There are several ways that big data may contain personal information, such as names, email addresses, photos, bank details, computer IP addresses, and posts on social networks.

Agriculture already uses big data technologies (Astill et al., 2020; Cockburn, 2020; Kamble et al., 2020; Pylianidis et al., 2021). Big data applications in smart farming pose socioeconomic challenges as well (Wolfert et al., 2017). Several important challenges exist in data-driven smart farming, including big data access, quality data availability, spatial data integration, data privacy, and the right to use data. Data privacy and security are hindered by a lack of data governance and appropriate policies. For different users to easily access distributed data, high-performance systems are essential. Spatial and non-spatial data availability and quality are often challenges in smart farming applications. To process and analyse high-resolution multispectral images, high-performance computing would be required (Reddy, 2021).

Based on the reviews, most big data applications have not been fully adopted by their intended users and are either in early development or have a limited scope in the sense that they do not adequately address agricultural risks. In recent years, big data technologies have continued to evolve as more experience, algorithms, good practices, and computing power have been made available (Oussous et al., 2018). There are several big new data and artificial intelligence applications for agriculture being developed all over the world (Lezoche et al., 2020).

Big data is typically characterised by five dimensions that are expressed as five Vs, which are illustrated in Figure 2.5. BD-driven smart agriculture is relatively new, but it has the potential to broaden food supply chain connectivity and food security, thereby bringing a revolution in the food supply chain (Chi et al., 2016). Each dimension is advancing, as are data management challenges and opportunities to make informed decisions in agribusiness. Data alone, however, is insufficient. Data analytics are the "secret sauce" of big data. The analysis process involves generating useful insights from available data using increasingly sophisticated methods (Sonka, 2016).

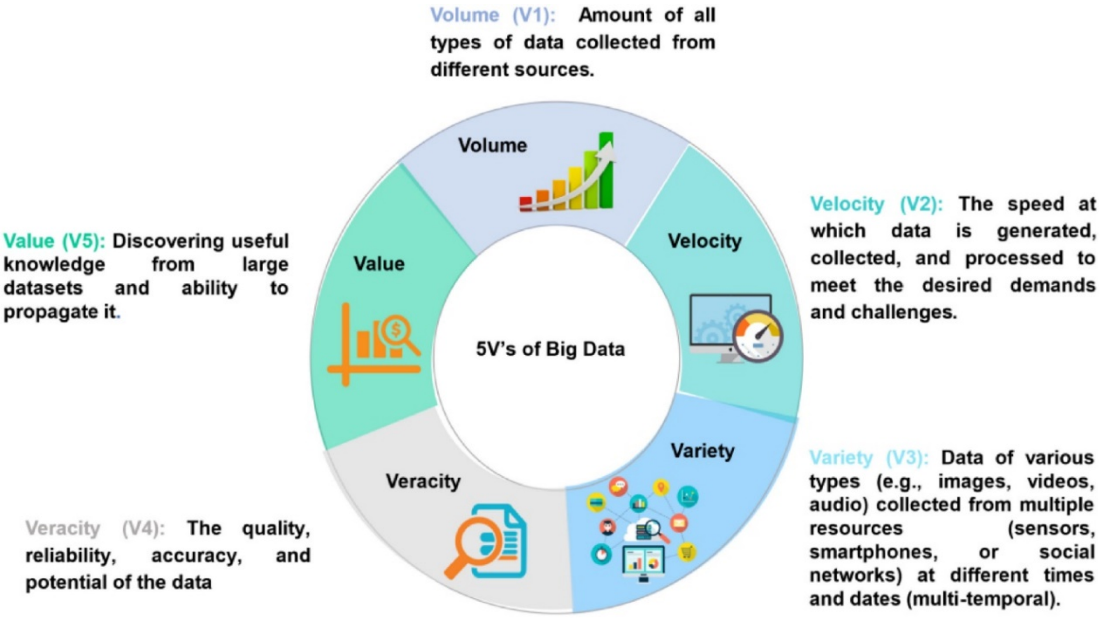


Figure 2.5. Five dimensions of “Big Data” (Chi et al., 2016).

Big data is generated in agriculture by various sectors and stages, which can be accessed and analysed through satellite imagery, aerial photography, special cameras, and sensors, reports and regulations from governmental organisations, online services from private organisations, as well as survey information obtained from farmers (Chi et al., 2016). Tesfaye et al. (2016) states that agricultural data can come from a variety of sources, including environmental (weather, climate, moisture levels), biological (plant diseases), and geospatial sources (Abbasi et al., 2022).

In a computer database, the collected data is stored, and then computer algorithms are used to analyse seed characteristics, weather patterns, soil characteristics (such as pH), and consumer behaviour. Analysing big data in agriculture involves a variety of techniques and tools. Machine learning, cloud-based platforms, and modeling and simulation are among the most used techniques. Machine learning technologies help predict, group, and classify problems. For commercial data storage, pre-processing, and visualisation, a cloud platform is used. Big data analytics offers the ability to address a wide range of agricultural concerns that have not received enough attention in the literature. Data-intensive greenhouses, indoor vertical farms, quality control, livestock health monitoring systems, genetic engineering, software platforms to assist farmers in designing indoor vertical farms, and models to assist policymakers in making sustainability-oriented decisions are just a few examples (Abbasi et al., 2012).

2.2.1.9 Cyber security

Smart technologies enable agriculture to monitor crops and livestock from a distance more than ever before. Data exchange between suppliers and vendors, as well as between farms and production facilities, generates unsupervised networks of information. Due to the adoption of these technologies, cyber-attacks on farms and agribusinesses are on the rise (Van der Linden et al., 2020). Additionally, cyber security measures are designed to protect the exchange of information among interconnected corporate systems (Tuptuk, 2018).

According to Cebula et al. (2014), cyber risks are described as those relating to information and technology assets that impact confidentiality, availability, and integrity. The most prominent cyber risk events are data breaches and attacks (Agrafiotis et al., 2018).

The bioeconomy and community are at risk if these attacks disrupt food supply chains. Protecting agriculture requires the adoption of effective cyber security and biosecurity practices, the implementation of critical control points, and changing human behaviours. Cyber security covers the protection and sharing of all electronic data, information, systems, and networks; however, cyber security is one of its most crucial applications since it aims to prevent illegal intrusion and other activities as well as safeguard life science information, medical information, and agricultural information online (Murch and DiEuliis, 2019).

The protection of agriculture and the food supply chain is a top priority, especially considering the growing global population as well as the Pandemic Covid-19 threat (Laborde et al., 2020). Despite this lack of preparation for cyber penetrations, farms may not be aware of how corrupted data impacts their decisions (Van der Linden et al., 2020). Based on Geil et al. (2018), the perceived risk of penetration as well as the perceived benefits of better security are key influences on the adoption of better security habits. The lack of cyber security or biosecurity training in agriculture leads to weak security practices at any point in the supply chain. To improve cyber security practices across the board, training and certification are necessary (Drape et al., 2021).

Advances in technology such as the worldwide web have led to agriculture and food production and processing becoming part of the cyber-enabled life sciences. As a result, government agencies, producers, and security experts recognise the need for cyber security to secure the nation's food supply chain from cyber-based threats (Murch et al., 2018). While smart technologies can be beneficial, they can also be exploited by hackers to disrupt the supply chain for farms using them, as well as downstream users who rely on them. (Chi et al., 2017) list false sensor data, equipment access controls, and data encryption as possible risks associated with precision agriculture and smart technologies.

2.2.1.10 Cloud computing

A cloud computing service consists of servers, storage, databases, networking, software, analytics, and intelligence delivered over the Internet ("the cloud") to promote faster innovation, flexibility, and economies of scale.

A cloud service provider offers anything from applications to storage rather than owning its own computing infrastructure or data center (Ranger, 2022). Alwada'n (2018) explains that cloud computing is primarily composed of four layers: data centers (hardware), infrastructure, platforms, and applications. Among these layers, there are SaaS, PaaS, and IaaS, which are categorised under a particular cloud service model (Shi et al, 2019).

Figure 2.6 illustrates the cloud computing architecture. It consists of four layers: the data center (hardware), the infrastructure, the platform, and the application (Alwada'n, 2018). There are three types of cloud service models: software as a service (SaaS), platform as a service (PaaS), and infrastructure as a service (IaaS). Agriculture has been greatly impacted by cloud computing over the past decade due to its ability to provide: 1) affordable storage of data gathered from various domains through WSNs and other IoT devices, 2) commercial computing systems for making intelligent decisions based on this raw data, and 3) a secure platform for developing agricultural IoT applications (Shi et al., 2019).

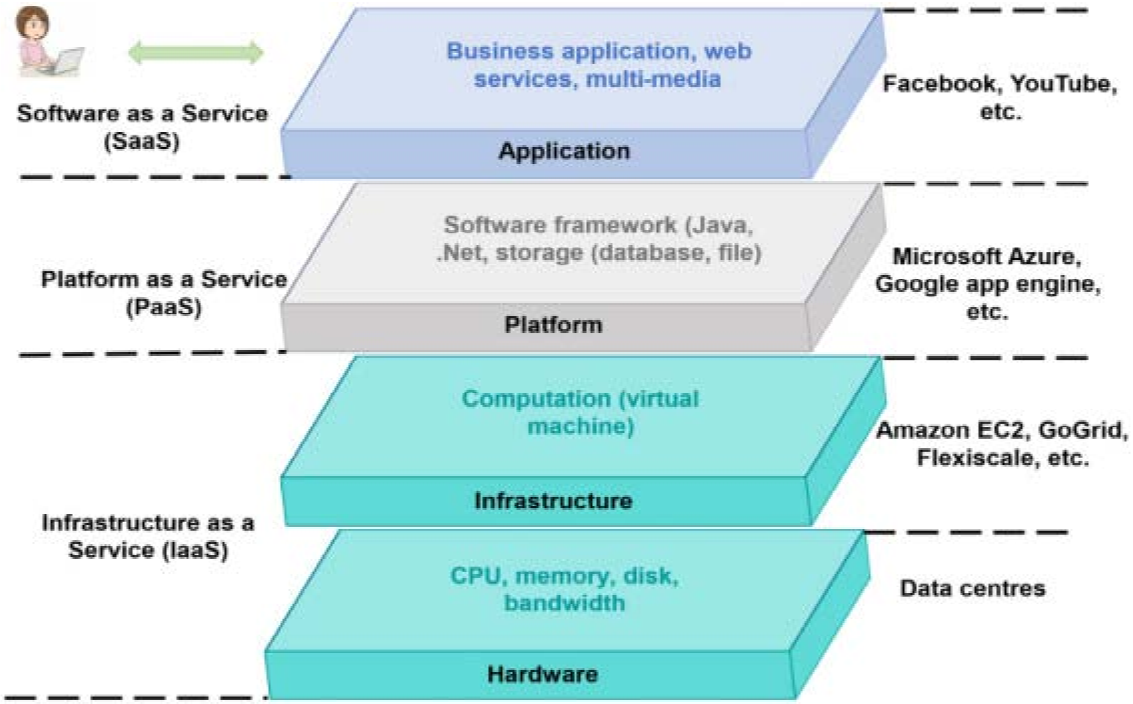


Figure 2.6. Architecture of cloud computing (Alwada'n, 2018).

Bernazzani, (2022) defines Software as a Service (SaaS) as a virtual service that delivers resources to organisations virtually (via the Internet). Organisations can use IaaS tools for building and managing servers, networks, operating systems, and data storage without having to buy hardware.

Peterson (2023) points out that you do not need to care about where the software is hosted, what operating system is supported, or what programming language is used for SaaS software. With SaaS, you can access the software from any device with an internet connection. IaaS Examples are Amazon Web Services (AWS), Microsoft Azure, Google Cloud, and IBM Cloud (Bernazzani, 2022).

Peterson (2023) describes Platform-as-a-Service (PaaS) as an application creation and deployment framework. It was emphasised by Bernazzani (2022) who mentioned that PaaS is a framework for developers to build custom applications. PaaS is not software delivered over the internet, but rather a platform for developers to build online apps and software. Peterson (2023) added that the PaaS cloud service provider manages the servers, storage, and networking, while the developers manage only the applications. Examples of PaaS include Google App Engine, Kinsta, Red Hat OpenShift, Heroku, and Apprenda (Bernazzani, 2022).

SaaS (Software as a Service) refers to a cloud computing model where vendors offer cloud-based software to users. As an alternative to traditional software installation in a business environment, SaaS eliminates the need to build servers, install applications, and configure them. Cloud-based applications are accessed over the web or through APIs and work like a rental (IBM, 2022). There are many examples of SaaS, such as HubSpot, JIRA, Dropbox, and DocuSign (Bernazzani, 2022).

Through cloud computing, large amounts of data can be archived, processed, and stored at high speeds, with flexibility and efficiency. Cloud computing can be used to build services that rely on data for a productive system such as quality assurance and quality control to improve operations. The use of Big Data analytics and the Internet of Things technologies brings both opportunities and risks (Mitra et al., 2018; Nieuwenhuis et al., 2018; Lal and Bharadwaj, 2016).

Furthermore, CC technology can be used to develop operational farm management systems (FMSs), which help farmers and farm managers monitor their farms efficiently (Wang et al., 2017). The cloud-based agricultural system can be a solution to the problems of increasing food demand, excessive pesticide use, and product safety. However, these FMSs cannot support run-time customisation, which might be necessary when farmers have specific requirements. Furthermore, the fragmentation and dispersal of farm data make it difficult for current FMS applications to record farm activities effectively (Fountas et al., 2015).

Marucci et al. (2017) suggest that the Fourth Industrial Revolution in agriculture will bring innovations such as cloud-based systems that can analyse and interpret farming data to provide comprehensive agricultural data. The Fourth Industrial Revolution will encourage smart farming, which will shift the focus from conventional farming to more robust methods. In addition, it will produce changes in how they farm, where they farm, and the people who farm (Shaharudin, 2019). A digitalisation of agriculture must be accompanied by human technical skills that ensure the sector does not fall into contradictions (Braun et al. 2018).

2.2.1.11 Vertical Farming

Vertical farming has been given several definitions based on its size, density, level of control, layout, building type, location, and intended use. As a result, different stakeholders see vertical farming differently, from marginal crop production to an essential component of future food security. Furthermore, as a noun, "vertical farming" and "vertical farm" have become equivalent (Waldron, 2018).

Vertical farming can be defined as the multi-layered production of plants to enhance yield per surface area in its most basic form (Van Gerrewey, 2022). According to SharathKumar et al. (2020) a vertical farm is a highly controlled indoor plant production system. A multilayer indoor plant production system in which all growth factors are precisely controlled, that is, artificial lighting, temperature, humidity, carbon dioxide concentration, water, and nutrients, is designed to produce a high volume of high-quality fresh produce year-round, independent of the availability of solar light and other outdoor conditions.

Vertical farming is an energy-intensive agricultural method that uses artificial lighting indoors, resulting in substantial environmental implications in our contemporary fossil-fuel economy (Wildeman, 2020). Vertical farms, on the other hand, will become a viable supplement to conventional agricultural operations as we move to nuclear and renewable energy sources, improving food safety and security for the world's rising urban population (Tuomisto, 2019). Even now, vertical farming has the potential to reduce food transportation, water use, and eutrophication (Wildeman, 2020).

2.2.2 Information and Communication Technology

As information and communication technologies are introduced in developing countries, new methods can be established for collecting, combining, and sharing knowledge about local and traditional livestock farming (World Bank, 2011; Singh et al. 2015; Zhang et al., 2016). ICTs are defined by Kumar (2012) as "technologies that enable collection, storage, and processing of data and information through the use of ICT applications, such as computers and mobile phones, or through online chatting and media technologies. Although ICTs have clear benefits for farmers in both emerging and developed countries, there is ample evidence that these tools do not meet the expectations of their users in developing countries and are thus not widely used by farmers. (Bell 2016; Braimok, 2017).

Udo et al. (2011) and Palmer (2012) state that several factors such as priorities, needs, and resources influence how livestock producers adopt new technologies However, Mapiye (2017) found that stakeholders need to examine the capacity of smallholder livestock farmers to develop, share, record, and communicate their extension activities to effectively solve and mitigate problems. Furthermore, the author suggests that a management database system would enable farmers to take a leading role in the creation and documentation of information regarding livestock breeds, pedigrees, and other agricultural activities. A database management system records, stores, retrieves, and updates information.

Information and communications technology (ICT) has made significant progress over the last two decades. Today, online services and industrial ICT have spread throughout the world. In addition to growth, employment, productivity, and quality of life, the IT industry impacts economic and societal activities to a significant degree (Plavia et al., 2017). Future ICT services will require a lot of special equipment including sensors to gather the data, data servers, edge computers, and 5G mobile network equipment (JEITA, 2016).

Agricultural knowledge and value chains can be linked via ICT. Agricultural technologies are becoming easier to access because of ICTs that reduce communication and information costs (Aker, 2011). Asenso-Okyere and Mekonnen (2012) describe how the wide range of aspects of ICT is facilitated by technology, including the collection, processing, storage, dissemination, and use of information in multiple formats. It is, however, important to have properly constructed ICT infrastructure and ICT-literate communities, both of which are not always common in developing countries including Tanzania (Lwoga, 2010).

2.2.3. Geographic Information Systems

Using GIS, the intricate data collected by RS and GNSS can be screened to obtain characteristic image information related to agricultural production. The emergence of GIS has laid a solid foundation for the collection, storage, analysis, and management of agricultural production information. GIS has developed rapidly in recent years. For example, Gu and Colleagues built a GIS-based agricultural big data visualization platform to provide comprehensive agricultural data (Gu and Qi, 2020). The agricultural information data presented on this platform is very clear and the visualization effect is excellent. To improve the analysis effect of farmland soil nutrients, Li et al. (2021) introduced GIS technology and sampling robot technology into the design of the nutrient analyser and used GIS technology to draw a nutrient distribution map of the farmland (Li et al., 2021). The visual presentation effect is good, and it can provide reliable data support for fertilizer management personnel. In regional agricultural planning, there are problems, such as data being scattered and disordered, a lack of spatial quantitative analysis, accurate implementation difficulty, and a lack of dynamic analysis. Zhou et al. (2019) used GIS to implement standardized storage and quantitative analysis of agricultural planning data and to draw auxiliary plans to solve these problems. In this way, standardization, rationality, and the accuracy of the planning are effectively improved. Zhao designed an agricultural information collection system based on mobile GIS (Zhao, 2018). The system uses Personal Digital Assistant (PDA) as the basic hardware platform, which can effectively meet the needs of real-time positioning, collection, and transmission of agricultural information.

2.3.4. Remote Sensing

Remote sensing technology uses different types of sensors to receive electromagnetic waves from RS platforms at different altitudes and then processes the received information to identify and detect different objects and their characteristics from a distance. With RS, it is possible to monitor crops that are geographically dispersed. Presently, RS technology has developed a three-dimensional earth observation system that includes aerial photography and satellite remote sensing. Observations have progressed from local to worldwide quasi-synchronous observations, moving from visible light to infrared, far-infrared, microwaves, and even ultra-long waves (Li and Yang, 2018).

It is possible to use agricultural RS technology to monitor and manage commercial open-air agriculture production uniquely. It can monitor crops that are scattered in type and located in complex terrain. Agri-resource research has three focuses: crop yield estimation, agricultural disaster forecasting, and precision agriculture (Gao, et al., 2020). As a result, RS technology is now being used to manage and protect farmland water conservancy projects (Ma et al., 2019), monitor ecological environments (Chui, 2017), and make real-time decisions about soil fertilization (Li, 2017).

A remote sensing technique can provide geoinformation to support land and agricultural policies at different scales, including local, regional, and global. Over the past 40 years, remote sensing has been used to map and study land characteristics (Bégué et al., 2020). By using remote sensing technologies at multiple stages of production, precision agriculture (PA) collects, visualises, and analyses crop and soil health as well as plant growth conditions with ease and efficiency. In addition, RS systems can be used to identify potential problems early, so they can be dealt with in a timely fashion. As a result of the launch of the Landsat Multispectral Scanner System (MSS) in 1972, RS technology was implemented in agriculture (Khanal et.al, 2020).

Consequently, Khanal et.al (2020) point out that due to the limited availability of high spatial resolution satellite data (5 m) and time resolution satellite data (daily) for PA, satellite-based data have mainly been used in commercial monitoring and mapping of agricultural health. RS technology can now be used at an application level far smaller than a field of operation due to technological advancements in GPS, machine hardware, software, cloud computing, and the Internet of Things (IoT). There are a variety of remote sensing platforms that can capture data at various spatial, temporal, and spectral resolutions, including handheld devices, aircraft, and satellites. Several factors determine the resolution required for PA, including crop growth stages, field sizes, and the ability of farm machinery to vary inputs, such as fertilizer, pesticides, and irrigation.

2.4. The status of the ICT, GIS, RS, and 4IR uptake in agriculture:

2.4.1. Adoption of ICT, GIS, RS, and 4IR in agriculture by developed countries.

This subsection discusses the use of the Fourth Industrial Revolution, Information Communication Technology, Geographic Information Technology, and Remote Sensing in agriculture by developed countries. Additionally, the benefits of using these technologies in agriculture will be discussed.

2.4.1.1 The Fourth Industrial Revolution technologies

Modern digital technologies are widely applied in the Russian agricultural sector, but primarily in large commercial agribusinesses. These companies have livestock assets, vast land, management expertise, and appropriate financial resources, and use satellites and variable rate application of fertilizers and hyper-local weather data. Through advanced e-services, farmers improved the planning and tracking of the use of agricultural equipment, and the buying and selling of their products is simplified (World Bank, 2018).

GPS, UAVs, and robotics are rapidly advancing technologies in agriculture, making farm work increasingly computerised. Digital images from UAVs and satellites can detect pests and respond rapidly and timeously to these threats. Utility of spaceborne remote sensing is increasingly being made to gather crop, soil, and weather data. Farmers use data collected from remote sensors and sensors installed directly on agricultural machinery to make better decisions. While UAVs collect detailed data at the field level, such as crop diseases, soil moisture, and property boundaries. These data are analysed and communicated to farmers, government agencies, and industry observers (World Bank, 2018; Dornich, 2017). For instance, a report by Sung (2018) showed that developed countries like the U.S. and Japan are trying to solve agricultural issues using automation, mechanisation, and modernisation. As a result of the 4IR, agriculture will be able to scale and become more commercialised.

As a result of this trend, Lee (2017) states that future agriculture will become high-tech industries where artificial intelligence and big data are combined. The systems will be combined into a single unit that combines farm management, seeding the soil, production forecasting, and irrigation. A new era of super fusion will be created by combining the 4IR core technology with agriculture, big data, and AI. Consequently, economic, social, and moral values will be incorporated into a variety of industries and expressed in business models.

The urban agriculture sector is a crucial component of Japan's economy and agri-food system. In Japan, one-third of agriculture output is generated in urban areas, and urban farming accounts for one-quarter of agricultural production (Moreno-Peñaranda, 2011). Commercialised agriculture is highly prevalent in urban areas, with farms increasing from 641 hectares on average in 2005 to 877 hectares in 2015 (Sim, 2018). In addition to its technological advancements, Japan is a pioneer in indoor crop production using ICT, the use of UAVs for harvesting, and innovative green initiatives such as using edible crops as insulation for buildings (Ecosperity, 2018). Spread, Fujitsu, and Aerofarms are all pursuing hydroponic (soil-less) and vertical agriculture in Japan. Spread has been engaged in vertical farming since 2006 and currently produces more than 20 000 heads of lettuce each day, which are shipped to more than 2 000 supermarkets (Goedde et al., 2015).

In Singapore, hydroponics and aeroponics are being used for vertical farming. In 2016, there were seven vertical farms, producing everything from vegetables to aquaculture (Singh et al, 2016). The Apollo Aquaculture Group, for instance, has developed a "high-rise" fish farming project that can produce six times as much as a traditional aquaculture project. The amount of fish feed dispensed is carefully managed and controlled remotely. Singapore's Urban Redevelopment Authority has lowered barriers to urban farming by letting rooftop gardens and urban farms contribute to landscape replacement requirements. Additionally, longer leases for urban farms (20 years instead of 10 years) can facilitate the adoption of more expensive farming technologies. The Agri-Food and Veterinary Authority of Singapore's $47 million Agriculture Productivity Fund can aid urban farmers with high adoption costs (Ecosperity, 2018).

2.4.1.2 Information Communication Technologies

ICT equipment and the data it generates are changing how farms operate (Perrett et al., 2017). ICT is the application of technology to manage, process, and communicate information. The term ICT covers a wide range of technologies, including computers, the internet, mobile phones, and other digital devices. Basically, it is the combination of hardware, software, and services that allow us to create, store, retrieve, and exchange information (Mwiinga, 2023).

Farming could be enhanced by digital agriculture in Australia through better input use, making quicker and more informed decisions, saving both time and money, and improving access to markets (Perrett et al., 2017). Using digital technology regularly and adopting the tools will allow farmers to reap the benefits. Farmers invest in ICT when they perceive that the benefits outweigh the costs, as they do with other technologies. A lack of clarity about the benefits resulting from a new tool tends to slow adoption because it reduces the value of the benefits until more learning and data are available to evaluate them (Duffy and Jackson, 2018).

Most ICT applications on farms are characterised by high complexity and uncertainty, in part due to the relatively early stages of development in both Australia and the rest of the world for these technologies. With the maturation of technologies and a decrease in uncertainty, farmers will be able to understand the benefits and costs more clearly. Computers and phones were the items most frequently purchased; they have relatively short lives and need to be replaced regularly. Mobile phones and desktop computers should last three years each, while GPS units and controllers are expected to last five years (ATO, 2017).

A large farm is more likely to invest in ICT than a medium-sized or small one. A reason for larger farms investing more in ICT is that they tend to be more profitable (Jackson and Shafron, 2016), which may increase their capacity to fund investment. Furthermore, larger farms can make more use of new technologies, which can increase the benefits (Castle et al., 2016; Sheng & Chancellor, 2018). ICT assets were most used for record-keeping across all industries. Data can be captured and analysed more easily, generated in reports, and shared with clients and service providers with electronic records. Yet, some businesses, especially older and smaller farmers, still use manual recordkeeping (Duffy and Jackson, 2018).

Many farmers also use ICT to market and manage their contracts, though face-to-face marketing is most common across all sectors. The relatively homogenous nature of grains and dairy products facilitates online marketing, which is why grain and dairy farmers are more likely to use ICT. A tendency for vegetable farmers to sell in wholesale markets may limit their use of ICT for marketing (Weragoda et al., 2017). Even more than that, farmers reported using ICT to access online resources and apps, free software, and online tools.

The purpose of using freeware was primarily to check the weather using applications such as the Bureau of Meteorology and other weather apps. Finally, farmers are not adopting new technology due to a lack of skills, lack of internet access, cost, or no interest in new technology (Dufty et al., 2018).

2.4.1.3 Geographic Information Systems

One of the powerful aspects of GIS is its ability to analyse multiple layers or variables. In agriculture, examples include a map showing farm injuries by district, or a parcel tax map showing areas of crops lost due to flooding. A more sophisticated spatial analysis for agriculture might compare factors such as soil type, rainfall amount, slope, topography, or elevation to aid in crop management, and site suitability, to protect against floods, erosion, and droughts. The use of GIS enables farmers to adapt to these variables, track individual crops' health, estimate yields from a field, and increase crop yields (Dornich, 2017).

The New York State government maintains a GIS clearinghouse with a wide range of datasets, some accessible to the public and stakeholders. The United States Department of Agriculture's (USDA’s) CropScape, an interactive web-based mapping application showing the types, quantities, and locations of crops across the country, is another free GIS-based resource available to the public. Land-use information, along with almost all food crop statistics and satellite data, is used with GIS to identify areas in need and the causes of food insecurity, contributing to the fight against global hunger (Dornich, 2017).

2.4.2. The utilisation of ICT, GIS, RS, and 4IR in agriculture by developing countries

This section will focus on the utilisation of ICT, GIS, RS, and 4IR in agriculture by developing countries such as Brazil, China, Japan, India, Bangladesh, Indonesia, Malaysia, Thailand, Singapore, and the Philippines and how these technologies are used in developing countries to improve the food security.

2.4.2.1 The Fourth Industrial Revolution technologies

Without innovative technology and efficient production support, Duckett et al. (2018) suggests traditional agricultural systems will not be able to meet the growing demand for food. The first step in promoting the 4IR effect in agriculture is creating a suitable environment, which should be safe in rural communities and provide space for network technology and cloud infrastructure. 4IR explains the smart agricultural culture, which allows agricultural sites to increase their products competitively. By introducing agricultural robot technology, advanced agricultural systems will be promoted, labour costs will be reduced, and quality and productivity will be improved.

In Bangladesh, the most demanding technologies are designing things such as smartphones, biometric sensors, GPS systems, Wi-Fi, and social media. Using applications, technology-based manpower is changing the performance of technology-based algorithms. Cooperating with 4IR to digitise agricultural farm management will bring tremendous progress, which will expand the traceability and sustainability of products for small farmers in Bangladesh. In addition, both governments and academics can play a vital role in entrepreneurship enrolment in business by holding seminar conferences and dialogue forums that provide knowledge for entrepreneurs to apply technologies in their respective fields (Ane and Yasmin, 2019).

According to CEPEA (2019), the Brazilian agribusiness sector accounted for 21% of GDP in 2018. Farming and farming-related businesses are part of the agribusiness sector, which encompasses all the activities related to farming. The agribusiness process involves all the steps required to bring an agricultural good to markets, such as production, processing, and distribution (Chen, 2021). In 2018, Brazilian agricultural investments in IoT solutions totaled USD 57.5 million in the Brazilian agricultural sector, according to some estimates (Brasscom, 2019). Brazil's largest cotton, soybean, and maize producer, Grupo SLC Agricola (SLC), is a prime example of how IoT applications can be used in the agricultural industry. With over 30 years of precision agriculture experience, SLC uses satellite images, sensors, and UAVs to monitor fields. To monitor crop performance and improve the use of inputs, including fertilizers, chemicals, water, or seeds, big data, and machine learning are being applied. These technologies reduce the use of fertilizers by up to 10% and chemical plant protection by up to 3%, according to the firm. Additionally, it offers gasoline savings, efficiency gains in process management, better tracking of machines, and massive data collection (MAPA, 2019).

Brazil's agricultural landscape is dominated by small family farms. The 2017 Agriculture Census indicates that 77% of all rural properties in Brazil are owned by family farmers, who also account for 67% of the total number of Brazilians employed in the area but deliver only 23% of the country's agricultural product. Many agricultural holdings are smaller than 10 hectares, accounting for only 2.30% of the total farm area (IGBE, 2019). Technology transfer, including through public and private extension services, is critical to the adoption of the latest technologies by small farmers and the improvement of their productivity (OECD, 2015; Filho, 2017). Mobile applications can greatly improve the coverage and effectiveness of extension services. Smallholder and farmers in remote areas can benefit greatly from smartphones, particularly those with a high adoption rate (Trendov et al., 2019).

In addition to providing mobile access to digital extension services, such as from abroad, smartphones also enable access to a variety of additional information (such as on plant diseases), digital tools, or services (such as accounting and planning software) that boost productivity, sustainability, and resilience. Through WhatsApp, Embrapa has been able to reach farmers in remote areas and has developed apps that provide information on specific grains and financial training (Jouanjean, 2019). Through its 43 research centers, the Brazilian Agricultural Research Corporation, commonly known as Embrapa, provides solutions for the sustainability of agriculture. Embrapa's mission is to provide solutions to Brazilian agriculture's problems, says Celso Moretti, the current president. Brazilian food insecurity led to Embrapa's creation in 1973. Brazil was a net importer of food back then. Beef, milk, and beans were imported from Europe, the US, and Mexico. Therefore, rural food poverty was widespread. In response, Brazil sent 1,000 researchers abroad for master's and PhDs. Moretti said that four to five years ago, they returned and began developing tropical agriculture. One of the key success factors was transforming Brazil from a food-insecure country to a leading food, fiber, and bioenergy powerhouse (Hope, 2022).

In China, urban farming is driven by rapid urbanisation. Urbanisation and environmental factors, such as depleted arable land and contamination of water, make it more important for cities to engage in urban agriculture (Bloomberg, 2017). The number of greenhouse companies has increased from five in the 1980s to about 400 in 2010 (Smart Agriculture Analytics, 2015). In Beijing, urban agriculture was incorporated into its overall development strategy when it developed five agri-parks. A variety of IoT applications have been used in China in agricultural production, such as farmland irrigation, agricultural product safety tracking, aquaculture, and animal husbandry. Additionally, China has developed high-precision information monitoring and diagnostic equipment that has contributed to IoT's application in agriculture. Currently, the equipment has been developed and used mostly to obtain crop and plant information, monitor environmental information, and monitor animal behaviours (Shan, 2019).

Because the East Asia region has a high population density in urban areas, it is well-suited to providing food delivery services via the internet. Several large multinational companies have shown an interest in fresh food commerce in the region, including Amazon and Walmart. However, Asian e-commerce players could dominate the food delivery business. Several initiatives are currently underway in China, and the Japanese messaging service Line has taken steps to sell and deliver perishable and non-perishable goods in Southeast Asia. Similar businesses have been established in Indonesia, Malaysia, and Thailand (Green, 2018). There is evidence that e-commerce platforms are being used to connect producers directly with consumers. DHL is currently working with Thailand's Ministry of Commerce to connect Thai farmers to e-commerce platforms using its e-commerce and logistics expertise (Green, 2018). Food e-commerce, however, may take some time to develop, especially in rural areas. Not all food e-commerce initiatives have been successful in Asia businesses have been closed, sold, or scaled back to focus on a handful of cities or countries (for example, Indonesia and the Philippines) (Green, 2018). In China, rural e-commerce has faced a general lack of professional internet-savvy personnel. Thus, farmers’ cooperatives and enterprises usually resort to third-party e-commerce platforms, such as Alibaba, Jingdong, Suning, Taobao, and Tmall, in starting their online businesses (ADB, 2018).

2.4.2.2 Information Communication Technologies

In a 2019 report, the Food and Agriculture Organisation (FAO) points out that smallholder farmers are not well integrated into markets due to high transportation costs and the inability to timely deliver consistent, high-quality products. Since agriculture is a large part of the economy in developing countries, there is a need for many extension agents to interact with remote and geographically dispersed farmers and to advise them on innovative production technologies that can be vital to their livelihood. In addition to reducing costs, ICTs can help transformations as well.

The video, voice, and call centers are also available to illiterate farmers. Using Internet kiosks, buyers, and farmers in India can connect via the e-Choupal platform. Furthermore, eChoupal offers farmers online access to best practices for improving productivity, as well as price benchmarking to help increase sales prices (Miller et. al, 2013). The development of digital technologies has improved communication and information sharing, as well as social connections. Technology contributes to development primarily through innovation, inclusion, and efficiency. In developing countries, 70% of the bottom fifth of the population owns a cell phone. According to World Bank Group (2016), there are more than three times as many people using the internet today as there were in 2005.

The efficiency of traditional extension services is limited in developing countries due to several challenges. Lack of infrastructure makes visiting remote areas more difficult and more expensive. Consequently, extension programs usually provide farmers with only one-time information, which lessens their long-term effects. A lack of accountability and principal-agent problems plague traditional extension (Nakasone et.al, 2014). There is a significant productivity gap between developing and developed countries, which may be due to the heterogeneous adoption of technology. Foster and Rosenzweig (2010) point out that adopting new technologies is one way in which poorer countries can catch up with richer countries. Jack (2011) identifies seven inefficiencies that could hinder technology adoption in developing countries: (a) externality-related factors, (b) input-output markets, (c) labour markets, (d) credit markets, (e) risk markets, and (g) information. In his view, ICTs' most important role is to help reduce the lack of information in developing countries.

ICTs can improve farmers' access to timely extension information in addition to reducing extension visitation costs, enabling two-way communication between agents and farmers, and increasing agents' accountability (Cole and Fernado, 2012). By using ICT, the cost of extension visits can be reduced, communication between agents and farmers can be enhanced, and agents can be held accountable so that smallholder farmers receive timely extension information (Cole and Fernado, 2012). For a country like India, the importance of ICT in agricultural development and agricultural extension is immense. E-agriculture is a rapidly developing field, which aims to improve the efficiency of agriculture and rural development by improving information and communication processes. Furthermore, the concept of e-Agriculture involves conceiving, designing, developing, evaluating, and applying innovative technical solutions to agricultural problems with a primary focus on agriculture, and stakeholders in this process need information and knowledge about the different phases of the farming process to manage them efficiently (Signh et al., 2015).

Wei et al. (2016) cites food security as a fundamental guarantee for world peace and development, which is always the priority in state governance in China. China's population has exceeded 1.4 billion as of 2019, and the growth curve will likely continue. Based on China's seventh national population census conducted in 2021, 1.41 billion people were living there at the end of 2020, which accounts for approximately 18% of the global population, and the growth rate is expected to continue. China's food demand, especially grain demand, will continue to grow in the future as its population and dietary habits increase (Wei et al., 2016). To ensure grain output security, the country must invest in and guarantee a continuously improving production system. The lack of adequate information dissemination is a major obstacle to improving agricultural production modes in developing countries (Ogutu et al., 2014). ICTs have been developing slowly in rural areas for a long time, so farmers have had limited access to agricultural information. The acquisition of technology and factor input, as well as the circulation of production factors, are hindered in such circumstances. Since modern information technology has boomed in the last two decades and has penetrated both rural and urban areas of China, more people can access any kind of information via the internet, alleviating the problems associated with inadequate information dissemination (Yin, 2021).

China's agriculture has transformed over the past decades, and the implementation of ICTs has improved as a result (Zhang et al., 2016). Due to these circumstances, integrating informatisation and agricultural modernisation became an effective method for increasing farm productivity and efficiency. The internet is a core component of information and communications technologies (ICT) and can serve as a platform for information dissemination, which can result in reducing farmers' search costs and facilitating the accurate acquisition of grain production information (Tack and Aker, 2014). Gebbers and Adamchuk (2010) note that Internet-based technologies are an important part of Agriculture 4.0, which addresses the issue of food security in agriculture and is being used widely. A customised management message could be sent based on a specific location, soil type, and management records, thus enabling farmers to monitor crop growth in real-time. The farmers would then apply standardised measures of irrigation, fertilizers, seeds, and other agricultural inputs, accordingly, resulting in improved yields and fewer input costs, labour, and environmental pollution.

To begin with, farmers' learning costs could potentially be reduced since agricultural technology knowledge is disseminated online (Tack and Aker, 2014). As portable mobile terminals become more popular, people can now browse technical information on the internet anytime, anywhere (Gao et al., 2020). Farmers can follow the opinions of experts online and communicate two-way with their colleagues, creating a channel of exchange not only for technical information but also for feedback that can be used to improve various applications (Yao and Ding, 2018). Furthermore, the internet can also be used to strengthen farmers' social networks by enabling them to construct interpersonal social communication media. Through social media, farmers can maintain their existing relationships, develop, and strengthen the network of 'strong bonds', communicate with strangers in a new way, and establish a network of 'weak bonds'. In addition, social networks can facilitate technological exchange, as well as the adoption of modern technology (Wood et al., 2014).

2.4.2.3 Geographic Information System and Remote Sensing

A study by Petja et al. (2014) observed that land assessment for agribusiness in India depended on soil study information coordinating GIS innovation. GIS evaluates land suitability and soil fertility considering soil survey information.

As indicated by Abah (2013), the improvement of high-resolution remote sensing in developed nations has featured the significance of biophysical factors in crop production as well as financial and climatic variables. Decision-makers can develop effective land management plans with the help of GIS and RS.

Remote sensing data tracked the loss of farmland because of urban expansion. In this respect, GIS and RS have proven to significantly contribute to the decision-making process of land management planning (Petja et al., 2014). By using GIS in agricultural planning and production, different types of soil can be identified. Petja et al. (2014) suggest that GIS can be used to improve natural resource management because it provides a unique perspective on the landscape. Analysing and evaluating land use for natural resource management can be accomplished with GIS and RS.

Although Malaysia is one of the top five aquaculture-producing countries in Southeast Asia, proper aquaculture spatial planning is lacking in the Malaysian aquaculture industry; for instance, the Department of Fisheries (DOF) continues to use the traditional method of site selection and in-situ water quality monitoring (Mamat et al., 2014). Similarly, compared to other Southeast Asian countries, the existing literature on GIS application for the aquaculture industry in Malaysia is limited. As a result, researchers can conclude that the use of GIS technology in aquaculture management and development in Malaysia is minimal. Traditional methods are not only time-consuming and inefficient, but they may also impede the country's future development of the aquaculture industry (Bandira et al., 2021).

Previous research has used GIS and remote sensing data in GIS analysis, demonstrating that this technology plays an important role in the development and management of aquaculture in both geographical and spatial aspects. Furthermore, GIS applications in this industry have the potential to reduce field sampling. It broadens the estimation's spatial and temporal coverage, making GIS a valuable tool for the efficient and cost-effective management of sustainable aquaculture (Radiarta et al., 2011).

Soil data is mapped based on classification (soil texture, land type, landform, drainage, slope, and surface water recession) and condition in the Soil and Land Resource Information System database, which is developed on a customized GIS (crop suitability, land zoning, nutrient status, and fertilizer recommendation). This GIS system can manage data at three different levels: Upazila, district, and national. For the past two decades, the Bangladesh Space Research and Remote Sensing Organisation has used these sensors to monitor important agricultural areas (Miah et al., 2020).

2.5 Application of ICT, GIS, RS, and 4IR In the agricultural sector in Africa

African food security is further challenged by the effects of climate change, which can range from rising food costs to malnutrition, to outright starvation. For this reason, digital technologies must be harnessed appropriately to improve food security in Africa (Reiter, 2022.). It will be discussed in this section how ICT, GIS, RS, and 4IR are being applied to agriculture in Africa.

2.5.1 Fourth Industrial Revolution

However, Africa has not yet fully utilised the full capabilities of its agricultural sector, and 4IR technology provides farmers with opportunities to increase agricultural productivity (Foresight Africa, 2020). Although things are progressing slowly, some African countries have already experienced innovation and technological development in agriculture and Agro-processing industries (Krishnan et al., 2021).

This successful integration of drone technology into the Rwandan agricultural landscape demonstrates the transformative power of innovation, which is another key component of Feed the Future, the U.S. initiative aimed at ending global hunger and food insecurity. In addition to enhancing food security, this approach empowers communities by providing jobs and economic opportunities. Based on the success of this intervention, Zipline partnered with the Rwanda Agriculture Board to deliver boar semen using UAVs (USAID, 2024).

In addition to remote sensing, crop monitoring, and pest management, Rwanda is exploring other uses for UAVs (Frąckiewicz, 2023). According to Rycroft (2019), agriculture has always been under pressure to produce more food as water resources are declining. Mechanical farming in Africa is capable of increasing food production, but it requires energy that is becoming more expensive. As in any other industry, more efficient methods and machinery are needed to control energy costs. Technology is reshaping the agricultural industry, and precision farming (PF), uses sensor technology, UAVs, GSP systems, agri-robots, and satellite imagery to monitor, control, and grow crops. When crop management is performed by the traditional method, herbicides, pesticides, and fertilizers are applied blankety, while precision farming uses artificial intelligence and automation to control fertilizer, herbicide, and insecticide applications, thus increasing yields and reducing pesticide applications. In addition, PF reduces energy consumption by directing machinery actions to only where they are needed and limiting activities to specific areas.

Supporting and controlling strategic innovation requires capacity building. Furthermore, digital technology needs to be utilised more effectively, integrated, and possibly redesigned integrated operations planning, control and decision support systems, predictive maintenance, and shared value for efficiency (Deloitte, 2018). In line with this, when implementing policy frameworks for businesses and governments, there is a need to recognise the responsibilities when leveraging

4IR dynamics for resource control and ownership. The challenges posed by the 4IR emerging technologies, however, may include but are not limited to, maturity issues related to technological disruption and whether the costs involved can be attained affordably for interoperability reasons (Ordoobadi, 2011; Van der Velden et al., 2012) (Micheler et al., 2019). There are still complexities regarding how emerging economies control resources and have access to them.

Rwanda's agriculture is supported by smallholder farmers who produce 70% of export revenues and 90% of national needs on less than half a hectare each (Cantore, 2011). Poor agricultural land management and soil degradation jeopardise efforts to increase agricultural yields and food security (Kagabo et al., 2013). Adopting and integrating UAV technology is not limited to designing and manufacturing them. Drone operation centres are being built in Rwanda to facilitate the uptake, training, and regulation of unmanned aerial vehicles (Collins, 2020).

The Rwandan government is actively promoting and enabling digital agriculture in the country. It is Rwanda's most famous digital agriculture service, E-Soko, a platform that serves agriculture value chain actors with timely market information compiled by the government. E-Soko assists farmers in earning a living wage from farming by assisting them in obtaining a fair price for their harvest. Another service provided by the Ministry of Agriculture is the Agri-Management Information System, which allows users to access video and audio extension services materials, reports, research results, surveys, and other advisory information. Several government agencies, including Rwanda's Ministry of Agriculture, use SMS/IVR systems to communicate with farmers, share vital information, and solicit feedback (Republic of Rwanda, 2016). In Ghana, farmers are using the internet and mobile technology to obtain weather data, agricultural guidance, and financial advice (Foresight Africa, 2020).

In Rwanda, technologies such as GPS, remote sensing, UAVs, satellites, mobile money, e-wallets, digital markets, e-commerce, and IoT are among the most promising aspects of the Producer Hub. As a result of these technologies, producers will be able to better control pests and diseases, connect to consumers, access financial services, increase mechanisation, and adopt smart farming practices. For the Distribution Hub, the most promising technologies are SMS, GIS, databases, smartphones, satellites, and digital weighing. Using GIS and satellite technologies to forecast weather and seasons will improve market transport timing and reduce the cost and losses associated with harvesting and delivering products in extreme weather. With the help of smartphone apps and SMS, producers and distributors can establish direct connections. The Consumer Hub has the greatest potential to overcome some of the key challenges with SMS/I, digital information platforms, and mobile apps (FAO, 2020).

African countries, particularly those with food security issues, can greatly benefit from artificial intelligence (AI). The potential for improving agriculture with artificial intelligence could, in theory, reduce food scarcity in Africa while contributing to environmental and agricultural justice. Artificial intelligence, like other technologies, can also marginalise the poor and disadvantaged, because they will not have access to advances and innovations designed for a more modern world than the one, they live in today (Technopolis Group, 2019).

By automating harvesting and weeding, AI would compete with humans, at least to some extent. AI technology can, however, improve crop yields and the efficiency of farming without negatively impacting the African labour force because it can predict important factors like weather and land conditions. AI may increase the need for workers in the agriculture sector by increasing the ability to predict floods and droughts, optimise land use, and increase yields. Therefore, AI does not necessarily compete with labour but could complement it based on visits application (Gwagwa, 2021).

Despite this, African agricultural practices can reduce the impact of AI. Lowder et al. (2016) notes that small farms occupying less than 2 ha account for 40% of farmland in sub-Saharan Africa, thus making a significant contribution to farmland, and the daily wages for farm labour in sub-Saharan Africa are significantly lower than those in highly developed countries. In contrast to developed nations, there is little economic incentive in Africa to invest in agricultural robots. However, sub-Saharan Africa may be less adversely affected by AI on-farm labour than developed countries due to the factors discussed above. Further, the effectiveness of technologies will likely grow with the addition of complementary tools, such as the combination of flood prediction and flood protection technologies (Gwagwa, 2021).

In the era of big data and better analytical tools, new opportunities for innovation have arisen, which are already having an impact on agriculture or may do so in the future. With a variety of technologies, innovation patterns can be executed in several ways; augmenting products to generate data, digitising physical assets, combining data across industries, trading data, and codifying a unique capability are all possible without cutting-edge technology. With sensors, wireless technology, and big data, it is now possible to collect and analyse huge amounts of data in a variety of settings, from kitchen appliances to intelligent surgical equipment. Agriculture is best served by augmenting products to generate information through the installation of sensors on tractors and wind turbines, improving inputs and improving accuracy. The datasets can then be used to improve the performance of assets or to improve the operation, maintenance, and repair of assets.

However, there are limitations to the use of big and high-value data; not only are such data often unavailable in emerging economies, but stakeholders may also lack the capacity to utilise them. Further, many countries in the Global South do not have access to their data which would make them unable to use and profit from them due to contract restrictions (Verhulst, 2019). In agriculture, a good example of data ownership rights is found in the micro-level application of digital sequence information for agricultural practices (Marr, 2018).

Then, in Nigeria, farmers are using a smart solution that uses IoTs to evaluate soil data to help them use the correct fertilizer productivity (Foresight Africa, 2020). In addition to using sensors to assess soil farmers in Nigeria, they also use geostatistical surveying and mapping instruments to assess the variability of soil nutrients in the yam-based planting system of small farms to recommend specific fertilizers suitable for the land (Onyango et al., 2021).

Adeoye (2019) says that TensorFlow, an open-source AI library from Google, is already being used in Africa to detect outbreaks of crop diseases since AI can detect disease through images, that humans are unable to see. A start-up in Kenya has trained a convolutional neural network model to understand species and diseases in the leaves of crops using TensorFlow. Obam (2019) reports that the same type of innovation also occurs within African start-ups that use machine learning to develop solutions to real-world problems. For example, young people in Ghana's hubs have created applications that use machine learning to diagnose crop diseases. Such technologies are useful in detecting disease earlier so it can be treated before it spreads throughout the crop (Wadhwa, 2019).

Furthermore, this solution does not only apply to crops but also animal diseases. In other continents, similar machine-learning applications were used to assess the health of animals, with Aquabyte envisioning a system that used a network of Edge AI-powered cameras to assess the size, health, and behaviour of gigantic schools of salmon. Similarly, animal diseases could be diagnosed with machine-learning techniques used for human diagnoses. Aajoh, a Nigerian start-up that incorporates artificial intelligence into medical diagnosis, relies on users submitting symptoms in text, audio, or photographs. Diagnosis, an app from Ghana, uses artificial intelligence to diagnose skin diseases using text, audio, and photos. By adopting these technologies, animal diseases could be diagnosed based on symptoms given by farmers, allowing for quicker action to be taken (Gwagwa, 2021).

2.5.2 Information Communication Technologies

The adoption of information and communication technology has changed the farming industry and many lives. In recent years, farmers are increasingly buying and using cellular phones. Despite the lack of electricity in some rural areas, mobile phone usage is increasing (Sife et al., 2010). Some developing countries, including Tanzania, have been using telecentres to access information in multiple formats in rural areas.

Systems like these are critical for agricultural communication networks since they facilitate the sharing of information among stakeholders (World Bank, 2007; Saravanan, 2010). In Kenya, for example, DrumNet connects smallholder farmers, retailers, and buyers of agriculture products through a cashless microcredit program. DrumNet provides credit ratings for banks based on DrumNet's credit rating provided to farmers for inputs (for example, seeds, fertilizer, and pesticides) from local input providers. Esoko, a mobile and web app that combines advisory calls with mobile and web services, is improving access to extension services in Africa, according to the FAO (2019).

2.5.3 Geographic Information Technology and Remote Sensing

As indicated by Bégué et al. (2020), metric and sub-metric resolution imagery is used to create base maps that provide geographically localised information and provide a shared vision for the territory. Global-level base maps are not yet available, but projects to develop these national-level maps are multiplying worldwide. Benin has recently joined these countries (Senegal, Mali, and Burkina Faso) in developing a homogeneous national topographical database and the tools to use it. These maps ranged in scale from 1:50,000 to 1:200,000, with mosaics ranging from high-resolution satellite orthoimages (for example, RapidEye and SPOT6) to aerial photographs.

The European Union-funded these projects, which were carried out in collaboration with the countries' national geographic institutes. In most cases, country base maps are produced annually, such as those produced by the South African National Space Agency (SANSA) since 2006 using a mosaic of SPOT imagery. Various ministries, universities, and research institutes receive the mosaic.

At global and regional scales (including continental to subcontinental scales) there are at least twenty land cover/land use maps referenced in the literature and progress is being made due to new services such as free access to high spatial and temporal resolution, continued data, and improved computing capacities (Tsendbazar et al., 2018). Several studies have shown that land cover maps show many discrepancies in estimating the area as well as locations of the main land cover classes in Africa (Fritz et al., 2010; Tsendbazar et al., 2018). The main reason for this discrepancy is the specific characteristics of smallholder agriculture in Africa. As a result of Waldner et al. (2015) review of global farmland datasets, the authors concluded that Africa (mainly the countries of West Africa and South Africa) should be a top priority area for improvements in farmland mapping.

It is widely acknowledged that remote sensing can be used to monitor agricultural production; the great diversity and complexity of agricultural species in Africa (Collier & Dercon, 2014), the complex interactions between weather and geography, where different rainfall patterns are found even in nearby areas (Becker-Reshef et al., 2020), and the lack of complementary data calls into question the application of remote sensing approaches originally developed for the Global North.

Bégué (2020) said that nowadays, many datasets are freely available on the internet and in data repositories. ESA's recently released Sentinel images, combined with free access to Landsat data (Wulder et al., 2012) are facilitating the development of a new generation of higher-resolution (For example 20 m) maps of land cover (Herold et al., 2016). Further, the development of new cloud-based technologies and processing tools, such as Google Earth, allows the processing of big data for scientific purposes and enhances the ability to work with higher spatial resolutions for large areas (Chen et al., 2015; Bégué, 2020). These technologies are used in the 30 m GlobeLand30 (Chen et al., 2015), the newly released ESA CCI S2 prototype Land Cover map (Lesiv et al., 2017), Copernicus Global Land Service (CGLS) dynamic Land Cover map (Buchhorn et al., 2017), and the Global Food Security-Support Analysis Data (GFSAD) project (Xiong et al., 2017).

The combination of satellite imagery and machine learning, or deep learning, algorithms will lead to a dramatic increase in the earth observation industry over the next decade as training databases become available, as they are not yet available in many countries in Africa and other regions. Creating a map of agricultural land use in each African country could be a priority based on remote sensing, local knowledge, and soil data at a scale of 1:50 000 to 1:100 000 where soil data are available (Bégué, 2020).

Agricultural maps can be used for several purposes, such as yield estimation, rural development, and food security assessment (Fritz et al., 2019). According to Rembold et al. (2019), the findings of this research can be used in the newly launched Anomaly Hot Spots of Agricultural Production (ASAP) early warning system. Additionally, for crop production, this system needs information about land cover and land use (FAO, 2014). Grasslands also play an important role in the supply of food in Africa, where they cover roughly half of the continent (Holechek et al., 2017).

With precision agriculture, farmers can reduce their inputs while increasing their outputs by using data to support their decision-making processes. This is particularly important for modern agricultural methods. With these practices, farmers can use spatial statistical methods to identify the type of soil, GPS technology for soil mapping, and geographic information systems for weather forecasts to improve the accuracy of operational spatial data. Farmers are becoming increasingly dependent on an IoT ecosystem that consists of advanced sensors, auto-guiding tractors that harvest crops and data along with servers and UAVs (Barr, 2017).

Africa uses geospatial technology differently in different ways. Ethiopia launched its first agricultural satellite into space in 2019 for agricultural monitoring, climate monitoring, mining monitoring, and environmental monitoring, allowing the Horn of Africa to better plan for changing weather patterns. Ethiopia's use of satellite communication for economic development has been made possible by the introduction of the African Union of an African space policy. Moreover, Ethiopia has developed a continental outer-space program. Using artificial intelligence, the Kenyan company Apollo Agriculture analyses satellite images, soil data, farmer behaviour, and crop yield models. Due to these algorithms, farmers can detect plant diseases and pests and receive customized financing, seed, and fertilizer packages. There is still a need to make these technologies accessible to all types of farmers and to develop them inclusively to benefit all subpopulations (Gwagwa, 2021).

The interpolation capabilities of GIS and RS techniques make them useful for assessing erosion. These techniques have many benefits for developing countries. An example of this is the use of GIS for the map and evaluation of agricultural land use patterns in Nigeria's lower River Benue basin (Abah, 2013). Using GIS technology combined with maps for land suitability assessment classified by FAO standards in Nigeria has recently been demonstrated to significantly improve the accuracy of land suitability evaluation (Abah, 2013).

International and Tropical Agriculture (IITA) uses remote sensing and GPS technologies to monitor and control the Banana Xanthomonas Wilt. A farm registration system developed by One Acre Fund uses USSD technology to allow farmers to register for its products, access microcredit, manage repayment, and monitor their balance from their phones. As part of the Rwanda Irrigation Master Plan Phase II, developed by the World Agroforestry Centre with the Ministry of Agriculture in 2010, GIS mapping tools were used to determine the total area suitable for irrigation and to provide decision-making tools for on-farm irrigation throughout Rwanda (N-frnds, 2019).

The SADC region is known for livestock and cereal. Maize is the staple food in many countries in the SADC region, followed by wheat, rice, and cassava. The region also produces crops like sorghum, beans, and millet. Geospatial technologies such as GIS, GPS, and remote sensing offer new methods to create and use maps to manage farms. Remote sensing technologies with UAVs, satellites, or land vehicles can use optical sensors to evaluate soil characteristics, including moisture content and an organic compound (Du Preez, 2020).

2.6. The use of ICT, GIS, RS, and 4IR in South Africa agricultural sector

This subsection will discuss the use of the Fourth Industrial Revolution, Information Communication Technology, Geographic Information Technology, and Remote Sensing in South Africa by government officials, smallholder, and commercial farmers in the agricultural sector. Moreover, literature will be used to explain how these technologies benefit the agriculture sector in the country.

2.6.1 Fourth Industrial Revolution

According to the DAFF (2012), the agricultural sector is considered an important foundation for economic growth, development, and sustenance in South Africa. A lack of adoption of advanced technologies in agriculture and the poor facilitation of modern technologies by agriculture extension, particularly towards smallholder farmers, are factors contributing to the contraction. The South African agricultural sector consists of both a formal and informal sector (Vink and Kirsten, 2003). According to Mzwakhe and Agholor (2021), the formal sector is made up of commercial agriculture, which in the formal sector is owned primarily by white people, while the informal sector consists of emerging and smallholder farms that are dominated by black people.

Raidimi and Kabiti (2017) contend that the government's public agricultural extension and advisory service serves as the backbone of the farming community in South Africa, particularly for emerging and smallholder farmers. The South African agricultural advisory service has a dualistic approach of public and private. DAFF (2014) reports that the agricultural extension and advisory service is strained and overwhelmed due to the influx of farmers requiring assistance.

For the overstretched agricultural advisory service to cope with the high demand for extension services, advanced technologies must be adopted. As technology disrupts agriculture worldwide, farms will shift toward smarter and more precise methods (Chisoro-Dube et al., 2019). Mzwakhe and Agholor (2021) believe there will be a need to train agricultural extension and advisory service providers on advanced agricultural technologies of the 4IR such as new breeding technologies, crop pest technologies, smart water technologies, agricultural robots, precision agriculture, delayed ripening technologies, sensors, and ICT for ease of communication.

The South African commercial farming industry is confident about adopting new technologies because it understands the benefits of, for instance, UAVs or satellite imaging to increase productivity. Farmworkers should not be replaced by these new technologies. Instead, they should be used as supplementary tools that can bring benefits in terms of inputs and outputs (Gillwald et al., 2019).

Agricultural advisory service in South Africa uses extension models that facilitate and cascade advancements in technology. A linear extension model entails the transfer of technology to farmers by extension practitioners (Ndoro, 2011). Sulaiman and Hall (2001) argue that to deliver technology efficiently and effectively, agricultural extension should follow certain approaches. For agricultural advisory services to be relevant, accurate, and applicable in the Fourth Industrial Revolution, policy reassessment is needed to prepare extension workers. Agricultural extension and advisory services play a critical role in assisting farmers in accessing and adopting new technologies (Walisinghe et al. 2017). Masere (2015) argues that smallholder farmers are more likely to innovate and succeed when technology is transferred. Adopting technologies associated with the 4IR can help reduce poverty and ensure food security. Payne et al. (2018) suggest that a digitally enabled extension and advisory service can provide for the needs and aspirations of a wider group of farmers in an effective and cost-efficient way while increasing impact and accountability.

In particular, the 4IR can potentially rescue South Africa from job losses and population growth or the economic growth crisis. This is because 4IR is increasingly being proposed as the solution that will reduce poverty, unemployment, and inequality in the country. Recent studies show that regardless of the excitement around the importance of taking advantage of current technological advances, some of the technologies that make up 4IR have yet to be implemented with any eagerness by South African companies. For instance, only thirteen percent (13%) of companies in South Africa have adopted Artificial Intelligence (AI), and, of the remaining, only twenty-one percent (21%) plan to implement it in the coming 12 to 24 months (Van Tonder, 2019).

In 2019 the National Economic Development and Labour Council (NEDLAC) stated the concerns with adopting the 4IR, there is constant civil conflict, and people are complaining about the issue of Robots taking their occupations. Labour unions refuse everything that suggests 4IR and they arrange protests and strikes, starting chaos in numerous industries. Businesses implement new technologies to stay profitable and to guard their interests. The Government is becoming more and more separated, more than because they did not embrace the potential positive impacts of the 4IR or put processes in place to mitigate against the negative consequences thereof (NEDLAC, 2019).

There is a perception that 4IR will negatively impact the business services sector by reducing jobs such as planting seeds, monitoring crops, spraying crops, and harvesting. However, we are expected to see a rise in roles such as Big Data specialists and machine Learning specialists, which are generally few and operate with robots instead of human operators, as well as robotic engineers. The technology driving the 4IR is already disrupting farming industries across South Africa. The technology includes Artificial Intelligence, UAVs, robots, and mobile applications. They are used to analyse soil, till, plant, monitor, and connect producers to the market. Technologies, such as high-resolution 3D aerial photography from UAVs, sensors, and Artificial Intelligence-driven analytics, may soon make it possible to evaluate soil attributes and crop performance down to the square inch (25,4 x 25,4mm) with a great deal less use of manures and pesticides (NEDLAC, 2019).

UAVs built in South Africa, Stellenbosch, using imported parts, are unique due to their software combination which enables autonomous flight. When paired with a laptop, these UAVs can fly according to a map (Daniel, 2022). Considering that these UAVs are custom-made, they can address the agriculture challenges facing the country (Collins, 2020). These innovative technologies can be utilised to share information about competitive prices, crop monitoring, and disease outbreak tracking and prevention. They can transform the agricultural sector to increase production, income, and output (Foresight Africa, 2020).

There will be UAVs spraying crops in South African fields soon. It is the first time a crop spraying drone has passed CAA regulations, proving that they can be operated safely and in accordance with commercial licence rules. Farmers who struggle to pay for aerial crop spraying can benefit from UAVs. Approximately 6 hectares were covered in 1.5 hours by the drone applying chemicals at a rate of 30 liters per hectare (Caboz, 2019). The use of UAVs in South Africa by smallholder farmers, mainly in areas facing water shortages, may well prove useful as they offer valuable information for improved operational decisions at the farm level, thus, assisting to reduce the risk of crop failure and small harvests. Real-time crop monitoring at the field scale, which makes it possible for farmers to timely intervene through the growing cycle till harvest, results in better-quality crops. This technology assists smallholder farmers to make informed strategic and operational decisions, for instance, the farmer will know when a plant, irrigate, and apply nutrients and chemicals. Continuous monitoring of crops using UAVs allows farmers to notice changes that are not simply detected by the human eye (Nhamo, et al., 2020).

In the agricultural sector in SA, the use of technology and digitisation have recently begun to rise. Advanced Technologies such as data analytics tools, Remote Sensing (RS), wireless communication, Unmanned Aerial Vehicles (UAVs), big data, robotics, satellite systems, and Artificial Intelligence (AI), are being merged to develop services intended at cost reduction, preserving resources, improving inputs, and maximizing outputs for the farmers (Aguera, et.al, 2020). Moreover, Smith (2018) emphasises that many of these recent technologies, particularly the on-site technical infrastructures related to data collection, processing, and storage, the internet of things (IoT), data analytics tools, Artificial Intelligence, and cloud services can be acquired by commercial farmers operating at a large scale, primarily because of the cost involved in the technology adoption.

The South Africa-based company Aerobotics uses aerial imagery and machine-learning algorithms to solve a range of problems, such as detecting early pest disease in several industries (Opudo, 2017). As of May 2019, Agri SA and Aerorobotics have signed an agreement to provide farmers with free satellite farming data and Aeroview field scouting applications. This partnership will speed up farmers' access to analytical information at scale so that they can identify pests and diseases early and improve crop yields. Aerorobotics enables farmers to identify weaknesses and stop pests and diseases from spreading through its web-based satellite data and In-Field App, which can increase yields. Growers can use this information to make better decisions. Farmers use this high-resolution data to track each tree during its life cycle and improve yields (Freshplaza, 2019).

2.6.2 Information Communication Technology

Information and communication technologies (ICTs) enable people to share and disseminate information rapidly (Nwafor et al., 2020). Consequently, ICT-based information sources can be used to provide relevant and timely market information to smallholder farmers. For livestock farmers, ICTs are used to process and transmit information (Serbulova et al.,2019). As agricultural information is essential for enhancing farming, ICTs play an important role in stimulating and disseminating it (Kante et al., 2016). As many people, especially in developing countries such as South Africa, depend on agriculture for their livelihood, agriculture continues to provide sustainable futures, rural development, and poverty reduction in the twenty-first century (Chiwawa, 2019).

In agriculture, ICT innovation has mostly been associated with increasing productivity and efficiency, especially for livestock production, since agricultural businesses are increasingly interested in solutions throughout the post-harvest process, transportation, and storage phase. Since livestock farmers have adopted this technology, they have been able to reduce transaction costs per unit and increase efficiency gains. South Africa has benefited greatly from ICT as ICTs have greatly increased access to markets for farmers (Eskia, 2019).

In livestock farming, ICT usage is rapidly growing due to the high demand for agricultural information, which is a key ingredient in improving smallholder agriculture and connecting farmers to profitable markets (Wawire et al., 2017). Even so, efforts have been made to encourage farmers to use ICTs, but their involvement has not replicated how ICTs encourage livestock farmers to access and use agricultural inputs and market information. According to Luqman et al. (2019), livestock farmers in South Africa use a variety of information sources to gain modernised, updated knowledge about farm practices to maximise profit and thereby improve livelihoods. Several steps are included in the e-Farming process outlined by Pradhan and Mohapatra (2015). They include conceptualisation, design, development, evaluation, application, farming. These steps are depicted in Figure 2.7.

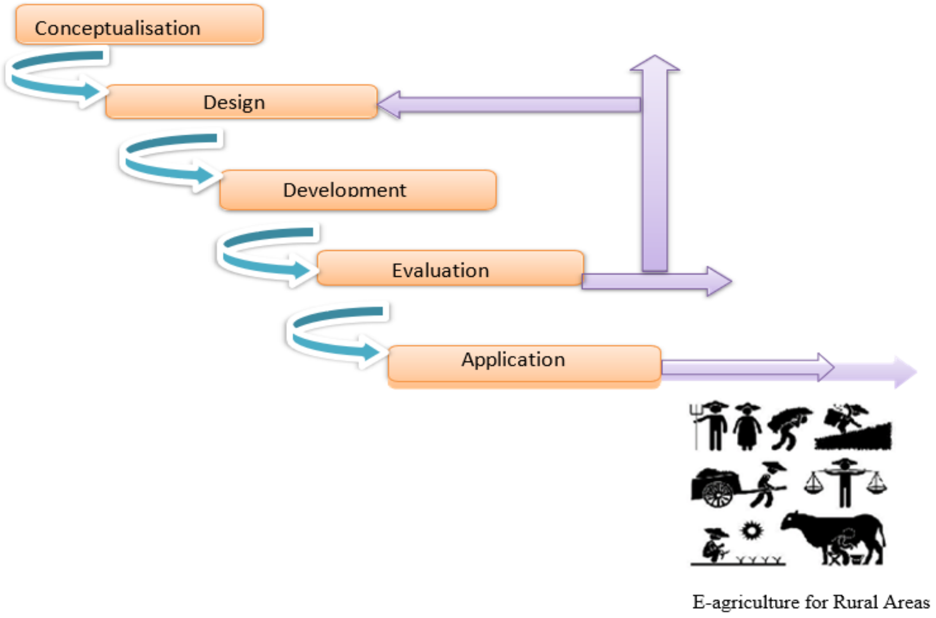


Figure 2.7: Steps implicated in e-agriculture (Pradhan & Mohapatra, 2015)

According to Pradhan and Mohapatra (2015), telecommunications networks have been used to enable ICT to become a vast field of technologies, applications, and services. ICTs include software, operating systems, computer hardware, electricity, phone lines, intranets, networks, radio, and satellites (Ntaliani et al., 2010). ICT technology consists of computers, communication, and information management. Data, knowledge, and information are managed, exchanged, and processed using these technologies. Even so, when observed, smallholder and rural household farmers also use ICT technologies such as smart pens, market information systems, and agricultural extension systems (Aker, 2011).

Makhura (2019) said that Gauteng Province is determined to be the economic engine of South Africa and the industrial, technological, and financial center of sub-Saharan Africa. He further mentions that Gauteng is the first provincial government to establish an e-government department in South Africa as part of our quest for a smart, innovation-driven, knowledge-based, and digital economy. The province has invested in broadband roll-out to peripheral and disadvantaged communities in the province to prevent digital exclusion, digital poverty, and digital inequality in an already unequal society. The Tshepo 1 million programs is already training one million young people with digital skills in cooperation with big technology companies.

More than 85% of households in Gauteng have a functional mobile phone and 65% have access to the internet, which has positively impacted the economy, business environment, and quality of life there. Several public services are being delivered digitally in Gauteng and citizens have responded positively to this switch.

2.6.3 GIS and Remote Sensing

South Africa's Spatial Data Infrastructure (SASDI) was established in 2003 by the Spatial Data Infrastructure Act (No. 54 of 2003) as a technical, institutional, and policy framework to facilitate the discovery, sharing, and use of geospatial data and services. It is the responsibility of the Committee for Spatial Information (CSI) to manage SASDI. Several provincial, municipality, and municipal initiatives exist in South Africa that aim to discover, use, and share geospatial data, but not necessarily under the SDI umbrella (Coetzee et al., 2020). For instance, the Provincial Government of the Western Cape might integrate new web services with the City of Cape Town Municipality (Heald, 2011).

There are also challenges for small-holder farmers who do not use GIS and remote sensing data. Remote Sensing Imagery is not only for commercial farmers. This type of dataset is also used by smallholder farmers and linked with extension services. Although some image data is freely available, some smallholder farmers still face the challenges of accessing the required equipment, the ability to use the data set, and connectivity issues (Du Preez, 2020).

The application of GIS to determine agricultural land suitability played a major role in finding suitable land for maize and sorghum in the Limpopo province's Vhembe district. This idea is especially noteworthy since land well-suited to maize farming is unsuitable for sorghum. Information like this can help farmers save time and money, as well as increase the yield of crops. After considering soil pH temperatures, soil structure, sowing times, and precipitation, the farmer will farm the crops appropriate for the area. Residents who rely on subsistence farming can still plant crops suitable for the land that was unsuitable for sorghum or maize to ensure food security (Mufungizi, et al.,2020).

Remote sensing tools are used to evaluate land management and planning. The application of RS in agricultural research has been extended to disaster management over time as technology has advanced (Abah, 2013). Petja et al. (2014) cite aerial photography and satellite imagery as common means of collecting spatial data processed into data such as land use, land cover, and mining activities. Planning and land management are improved with RS and GIS (Rogan, 2004). Agricultural planning and production can benefit from remote sensing and GIS because they can predict yield, monitor crops, manage lands, assess risks, and support decision-making. We can combine spatially varying inputs and outputs by integrating GIS and remote sensing. Agricultural production can be identified, monitored, and assessed using both techniques (Simms, 2009).

The use of satellite images allows for early warning systems and better prediction (Simms, 2009). A wide range of data can be obtained in a short amount of time, which will allow both accurate damage estimation and better emergency management. The use of RS to identify hazard zones associated with active faults, coastal flooding, and flood plains has been successful for risk reduction initiatives. To provide warnings about potentially deadly weather conditions, meteorologists mostly rely on imagery. Furthermore, remote sensing satellite image processing data can also be shared via the Internet for global viewing (Dragonfly Aerospace, 2022).

According to Simms (2009), remote sensing satellites can be a valuable tool for providing managers with an objective, dependable, and economically efficient data. Since satellite images to be captured periodically by remote sensing sensors are now available in the same geographic area, the possibility of developing a system capable of automatically updating and producing land cover maps is extremely exciting. Currently, land-cover maps are updated using supervised classification, which always requires a large sample size (Crawford, et al., 2013). Several methods for automating training data have been proposed as alternatives to manual selection. For example, Training Data Automation (TDA) methods have been designed to map forest cover and extract built-up areas (Li, et al., 2015). Li, et al (2015) proposed an automated approach for classifying vegetation, water, impervious surfaces, and bare land with training data automation procedures based on several spectral indices. Nevertheless, most of the current methods focus on several specific land-cover types, and some important land-cover types are not considered (e.g., cultivated land and wetlands) (Tuia, 2016).

Petetja et al. (2014) demonstrate how increasing the availability of remote sensing images may be key. Over time, satellite images can be used to monitor the vegetation of an entire farm. Satellite images can be used to monitor ecological data effectively, according to Abah (2013).

Satellite images can be used for detecting environmental problems in agriculture. Simms (2009) maintains that the spatial component of satellite data can be used to relate local vegetation changes to specific ground coordinates, allowing for more precise field investigation. Besides improving decisions, land use planning also provides information about agricultural expansion potential and reduces land deterioration (Collet, 2008).

Furthermore, NDVI and precipitation products are used to forecast and estimate crop and pasture yields. Many African countries produce monthly or seasonal forecasts based on different datasets and models. In South Africa, official crop forecasts are released by the Crop Estimates Committee each month. Data derived from remote sensing is widely used for monitoring crop health. Although some progress has been made, crop acreage assessments using remote sensing data are still not operating in South Africa due to the lack of resources (Bernardi et al., 2016).

According to Coetzee et al. (2020), the GIS Directorate in the Planning Division at the Office of the Premier in Gauteng is responsible for coordinating GIS activities for the Gauteng City-Region (GCR). In 2015, the GIS Directorate in the Planning Division at the Office of the Premier established the GCR GIS Forum. Gauteng provides a platform where GIS specialists from various municipalities, government departments, academia, and the private sector gather regularly to discuss GIS-related activities. The GCR Integrated Geospatial Data Platform is accessible to the public and serves as a central repository of geospatial and other data contributed by GCR stakeholders (Sector Departments, Municipalities, and State-owned Agencies). In addition to performance monitoring, infrastructure locations, transportation, imagery, and base maps, the platform provides authoritative data.

An important advantage of GIS is how flexible it is and how it can be used to obtain a large variety of different data sets (Meghdadi & Kamkar, 2011). Then, Malema (2014) indicated that data sets that are used commonly by Gauteng, including farm boundaries, land parcel boundaries, and the boundaries of subdivisions of land parcels are still used with electronic satellite imagery in place of topographical maps. Besides land assessment techniques, Kabanda (2015) shows that GIS can likewise be utilised to give thematic data related to the rigidity of land use limitations and land management. Malema (2014) notes that organisations typically use ESRI GIS software because only users with advanced GIS skills can access the ESRI products and those with limited GIS skills can use the GIS viewer to view GIS outputs such as general-purpose maps. GDARD GIS cooperate unit introduced an intranet GIS system utilising web technologies.

Dedicated servers, ArcSDE geodatabase links, and large colour graphics monitors were acquired for multi-user data storage and delivery of the web-based GIS. There are also printers and plotters needed for each unit that uses GIS. A thematic map is created by combining and analysing data. Gauteng Integrated Decision Support (GIDS) provides various maps and thematic layers, such as conservation plans that show reserves, protected areas, and irreplaceable areas. Gauteng Agricultural Potential Plans (GAPAs) protect agricultural hubs that contribute to food security in Gauteng. Information like chicken and pig infrastructure and production inputs are stored in agricultural databases by the agricultural directorate using ICT applications called agricultural databases. Despite this, the system does not directly contact farmers, since the farmers' plan expansion would pass their information to them, and they could receive it directly, which could be an innovation in the future (Malema, 2014).

Field workers at the GDARD appreciate GPS technology because it helps them navigate to remote farms and saves them time and petrol. An electronic field pen solution tool used for field data recording can reduce the amount of time spent converting media data, such as pictures, GPS coordinates, and field reports, directly into a central database that can be accessed by decision-makers. In the long run, maintenance of such tools will cause problems, such as charging mobile phones and downloading software to other devices that can only be done by the original service provider (Malema, 2014).

2.7. The adoption of agricultural technologies by South Africa compared to other countries.

This subsection discusses South Africa's adoption of Information Communication Technology and precision agriculture technologies compared to the adoption by developing countries such as Argentina, Brazil, and Turkey, as well as developed countries such as the United States, Australia, and Canada.

2.7.1 Precision Agriculture (PA)

PA technologies are becoming more widely adopted in some developed and developing countries. Over the past decade, auto-guiding systems have gained more popularity in both developed and developing countries. Yield monitoring technologies and variable rate technologies were prevalent earlier.

The PA technology is used in developing countries such as Argentina, Brazil, South Africa, and Turkey. Additionally, other countries may use PA technologies that were not reported in the publications (Say et al., 2018). PA technologies are among the many new technologies where the US leads the world. Fountas et al. (2005) report that more than 90% of yield monitors are based in the United States. Some states/regions have adopted automatic guidance technology at a rate of 60-80% (Miller et al., 2017). Several other countries in the European Union have also embraced PA technologies (Leonard, 2014). As stated by Leonard (2014), about 80% of grain growers in Australia rely on automatic guidance. Moreover, Steele (2017) found that 98% of surveyed western Canadian farmers used GPS guidance. There is a common factor among these three countries (the US, Australia, and Canada): farmers in these countries are more accustomed to adopting new technologies due to their larger farms. When it comes to PA technologies, the size of the farm is an important factor (Keskin, 2013; Keskin & Sekerli, 2016). Most farmers who adopt high-cost new technologies farm a few hundred hectares or more.

2.7.2. Information Communication Technology

It has been widely reported that information and communication technologies (ICTs) assist in disseminating information to farmers. This indicates that smallholder farmer’s need for relevant and timely market information can be met using ICT-based information sources (Nwafor, et al., 2020). This has resulted in the development of platforms that use ICTs for disseminating market information to farmers in many African countries, South Africa included. These aim to address the perceived lack of market information, especially among rural smallholder farmers. ICT-based information sources available to smallholder farmers in South Africa include radio, television, mobile-phones, and computers with internet. While there are arguments related to the availability, accessibility, costs, and benefits of using relevant ICTs, the requirement of smallholder farmers for relevant information is undisputed. While ICTs may not be considered as a solution to all the market challenges of smallholder farmers, they can make a meaningful contribution, especially to information-impacting decisions (Nwafor, et al., 2020).

There has been an increase in the use of ICTs in different sectors throughout South Africa. According to Aruleba and Jere (2022), the number of Internet users will increase from 5.3 million in 2009 to 38.13 million in 2021. The number of people using the Internet increased from 1.73 billion to 4.66 billion (Ostrowick, 2018).

Moreover, most ICT infrastructure users in rural areas are not advanced users; they mostly use phones for making voice calls, sending SMS, and checking social media. Nonetheless, some initiatives and works have been initiated to develop comprehensive IT-based livelihood services in these fields, namely agriculture (Aguera, 2020) and education (Aruleba and Jere, 2022).

In South Africa, the digitalisation of economic sectors, including agriculture, is mostly determined by the affordability of devices and data, and by the availability of the Internet. Surveys conducted by Research ICT Africa (RIA) in 2018 revealed that 53% of South Africans have access to the internet, which is the highest proportion compared to other Sub-Saharan African countries. In the study, it was also found that access to the internet varies between urban and rural areas of South Africa. This indicates that ICT infrastructure development is still needed to support smallholder farmers who operate in rural areas. In addition, the survey found that 85% of South Africans own a cell phone. However, only 47% of these people own smartphones. This is a key factor to address since smartphones, like marketing, have become an important part of agribusinesses and digitalisation. Based on the 2018 survey, 47% of South Africans lack access to internet services because internet-enabled devices and data are extremely expensive. Limited knowledge, inadequate digital skills, illiteracy, and a lack of awareness about the internet are also contributing factors to the lack of access to the internet (Gillwald and Mothobi, 2019).

Farmers doing commercial farming in South Africa are confident and willing to use ICT to increase their farm productivity since they are aware of the benefits of using advanced technologies like UAVs and satellites (Maumbe and Tembo, 2011). Although ICT applications should not be considered a replacement for farmworkers, but rather a means of supporting them so they can minimise input costs while maximising outputs (Gillwald et al. 2019). In South Africa, ICT and digital technology have begun to gain momentum in the agricultural sector. There is an increase in the use of technologies such as satellites, UAVs, automatic sensing, wireless communication, and data management (Hanson & Heeks 2020). In agriculture, these advanced technologies are applied to reduce input costs, increase productivity, and promote sustainability. It is difficult for smallholder farmers to adopt modern digital technology due to costs involved. Commercial farmers will likely adopt most of these technologies that require on-site infrastructure to collect and process data (Smith, 2020). Both commercial and smallholder farmers can benefit from advanced technologies when applied through extension services and market information systems that are accessible on mobile devices (Aker 2011).

2.7.3 Remote Sensing

As defined by Du Preez (2020), NDVI measures how plants absorb and reflect visible and infrared light. Correspondingly, UAVs that are mounted with inexpensive sensors in the infrared spectrum can spot crop stress during crop monitoring about two weeks earlier than the person's eye can notice it (ThirdEye Water, n.d). The use of remote sensing in agriculture is increasing rapidly. For instance, in South Africa, farmers use satellite imagery that offers once a week, semi-real-time data on how the crop is growing, crop nitrogen, and evaporation deficits to deciduous and grapefruit cultivators in the Western Cape province, helping them to save on the inputs of fertilizers, water, and electricity. Smallholder farmers in Mozambique, use airborne sensors for decision-making about the application of inputs such as water and crop protection chemicals (Du Preez, 2020). Other countries have also shown that a lack of Internet access does not necessarily hamper the use of digital extension services. In Zimbabwe, the mobile app "Kurima Mari" offers an offline toolkit and library for farmers. Currently, the app is being scaled up to the national level by the federal government (Welthungerhilfe, 2018).

2.8. Indicators that can be mapped in agriculture using remote sensing and their purpose.

2.8.1. Crop Health and Stress Detection

2.8.1.1. Normalized Difference Vegetation Index (NDVI)

The use of a centralised decision support application for farming multiple crops together in an area, a general practice among smallholder in Africa, has provided diagnostic information on 90% of the familiar African crop diseases, and remote sensing was used to generate a genetic plot for stripe rust resistance in wheat (Onyango et al., 2021). Normalized Difference Vegetation Index (NDVI) and precipitation information are used to predict and estimate the yield of crops and pastures. Many African countries use datasets and models to develop forecasting systems and publish monthly or seasonal bulletins. In South Africa, the Crop Estimates Committee publishes an official crop forecast every month. Although harvesting conditions are continuously monitored using remote sensing data, this has not yet reached an operational level. This problem is attributed to resource limitations (Bernardi et al., 2016). Each year, Senegal estimates the biomass of its national pastures to determine how much forage they need. This technique is based on an empirical relationship between the satellite derived NDVI and in situ biomass measurements (Diouf et al., 2015).

Furthermore, NDVI and precipitation products are used to forecast and estimate crop and pasture yields. Many African countries produce monthly or seasonal forecasts based on different datasets and models. In South Africa, official crop forecasts are released by the Crop Estimates Committee each month. Data derived from remote sensing is widely used for monitoring crop health. Although some progress has been made, crop acreage assessments using remote sensing data are still not operating in South Africa due to the lack of resources (Bernardi et al., 2016).

2.8.1.2 Leaf area index (LAI)

Leaf area index (LAI) measures the amount of leaf area in an ecosystem. LAI is one of the most important parameters for understanding terrestrial ecology, hydrology, and biogeochemistry. Remote sensing data can be used to estimate LAI either statistically or physically. LAI is analyzed statistically using the empirical relationship between surface reflectance and vegetation indices. In physical methods, LAI is determined by radiative light transfer processes within the canopy. Using a forest model, LAI can be calculated using light detection and ranging technology. There are several major global moderate-resolution LAI products, such as GLASS, Moderate Resolution Imaging Spectroradiometer, CCRS, GLOBMAP, and ECOCLIMAP (Liang and Wang, 2020).

2.8.2 Land Cover and Land Use Change

Land cover includes vegetation, bare soil, water, and artificial structures as the material covering the surface of the earth. The data on land cover is crucial for a wide range of activities, from environmental planning to economic development, compliance monitoring to enforcement, and strategic decision-making. South Africa's National Land Cover Project developed an automated, operational process for producing future national land-cover data, based on Gazetted Land Cover classes (SANS 19144-2). With the Computer Automated Landcover (CALC) system, it is possible to create automated land cover datasets, perform accuracy assessments, and detect changes between comparable land cover datasets. CALC was used to generate the South African National Land Cover (SANLC) datasets and all associated change assessments for 2018, 2020, and 2022 (DFFE, 2022).

Several African countries have produced national land cover maps, mainly as part of North-South partnership projects or national land cover programs. For example, the Food and Agriculture Organization (FAO) has mapped more than fifteen countries, mainly in East Africa, through visual interpretation of Landsat imagery used for Africover and the Global Land Cover Network projects (Latham et al., 2014). Sen2-Agri recently developed a platform that produces monthly dynamic farmland masks and cultivated crop species maps with a resolution of 10m twice during the growing season using Sentinel-2 and Landsat-8 imagery (Defourny et al., 2019). Furthermore, many isolated land cover projects have been undertaken at the sub-national level based on the need for research or thematic expertise (for example, AfricaRISING in southern Mali). However, these maps are generally not accurate enough to calculate agricultural statistics or create land-use plans for commercial projects. For large areas, multiple land-use maps with relatively high spatial resolution can be produced on request, often as part of a project. For example, the Burkina Faso Institute of Geography (IGB) has developed the Burkina Faso land cover database (BDOT13 at a scale of 1/100 000) (Bégué et al., 2020).

2.8.3. Crop yield estimation

It is possible to use agricultural RS technology to monitor and manage commercial open-air agriculture production uniquely. It can monitor crops that are scattered in type and located in complex terrain. Agri-resource research has three focuses: crop yield estimation, agricultural disaster forecasting, and precision agriculture (Gao, et al., 2020). As a result, RS technology is now being used to manage and protect farmland water conservancy projects (Ma et al., 2019), monitor ecological environments (Chui, 2017), and make real-time decisions about soil fertilization (Li, 2017).

The rapid development of remote sensing (RS) techniques has resulted in cost-efficient and inclusive solutions to agro-environmental monitoring. Consequently, RS data have become essential for monitoring crop growth and management at different scales in the last decade (Awad, 2019). RS data has different spatial resolutions that play an important role in crops estimation or monitoring at regional or field level, where high spatial resolutions are necessary to reach field-level crop management (Ferencz et al., 2004), whereas low spatiotemporal resolutions represent regional or county-level management (Tuvdendorj et al., 2019); (Ahmad et al., 2020).

2.9. Conclusion

In conclusion, the literature review provides a detailed overview of the adoption and utilisation of GIS, RS, ICT, and 4IR technologies in the agricultural sector across a range of global contexts, including developed and developing countries, with a particular focus on Africa and South Africa. Several studies have shown that the use of these technologies can improve food security, resource management, and agricultural practices. It is the lack of a localised, in-depth analysis of these technologies' potential and impact within Gauteng Province that adds to the existing gap in literature. The next chapter looks at the approach and methodology that will be employed in the study to empirically investigate the uptake of these technologies in Gauteng agriculture, with the intention of enhancing knowledge on the subject.

CHAPTER 3: RESEARCH DESIGN AND METHODOLOGY

3.1 Introduction

Research methodology is an approach and process researchers employ to conduct their studies (Silyew, 2019). This chapter discusses the methods employed in this study to collect and analyse the data. This includes the research approach, design, the sampling strategy employed, and specific methods selected to collect and analyse data. Motivation is provided for the selection of survey questionnaires as an appropriate tool to collect quantitative data and the utilisation of interviews and observation to collect qualitative data in this mixed methods study. Kernel density estimations (KDE) statistical method and descriptive statistics were used to analyse quantitative data and content analysis was used to analyse qualitative data.

The chapter concludes with a discussion on the limitations of the research and how issues dealing with ethics were managed in the study. The conclusion in the end provides a summary and an overview of the next chapter.

3.2. Conceptual framework

A conceptual framework, according to Ravitch and Riggan (2016), is an argument as to why the subject one wishes to study is relevant and why methods adopted to study it are appropriate and rigorous. Conceptual frameworks are sequences of logical statements put together to justify the study and convince the reader of the importance and rigor of the research. Arguments on why the study is important are very different depending on the target group (Ravitch and Riggan, 2016).

The conceptual framework serves to formulate and carry out a research design. Essentially, it specifies the primary or core design of a study and how they relate (Miles et al., 2014). Beyond that, conceptual frameworks evolve and change as your understanding changes, meaning that a conceptual framework is simply the differentiated and integrated version of the researcher's map at a given point in time. As you dig deeper and understand the parts and the whole together, the conceptual frameworks become more sophisticated. In an ideal world, a conceptual framework would help you become more sophisticated and selective in terms of methods, underlying theories, and research approaches (Ravitch & Riggan, 2016).

Maxwell (2005) asserts that the comprehensive rationality of a conceptual framework is something that one constructs and not something that is off the shelf. Maxwell (2005) provides four potential sources that can be exploited to develop an abstract framework: the academic's, personal experiences and knowledge; present philosophy and research; exploratory study; and thought experimentations.

For this study, the conceptual framework was adopted because the research will comprise the researcher's thinking about different components of the research; personal experiences, and knowledge and to explore and describe the uptake and/or non-uptake of these technologies by the agricultural communities in Gauteng. This study applied the mixed-method approach of personal experiences and knowledge and exploratory study.

3.3 Research Approach and Design

3.3.1. Mixed methods approach

A mixed methods approach was adopted to answer the research question in this study. A mixed methods approach is used when qualitative and quantitative elements are combined in a study (Saunders & Lewis, 2018). A mixed methods study provides a more comprehensive picture than a qualitative or quantitative study alone (George, 2022). To address the main research objectives, this study combined qualitative and quantitative methods using primary and secondary sources. Qualitative data was used to support results obtained from quantitative data (Kumar, 2010). Research using mixed methods may be appropriate if quantitative or qualitative data alone is not sufficient to answer your research question (George, 2022).

As a result of using both qualitative and quantitative data in conducting the study, triangulated results were obtained. The discussion below focuses on the description of the data sources, and the sampling method. For the purposes of this study, a combination of both qualitative and quantitative approaches was applied.

Research is categorised as qualitative if the objective of the study is primarily to state a condition, a phenomenon, or occasion; if the data is gathered using variables measured on nominal or ordinal scales and if the assessment is done to establish the variation in the condition, phenomenon, or problem without measuring it (Kumar, 2010).

The portrayal of witnessed conditions, the historical enumeration of occasions, a justification of diverse sentiments everyone may have about an issue, and an explanation of living situations of the society is another instance of qualitative research. Alternatively, the research is categorised as quantifiable if you aim to measure the discrepancy in an event, situation, dilemma, or matter; if the data is collected through the use mainly of quantitative variables; and if the evaluations are geared to establish the extent of the variation. Examples of quantitative characteristics can be such as the number of people having certain problems or how many individuals embrace a certain attitude? (Kumar, 2010).

Methods used to collect quantitative data involve mathematical calculations in a variety of formats. Among methods used to collect quantitative data are closed-ended questionnaires, correlations, and regressions, mean, mode, and median. Combining the two methods can provide richer insights into the phenomenon under study than using either qualitative or quantitative methods alone. Mixing and synthesising multiple sources of data can be useful when studying complex problems (Poth and Munce, 2020).

3.3.1.1 Mixed methods strength

Out of the three methods typically used by researchers, the mixed method is preferred by many as it has several advantages. In utilising this method, researchers can benefit from the strength of both quantitative and qualitative designs. In addition, terms, pictures, and narratives can be used to give numbers more meaning. Furthermore, researchers have the advantage of adding precision to words, pictures, and narratives when using mixed methods research. Another benefit of using mixed methods in research is that researchers can develop and test grounded theories (UKEssays, 2018).

A mixed-method study (MMR) has the first advantage of extending the study. Research can be performed with sufficient depth and breadth using the MMR method. Researchers should record both closed quantitative data and open qualitative data if they intend to extend knowledge and determine what a phenomenon or concept means to an individual (Creswell et al., 2003). Secondly, mixing two methods gives a more comprehensive picture and an additional opportunity for divergent or complementary perspectives, which are important because they lead to greater reflection, help explain a phenomenon, and open new possibilities for further study (Teddlie and Tashakkori, 2009).

A third advantage of MMR is that it allows for more rigorous inferences since two methods are employed so that qualitative strengths counteract quantitative weaknesses (Plano Clark and Ivankova, 2016). Quantitative methods can work where qualitative methods lack strength and vice versa. It is possible for qualitative methods to be well suited to answering one question, while quantitative methods can be well suited to answering another (Dawadi et al., 2021). When a researcher performs a comparative analysis between two different methods to determine convergence and/or divergence, he examines the results directly to get a more accurate picture of the research topic under study (Plano Clark and Ivankova, 2016).

3.3.1.2 Mixed methods disadvantages

According to David et al. (2018); Fauser (2018); and Dawadi (2019), mixing qualitative and quantitative components can also have challenges. Firstly, collecting and analysng data can take a lot of time. As a result, the process may be more time-consuming and expensive. Researchers often struggle with designing research within their estimated time and budget (Fauser, 2018; Hauken et al., 2019). Some researchers claim that recruitment is time-consuming and data collection is labor-intensive (David et al., 2018; Linnander et al., 2019).

The second challenge for many researchers is integrating qualitative and quantitative data (Wisdom & Creswell, 2013). It is worth noting that Dawadi (2019) did not feel confident about the way she brought together quantitative and qualitative data. Furthermore, Casey et al. (2016) found it difficult to integrate their data sets. Also, there are few guidelines on how to merge data from different sources in the existing literature. Youngs and Piggot-Irvine (2012) raised a similar question: ‘‘When do you stop analysing, comparing, and contrasting data?’’. Thirdly, Dawadi et al. (2021) emphasises that selecting a proper design and ensuring data integration quality are challenges in the mixed-methods approach.

In some cases, one method may affect the way data is collected and interpreted by another. A sequential design, for example, may be influenced by the findings of the first method. The fourth and most important challenge for a mixed-method researcher is choosing the right study design. The selection of the study design depends on its purpose and the relative importance of qualitative and quantitative elements. Therefore, early-career researchers may not feel confident enough to choose one design from a number, especially when they each have their own disadvantages (Dawadi et al., 2021).

3.3.2 Research Design

According to McCombes (2023), a research design involves using empirical evidence to answer your research question. When you design a research study, you need to consider (a) your research objectives and approach, (b) whether you will conduct primary or secondary research, (c) your sampling methods, (d) your data collection methods, and (e) the procedures you will follow to collect data, and (f) data analysis strategies. Choosing the right methods and conducting appropriate data analysis are essential parts of your research design.

As reported by Creswell et al. (2003) the three concurrent mixed-methods designs are (a) concurrent nesting, (b) concurrent triangulation, and (c) concurrent transformative designs. Each of these designs collects both quantitative and qualitative data simultaneously, although preference can be given to one type of data over the other. Concurrent triangulation designs aim to define relationships more accurately between variables by combining qualitative and quantitative data. In the context of concurrent nested designs, qualitative and quantitative data are collected simultaneously, with one data form being given a higher priority (Creswell et al., 2003). As with sequentially nested designs, concurrent transformative designs aim to initiate social change or advocacy and can support a wide range of perspectives.

For this study, concurrent triangulation data collection design was applied where qualitative and quantitative information is gathered and simultaneously analysed.

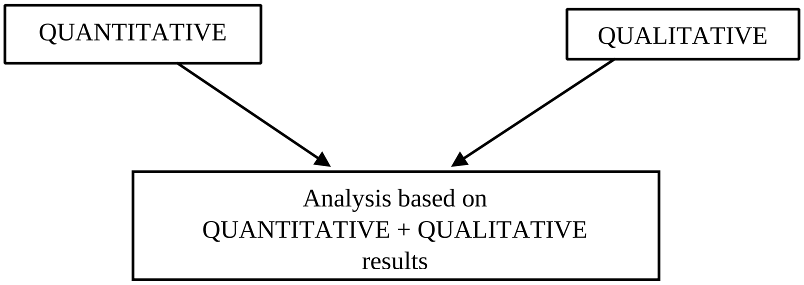


Figure 3.1: Triangulation sketch (adapted from Creswell & Plano Clark, 2007: 63)

Triangulation was used to get a complete picture of the significance of ICT, GIS, RS, and 4IR technologies to improve food security in the agriculture sector. During data collection, priority was given equally to both qualitative and quantitative methods to gain adequate information on all the research objectives. Quantitative and qualitative techniques were integrated during the interpretation and analysis stage of the study, this integration offered an inclusive analysis of the study problem. Closed-ended questionnaires were utilised for data collection from GDARD Agricultural advisors and extension officers, and open-ended interviews with the farmers on 4IR uptake. Publicly available data and the data collected by the researcher were used to map the distribution of the uptake and to determine underlying causes for the uptake or not of ICT, GIS, RS, and 4IR technologies.

3.4. Methodology

3.4.2. Research instruments

Collins (2021) defines a "research instrument" as any tool utilised by a scientist for obtaining, measuring, and analysing data. Different tools can be used to conduct quantitative, qualitative, or mixed studies. The choice of instruments depends on the type of study you are conducting. Whatever method researchers choose, they must describe the methods section. Data may be collected with a variety of approaches, such as questionnaires, interviews, diary entries, classroom observations, and journals.

In mixed-method research, questionnaires, interviews, and classroom observations are instruments often used. The validity and reliability of data can therefore be increased by using these different methods of gathering information. The most used quantitative data collection method is the closed-ended questionnaire, while open-ended questionnaires, classroom observations, and interviews are most used to generate qualitative data (Zohrabi, 2013).

3.4.2.1 Questionnaires

According to Bhandari (2023), a questionnaire is a list of questions used to gather information about respondents' attitudes, experiences, and opinions. Debois (2022) defines a questionnaire as a way of collecting data by asking a given subject to answer either oral or written questions. Furthermore, Bhandari (2023) points out that questionnaires may be used to collect quantitative or qualitative data. There are two types of questionnaires: self-administered and administered by researchers. A researcher-administered questionnaire is a better option because it provides deeper insights than self-administered questionnaires. In researcher-administered questionnaires, researchers and respondents conduct telephone interviews, in-person interviews, or online interviews.

The questions in a questionnaire may be open-ended or closed-ended, or a combination of the two (Bhandari, 2023). Open-ended questions allow the respondent to be as creative as they want. Answers to closed-ended questions are either "Yes" or "No," or they have a limited range of choices (such as A, B, C, or All of the Above). When users do not have to type so much, closed-ended questions are good for surveys. In addition, closed-ended questions can be easily analysed statistically, which is what most survey data are used for (Farell, 2016). When using closed-ended questions, you are limited in what you can say, while when you use open-ended questions, you have a wide range of options to choose from (Bhandari, 2023).

Advantages of the Questionnaire

The most affordable way to gather quantitative data is through questionnaires. One of the most economical ways to quickly gather mass amounts of information from many people is to conduct self-administered surveys, which do not require face-to-face interviews. The researcher can place a questionnaire on your website or send an email to your customers. A questionnaire is not only inexpensive, but also a practical tool for gathering data. Questions and formats can be selected as needed (open-ended or multiple-choice). Using them, you can collect vast amounts of data about any topic (Debois, 2022).

Cornell (2022) argues that questionnaires are the simplest and fastest way to collect data. In just a few clicks, you will be able to share your questionnaire with your target audience. Online tools help you create questionnaires that can be accessed anywhere and anytime by your target audience. In most cases, the results of surveys and questionnaires can be easily analysed since they are quantitative in nature. Analysing your results without a background in statistics or scientific research is simple with built-in tools (Debois, 2022). Respondents' identities are kept private by the online questionnaire creator. By respecting privacy, respondents are more likely to share their thoughts, which in turn provides better data (Cornell, 2022).

Disadvantages of the Questionnaire

A questionnaire that contains questions about income, voting, sexual behavior, and drug abuse is generally considered sensitive. In such questionnaires, only a small number of people respond.

It is possible that those who participate will not answer honestly. Often, respondents ignore certain questions in questionnaires or do not feel they are important enough to answer. Most respondents ignore questions they do not feel are necessary. Understanding the target audience is essential before creating a questionnaire (Cornell, 2022).

There is a lot of data produced by questionnaires. Open-ended questions cannot be tabulated or graphed like multiple-choice questions. Answers to open-ended questions can be individualised and cannot be quantified, so they must be reviewed by a human. When there are too many open-ended questions, there can be a lot of data that can take a long time to analyse. Lack of accessibility is a threat regardless of the delivery method. Surveys may not be suitable for users with visual impairments, hearing impairments, or other impediments such as illiteracy. When choosing to conduct research in this manner, this should be considered. It is always preferable to use a questionnaire platform with accessible options (Cornell, 2022).

3.4.2.2 Interviews

Interviews are qualitative research methods that involve asking questions to collect data. Two or more people participate in an interview, one of whom is the interviewer (George, 2022). The purpose of an interview is to get information from a person by asking questions and listening to their answers. Interviews consist of one person asking questions, and the other person answering them. Alternatively, there may be more than one interviewer and more than one participant (Bhat, 2023) in a one-on-one, two-way conversation.

Structured, unstructured, and semi-structured interviews are among the types of interviews. There is a difference between these types based on their level of structure. Structured interviews consist of a set order of predetermined questions. Questions like these tend to be closed-ended, dichotomous (yes or no), or multiple choice. Although structured open-ended interviews exist, they are much less common. Structured and unstructured questions are asked in a semi-structured interview. Although the interviewer has a general idea of what they intend to ask, the questions do not necessarily have to follow a particular format. Semi-structured interviews often use thematic frameworks to provide a sense of order and flexibility. As a result, they are often called "the best of both worlds" (George, 2022).

Advantages of interviews

An interview is one of the most common ways qualitative researchers collect primary data. Research can be conducted qualitatively and in-depth using it. Often, people tell you that asking someone for information is the easiest way to find out what they know. Through the interview, researchers can observe the body language and facial expressions of research respondents. In addition, it is important to understand their personal opinions, beliefs, and values. Research participants can establish a good rapport with researchers. As a result, the latter will soon feel comfortable and engaged in the process, leading to very favorable responses (Rahman, 2023).

Disadvantages of interviews

It takes a lot of time to conduct an interview. It may take a considerable amount of time for each interview. Additionally, for final reporting purposes, researchers must collect and code responses, organise them, and analyse them. Biased responses can result from interviews.

Interviewers' perspectives on the world may influence interviewees' responses. This can have a positive or negative impact on the outcome. It can also be expensive to conduct interviews. To get the best responses from participants, researchers need to conduct interviews skillfully. The situation may not be the same for many new researchers. As a result, they may need training on how to conduct interviews, which can be very costly (Rahman, 2023).

3.4.2.3 Observation

Data is collected through observation, as its name implies (Dudovskiy, 2022). Bhasin (2023) defines observation as observing and describing a subject's behavior. Observation is a method for gathering relevant information and data. In addition to being called a participatory study, the researcher must establish a connection with the respondent by immersing himself in their environment. Observation can only be used for recording and taking notes.

Data can be collected using the observations in a structured or unstructured way. Structured or systematic observation requires a predetermined schedule and specific variables to collect data. On the other hand, unstructured observation is conducted in an open and free manner, whereby no predetermined variables or objectives are in place. Furthermore, this method can be classified as either overt or covert. Overt observation is when the subject knows he or she is being observed. As opposed to covert observation, members of the sample group are unaware that their behaviour is being observed when the observer is concealed. Covert observation is more effective because sample group members will behave naturally, which is positively correlated to the validity of findings (Dudovskiy, 2022).

Advantages and Disadvantages of Observation

While observation has its strengths and weaknesses, like every research tool, it is possible to obtain direct access to the research phenomena, produce a permanent record of the phenomena, conduct the experiment in a natural environment, and acquire contextual factors (Dudovskiy, 2022). This method is also disadvantageous due to a large amount of time required to analyse observational data, the difficulty of observing large populations, and the presence of the observer, which may influence the behaviour of sample group elements (Dudovskiy, 2022).

3.4.2.4 Research instruments used

A self-administered questionnaire, an open-ended interview, and an observation were used to gather data for this study. Furthermore, a quantitative method of collecting data using a questionnaire to gather information from agricultural extension and advisory officers on services they provide to farmers and technologies they use to assist farmers within Gauteng was employed. Also, to assess the willingness to learn and adapt to the use of the recent technologies if they can be provided to them.

Again, an online questionnaire was used to collect information on the adoption of 4IR, ICT, RS, and GIS among commercial farmers and small-holding farmers. There were 150 questionnaires distributed to smallholders and commercial livestock and crop farmers receiving support from the Gauteng Department of Agriculture and Rural Development. These participants are from different municipalities. These are farmers who participate in the farmer register and receive government support through extension and veterinary services. To communicate with some of the selected farmers, the researcher had to liaise with the extension services team and the VETS team.

Open-ended interviews and observation were utilised to collect qualitative data. In this regard, Agriculture, GIS, and ICT DALRRD personnel were interviewed to get their views on how they see 4IR technologies benefiting provincial agriculture departments and farmers in Gauteng. Moreover, the observation method was used where the researcher visited farmers in Gauteng to map and determine clusters of various levels of uptake of 4IR products, RS, and GIS and to compare the uptake by commercial farmers versus small-holding farmers.

Survey123 tool was used to design the questionnaire and open-ended interview questions. Survey123 is one of the mobile data collection applications integrated with the Esri ArcGIS platform (Fornace et al., 2018). With Survey 123, field workers can easily create smart forms and collect data. With Survey123 for ArcGIS, you can create, share, and analyse surveys in a very easy and intuitive way. Through this app, researchers can collect data anytime, anywhere. As a native app and web-based tool, it works on smartphones, laptops, and desktops. It can develop surveys that use predefined questions, provide easy-to-fill answers, embed audio and images, and incorporate geospatial information into the data collected, the survey process can be expedited (Gletham, 2017). Furthermore, secondary data were used, including GIS agriculture, boundaries, towns and cities, roads, and satellite imagery.

3.4.3. Data collection

Collecting data is the process of testing hypotheses, answering research questions, and evaluating results (Dudovskiy, 2022). Richmond (2006) points out that data collection is a process, as well as a part of a larger process.

A variety of methods can be used to collect data, including observations, questionnaires, interviews, documents, tests, and more. Bhandari (2020) cites that collecting data can help you gain first-hand knowledge and original insights into your research problem, whether it is for business, government, or academic purposes.

Various methods used to collect data are classified as primary and secondary methods. Publications such as books, newspapers, journals, magazines, and online portals contain secondary data. In contrast, primary data has never been published before. It represents unique findings of your research. The collection and analysis of primary data usually takes more time and effort than secondary data. Data collection can be qualitative or quantitative (Dudovskiy, 2022).

3.4.3.1 Population Sampling and Size

Purposeful sampling methods are widely used in qualitative research to identify and select the most informative cases and make the most efficient use of resources (Patton, 2002). This study used a purposive sampling method to develop its sample. Using this non-probabilistic sampling technique, sample members are chosen according to their expertise and knowledge of the research topic (Freedman et al., 2007, Cresswell & Plano Clark, 2011). Bernard (2002) and Lopez & Dean (2013) highlight the importance of people being available and willing to participate, as well as the ability to share feelings and experiences coherently, meaningfully, and philosophically.

Purposeful sampling was applied to select participants for this study based on their expertise and knowledge associated with this study, also people who are willing to participate play an important role during sampling. The population is defined as the total category of subjects which is the focus of attention in a research project (Veal, 2011). The study is comprised of agricultural extension officers, farmers and advisors, GIS personnel in the agricultural sector, and service providers who provide GIS, remote sensing, and ICT services in the agriculture sector.

The total number of Agriculture Extension officers and Veterinarians (VETS) Animal Health officials is 199 officials, and the study sample size is 60 participants which represents 30% of the population. Purposeful random sampling was used to sample 60 Extension officers and VETS officials from all different GDARD regions namely, Pretoria, Germiston, Randfontein, and Vanderbijlpark.

The total number of smallholder and commercial livestock and crop farmers on the farmer register was 1,303. Of these, 1,250 were smallholder farmers and 53 were commercial farmers. A sample of 150 farmers, consisting of 130 smallholder farmers and 20 commercial farmers, was taken, representing 11.51% of the population. Limited resources are the primary reason for the choice of sample size. Purposeful random sampling was used to select farmers who are receiving support from the Gauteng Department of Agriculture and Rural Development and are listed in the farmer register. Participants from different municipalities were sampled.

The number of DALRRD personnel in Agriculture (Smallholder Development, National Extension Support, and Veterinary Public Health), ICT Development solutions, and Land Use and Soil Management (GIS unit) is 78 officials, a sample of 26 officials was selected, which represents

33% of the population. Sampling 26 people will give a fairly accurate result. Convenience sampling was used to sample DALRRD personnel. Mocănașu (2020) indicates that a sample size of 30 participants in qualitative research is sufficient for a master’s thesis.

3.4.4 Data Analysis

The analysis process involves preparing and organising textual data, encoding them, then compressing them, and presenting them in discussion (Cresswell, 2013). As part of qualitative research, the process of systematically searching and collating interview records, observation records, and other non-textual materials is defined as a process of increasing understanding of a phenomenon. To analyse qualitative data, it is mainly necessary to encode or categorize it. Data analysis involves taking large amounts of raw information and reducing the volume of information, identifying significant patterns, obtaining meaning from the data, and putting the data in logical order. In the process of qualitative data analysis, coding or categorisation is the most crucial step (Wong, 2008).

To analyse the collected quantitative data, software such as MS Excel and ArcGIS was used to perform the following statistical methods, Kernel density estimations, and descriptive statistical method. Content analysis was used to analyse the qualitative data. Luo (2023) describes content analysis as a method of identifying patterns in recorded communication. Quantitative content analysis uses measurements and counts, while qualitative content analysis uses interpretation and understanding. Regardless of which type of analysis you perform, you categorize, or code, the words, themes, and concepts within the texts.

3.4.4.1 Kernel density estimations (KDE) statistical method

Methods for estimating kernel density from Silverman (1986) are often applied to spatial data analysis to understand and potentially predict event patterns (Smith et al., 2015). Danese et al. (2008) state that Kernel Density Estimation (KDE) is one of the most popular methods to analyse and understand statistics and more recently geostatistics. KDE has many applications in various fields, including the detection of disease outbreaks and local crime hotspots (Chan et al., 2021) and risk assessment and damage analysis (Ahola et al., 2007), as well as emergency response planning for firefighters (Krisp et al., 2005) and the response to traffic accidents (Anderson, 2009). Crime analysis relies heavily on KDE-based maps (Ratcliffe, 2010; Mburu & Zipf, 2014; Levine, 2017).

KDE is particularly efficient in detecting hot spots because its estimations are based on a grid placed on the entire point pattern. In each case, the estimates indicate the density at a specific place and show how the patterns of point densities change over time. The user must specify an appropriate bandwidth for the estimation. Local data will be more significant when the bandwidth is small. They suggest putting the pre-processed KDE maps in the same output window as the bandwidth slider tool (Krisp et al., 2009). Using this method of showing kernel bandwidth to KDE, one can visually determine a bandwidth that is appropriate for KDE. Furthermore, (Krisp and Spatenkova, 2009) identified a second problem in the KDE classification of output rasters. It is important that the classification maintain characteristic patterns of the phenomena while resembling the original surface as closely as possible.

3.4.4.2 How kernel density is calculated.

According to ESRI (2011), the Kernel Density Tool calculates the density of features in a neighbourhood around each feature. Line and point features can be calculated using this tool. Different kernel densities are calculated for different features.

Line features

Kernel Density can also calculate the density of linear features within each output raster cell ESRI (2011). In theory, each line is covered by a smooth curved surface.

The value of this parameter is greatest on the line, decreases as you move away from the line, and approaches zero once you reach the specified search radius distance away from the line. Below the surface, the population value is divided by the line length, giving the volume of the surface. Adding the values of all kernel surfaces where they lie across the center of the output raster cell gives the density at each cell. Silverman (1986) describes the use of the quartic kernel function for point densities for kernel functions for lines.

Point features

According to ESRI (2011), Kernel Density calculates the density of point features surrounding each output raster cell. In theory, each point consists of a smooth, curved surface. At the search radius distance from a point, the surface value decreases and reaches zero. Circular neighbourhoods are the only option. Subsurface volume is determined by the point population field value, or 1 if NONE has been specified. As part of the density calculation of each output grid cell, we add the values of the kernel surfaces that cover the center. The quartic kernel function is based on that described by Silverman (1986).

The kernel density estimations (KDE) statistical method was used to indicate hot spots regarding the uptake of ICT and 4IR technologies by smallholder farmers and commercial farmers. The kernel density for the point features tool was used to calculate the density of uptake of ICT and 4IR point features around each output raster cell.

3.4.4.3. Descriptive statistical method

Battacherjee (2012) defines descriptive analysis as the statistical description, aggregation, and presentation of structures of interest or the interactions between them. According to Kaur et al. (2018), descriptive statistics describe the relationships between variables in a sample or population, summarising data in an organised manner. When conducting research, it is necessary to calculate descriptive statistics first and then compare inferential statistics. Descriptive statistics can be used to describe statistical measures such as frequency, central tendency, distribution/variation, and location.

Variable Type

In Kaur et al. (2018), there are many different types of variables that should be considered before analysing the dataset. To perform an analysis, variables must be quantified, which means they must be given a number and scale. Identifying variables and determining how to measure them may seem simple, but measurement can also be difficult when variables are not well-defined. The categories of categorical variables (also known as qualitative variables or discrete variables) can be further classified into nominal, ordinal, or dichotomous types according to Kaur et al. (2018) and Kaur (2013). In addition to quantitative and numerical continuous variables, interval variables and ratio variables are also classified.

Categorical variables

Variables that have multiple classes, but no inherent order are called nominal variables. The type of property on the market from a realtor’s perspective can be classified into distinct classes such as homes, condominiums, co-operatives, or bungalows (Kaur et al., 2018). The term 'dichotomous variables' refers to nominal variables with solely 2 classes (Kaur et al., 2018 & Laerd Statistics, 2018). As an example, consistent with Laerd Statistics (2018), we tend to presumably reason an individual as either "male" or "female." We can ask if an individual owns transport, as a second example. Therefore, we can reason transportable possession as either "Yes" or "No." what is more, Kaur et al. (2018), signify that the ordinal variable has 2 or a lot of classes because of the ability to rank or order, however, the rankings lack objective worth (for example, patient satisfaction scale with robust disagreement, disagreement, unsure, agreement, and powerful agreement).

Continuous variables

The interval scale is the numerical distance between intervals. It can also be categorised and ranked. For example, the difference between 70 and 80 meters will be the same as the difference between 30 and 40 meters. So, the two categories are 10 degrees apart. Ratio scales measure categorical, ranked, equally spaced variables that appear on a continuum and includes an absolute zero such as the temperature on a Kelvin scale (Kaur, 2013).

Measure of Frequency

In addition to variable types such as central tendency, dispersion, and location, descriptive statistics also include frequency measures.

Frequency distribution

In frequency distributions, the number of observations is described for each possible value of a variable. A frequency distribution is visualised using graphs and frequency tables. A value's frequency is determined by the number of times it appears in a dataset. Frequency distributions are patterns of frequency for a given variable. The frequency distribution represents the number of times each possible value of a variable appears in a dataset. Pie charts, bar charts, and histograms can be used to illustrate frequency distributions. To make the best choice, you should consider the type of variable and what you are trying to communicate (Turney, 2023).

Central tendency

Central tendency determines where values are distributed in the distribution. The central tendency can be expressed as a mean, median, or mode. In math, the arithmetic mean (commonly referred to as the "mean") is the simple average of all values in a distribution. Here are ten test scores: 17, 25, 22, 15, 38, 17, 27, 17, 20, and 24. (17 + 25 + 22 + 15 + 38 + 17 + 27 + 17 + 20 + 24)/10 = 22.2 is the arithmetic mean of these values (Bhattacherjee, 2012).

The central tendency is also measured by its median, which is the middle value of a range of values. The middle value of a distribution is determined by sorting values in increasing order and selecting the middle value. If there are two middle values, the median is the average of the two middle values. These are the sorted values in the above example: 15, 17, 17, 17, 20, 22, 24, 25, 27, 38 (Bhattacherjee, 2012). There are two middle values of 20 and 22, so the median is (20 + 22)/2 = 21. According to Bhattacherjee (2012), the mode is the most frequently occurring value in a distribution of values. The mode of the above set of test scores is 17, which corresponds with the most frequently occurring value. All values that are estimated from samples, such as mean, median, mode, or any of the other later estimates, are called statistics.

The descriptive statistics were applied to summarise and organise characteristics of the demographics dataset, assess the implementation of GIS and RS in local farms including support, assess the uptake of ICT and GIS by Agriculture personnel, extension officers, and veterinary officials, assess the uptake of ICT and 4IR technologies by small and large scale farmers in Gauteng using the following statistical measures; measures of central tendency and measures of variability together with graphs and tables.

3.5. Limitations

A study may have limitations that are beyond the researcher's control (Strydom, 2011). This study aims to assess how ICT, GIS, RS, and 4IR technologies are used to improve food security in the agricultural sector in Gauteng. However, the study has certain limitations. The study focuses on farmers receiving support from GDARD, GDARD VETS technicians, and extension officers, as well as DALRRD personnel from Agriculture, ICT, and GIS sections. Furthermore, due to logistical issues, significant stakeholders such as farmers who do not get support from GDARD, private VETS and Extension officers, as well as other agriculture workers in the private sector who could have added some valuable insight to the study have been excluded. It is, however, recommended that a follow-up study be conducted to address this limitation. Based on what was explained, the limitations of this study were obviously limited resources, time, and financial constraints, which ultimately limited the researcher to this scope of the study.

Furthermore, another limitation of self-administered surveys is that researchers cannot control the course of the investigation and clarify any questions respondents may have. Self-administered questionnaires are also subject to missing data due to respondent withdrawals or failure to complete the entire survey, but since it is an online survey, the researcher cannot prevent this. Participants were encouraged to complete the entire questionnaire as part of the research.

3.6 Ethical considerations

Research that involves human beings and mammals should consider the ethics and appropriate behaviour when dealing with subjects participating in the study. The research must not be done at the expense of the subjects. Researchers must remember that their subjects are real people and by giving their consent to participate in the research, they are doing researchers an enormous favour. It is important to respect individuals, their human rights, as well as particulars of their lives (Pickard, 2007).

David and Sutton (2011) define ethical principles as guidelines for researchers on how to protect research participants from harm and protect their rights. Creswell (2012) argues that ethical behavior should be integral to the researcher's role as an insider/outsider when assessing issues that might cause interviewees to be hesitant to reveal sensitive information. Researchers should treat participants with respect and support, without stereotyping or judging them.

Research that involves human beings and mammal matters should consider ethical consequences. It is important that the research is not done at the expense of the subjects in relation to mistreatment. Researchers must recognise that their subjects are real people and by approving to participate in the research they are doing researchers an enormous favour. It is fundamental to respect individuals, their human rights, as well as particulars of their lives (Pickard, 2007). Ethical concerns traditionally focused on three topics, informed consent in this case getting participants’ permission after vigilantly and honestly notifying them about the objective of these studies, secondly, the right to privacy to ensure the safety of participants’ identity, and lastly, protection from harm, be it emotional, physical or any other nature of the damage (Denzin and Lincoln, 2003).

Halai (2006) advises researchers to obtain the consent of everyone directly involved in the study. Participants should have access to relevant data prior to consent, to guarantee that they are not coerced into participating and are given access to relevant data prior to consent. Written consent forms are usually utilised to obtain consent, and a review board determines the main components of consent. The information includes a prior understanding of key elements of the study, such as purpose, steps, time frames, risks, benefit, and conditions, to show that participants are participating voluntarily and may withdraw at any time. When conducting observations, COVID-19 regulations were strictly followed. All interviews were conducted electronically using online questionnaires.

It is important to obtain ethical clearance for the research to protect the data and information of participants and those affected by the research. Furthermore, researchers should be upfront and transparent about confidentiality issues, as well as the purpose of the study, and should clearly indicate that participation is not mandatory (White, 2000). As part of the ethical clearance process, participants are also assured that their data will not be misused or used for any purpose unrelated to the research (Gitlin and Czaja, 2016).

The researcher considered all these issues and informed participants of what is expected and stressed the importance of voluntary participation and confidentiality. According to the University's guidelines, a request for participation form and a consent form were developed.

Taking into consideration all the above, how ethical issues were addressed in the research is explained below:

- Approval to conduct the research was obtained from the Research Ethics Board in the College of Agriculture and Environmental Sciences, University of South Africa (REC Reference: 2021/CAES_HREC/160).

- Authorisations to conduct the research were obtained from the Head of the Department in GDARD (See the attached Appendix: E) and from the Acting Director of the Department of Agriculture, Land Reform and Rural Development (See the attached Appendix: F) to undertake study within the Department.

- A cover letter for the questionnaire was drafted to highlight objectives of this research.
- Permission forms were developed for people selected for questionnaires and interviews clarifying objectives and aims of this research.
- Privacy and namelessness were guaranteed by coding answers.

3.6.1. How the potential risks of harm were mitigated.

The researcher tried as far as possible to avoid face-to-face interviews. If it was not possible, strict adherence to Covid-19 regulations as published by the national government as well as those released by UNISA was done when conducting face to face interviews. The researcher always wore a cloth mask and had sanitizer available during field visits. The researcher captured the answers personally on a laptop or smartphone to avoid paper-based questionnaires that could have been contaminated by the Covid-19 virus. The researcher carried extra disposable masks that were given to participants if the participant did not wear a mask. The disposal of the mask was done by the participant after the interview.

3.7. Conclusion

This study used a mixed-method approach and a concurrent triangulation research design. Permission to conduct research was obtained from GDARD and DALRRD. This chapter addressed the research methodology and how it was applied to the study. It also focused on the research approach, research design, and sampling procedure that were employed in the study. Furthermore, the chapter provided details regarding instruments used to collect and analyse data, and their advantages and disadvantages. Lastly, limitations and ethical consideration of the study were presented. The next chapter focuses on the analysis and interpretation of the data collected in the research.

CHAPTER 4: RESULTS AND DISCUSSIONS

4.1. Introduction

The findings of this chapter relate to farmers, GDARD (Agriculture and Veterinarian) officials, and DALRRD (Agriculture, ICT, and GIS) officials. This study explored the extent to which ICT, GIS, RS, and 4IR technologies are being used in Gauteng's agricultural sector to improve food security. Since a mixed method approach was adopted, the qualitative findings of the farmers, GDARD officials, and DALRRD officials were presented simultaneously with the quantitative results in accordance with the research design. Survey123 analysis, tab, and ArcGIS spatial analyst and descriptive statistical tools were used to analyse quantitative data, while content analysis was used to analyse qualitative data.

4.2. Data Presentation

4.2.1 Research Participants and response rate

Participants in the study were GDARD officials from the Agriculture and Veterinary services. These officials provide support to farmers with expertise such as Extension Advisory Services, Agriculture Advisors, Senior Agricultural advisors, Animal Health technicians, State veterinarians, and Scientists. The response rate from the GDARD questionnaire was 81%. 60 officials were requested to participate, and 49 of them responded.

At DALRRD, participants comprised of officials from the following Directorates: ICT Development Solutions, Land Use and Soil Management (GIS unit), Smallholder Development, National Extension Support, and Veterinary Public Health. In total, 26 employees were asked to participate in the study, and 14 of them responded to interview questions, resulting in a 53.84% response rate.

Two types of farmers were selected for the study, smallholder and commercial farmers who were registered on the farmer register database or receiving support from the government in Gauteng. A total of 150 online questionnaires were distributed to farmers, and 93 of them answered the questionnaire, with a response rate of 62%.

Quantitative data were presented using maps, tables, pie charts, and bar graphs. Qualitative data were presented using pseudonyms as indicated in Table 4.1.

Table 4.1. List of research participants' pseudonyms.

Participants	**Pseudonyms**
Farmers Participants	
Farmer 1, Farmer 2, Farmer 3, etc.	F1, F2, F3, etc.
GDARD Participants	
Participant 1, Participant 2, Participant 3, etc.	P1, P2, P3, etc.
DALRRD Participants	
Participant 1, Participant 2, Participant 3, etc.	T1, T2, T3, etc.

4.3. Demographic information of farmers

In this study, 55% of respondents were males and 45% were females as shown in table 4.2, it is interesting to note that more women are now involved in farming. In terms of age, many respondents (69%) were between the ages of 36 and 64 years old, followed by young people at 24%. Globally, women play an increasingly significant role in agriculture, according to FAO (2011). Buzzcommunity (2017) notes that despite the more widespread recognition given to women's roles in agriculture today, there is much more that needs to be done to assist them. As per the report by Appasamy (2018), the government encourages women and young people to be involved in agriculture through several awards, such as the Female Entrepreneurs Awards which were established by DAFF in 1999, and the Young Farmer Awards (YFA) were initiated by the GDARD in 2012.

Table 4.2. Demographic characteristics of the farmer participants

Descriptive variable	Categories	Frequency	Percentage
Gender	Male	51	55%
	Female	42	45%
	Prefer not to say	0	0
Ethnicity	African	78	84%
	White	8	9%
	Coloured	3	3%
	Indian	3	3%
	Prefer not to say	1	1%
Age	18 – 35 years	22	24%
	36 – 64 years	64	69%
	Above 65 years	7	7%
	Prefer not to answer	0	0%
Educational level	No formal educational	2	2%
	ABET	2	2%
	Grade 7/Standard 5	6	7%
	Grade 12/Standard 10	27	29%
	Post Matric qualification/s (Certificate, Diploma, Degree, etc)	55	59%
	Prefer not to say	1	1%

The ethnicity of the farmers is mostly African, with 84% of them being African, followed by Whites with 9%, then Coloured at 3%, and Indians at 3%. Many respondents in this study are black smallholder farmers, which corresponds with the general assumption that smallholding farming is done by black farmers (Khapayi & Celliers, 2016; Xaba & Dlamini, 2015). A similar trend can be seen in government programs that are aimed at emerging farmers, for example, the Comprehensive Agricultural Support Programme (CASP) (Department of Agriculture, Forestry and Fisheries [DAFF], 2015).

There is a high level of education among farmers, with 59% of them indicating that they have post-matric qualification such as certificates, diplomas, and degrees, and only a few individuals (2%) do not have any kind of formal education. As Ferreira (2018) points out, educated farmers are more likely to be early adopters of new technologies, and by using these technologies, they can enable other less educated farmers in the community to benefit as well. In turn, this leads to the increased utilisation of the latest technology among other farmers in the community.

4.4. Farmer classification, Farming type, and number of years of farming

4.4.1. Number of years doing farming

Figure 4.1 shows that respondents have practiced farming for a minimum of one year and a maximum of 54 years. 55 farmers have been farming for between 1 and 12 years. This is followed by 24 farmers who have been in the industry for 12 to 22 years. In addition, 12 farmers have been farming for 22 to 33 years, plus two farmers have been farming for 39 and 54 years.

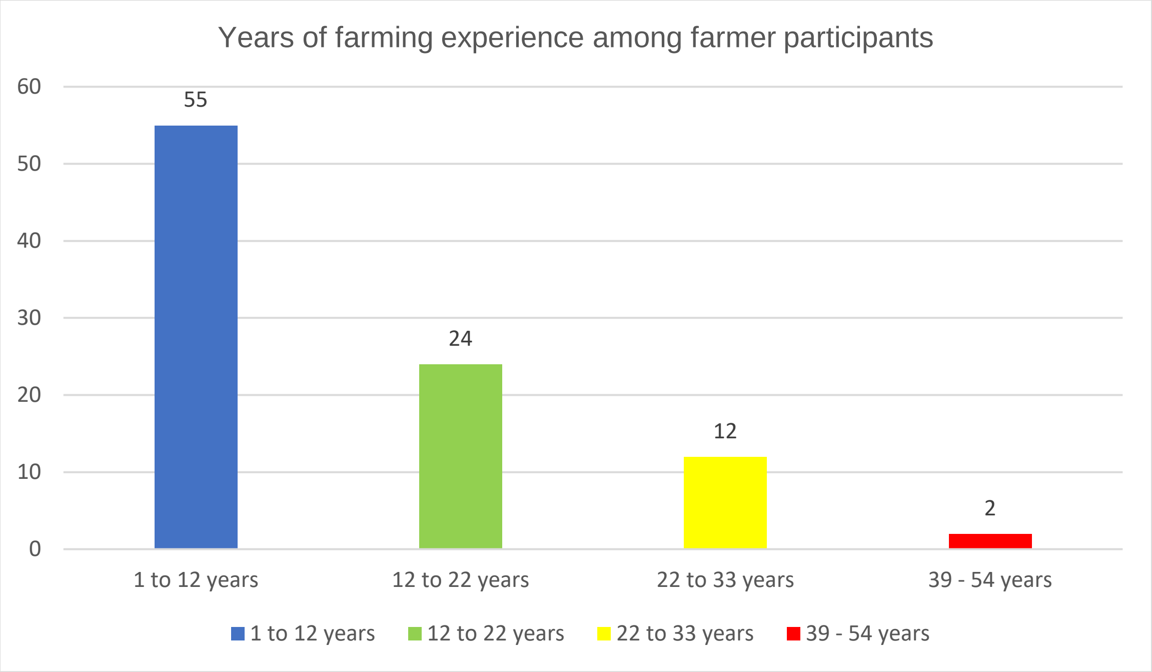


Figure 4.1. Number of years farmer participants have been farming.

4.4.2. Farmer classification and farming type

South African agriculture is best described as 'dual', with both smallholder and commercial farmers living side by side. These farms are largely unequal in terms of both size and productivity. About 85% of participants in the study were small-holder farmers, while 15% were commercial farmers as indicated in Table 4.3. Throughout the country, there are more than 2.3 million smallholder households that are involved in agricultural practices for consumption at home as well as the sale of surpluses, and approximately 40 122 commercial farms that produce 90% of the country's food needs (Greyling et al., 2015; StatsSA, 2020).

As demonstrated in Table 4.3, 39 % of farmers are involved in both livestock and crop production. This is followed by crop production at 30 %, livestock production at 27%, and finally, there is another at 4 % where participants indicated they are engaged in bee keeping.

Table 4.3. Farmer participant's classification (N=93) and farming type (N=93)

Descriptive variable	**Categories**	**Frequency**	**Percentage**
Farmer Classification	Smallholder	79	85%
	Commercial	14	15%
Farming type	Livestock production	25	27%
	Crop production	28	30%
	Livestock and crop production	36	39%
	Bee keeping	4	4 %

Figure 4.2 shows 12 commercial farmers and 64 small-holder farmers. This excludes 2 commercial farmers and 15 small-holder farmers who were not properly mapped by farmers because they are outside Gauteng. These farmers' responses are included in this study despite being excluded from the map. According to the map below, Tshwane and Sedibeng have the most commercial farmers with four each, followed by West Rand with two and the City of Johannesburg and City of Ekurhuleni with one each. For the small-holder sector, Sedibeng has the highest number of 21 farmers (N=21), followed by the West Rand with farmers(N=15), then the City of Ekurhuleni with 11 farmers, with the City of Tshwane having 10 farmers, and finally, the City of Johannesburg represented by only 7 farmers in this study.

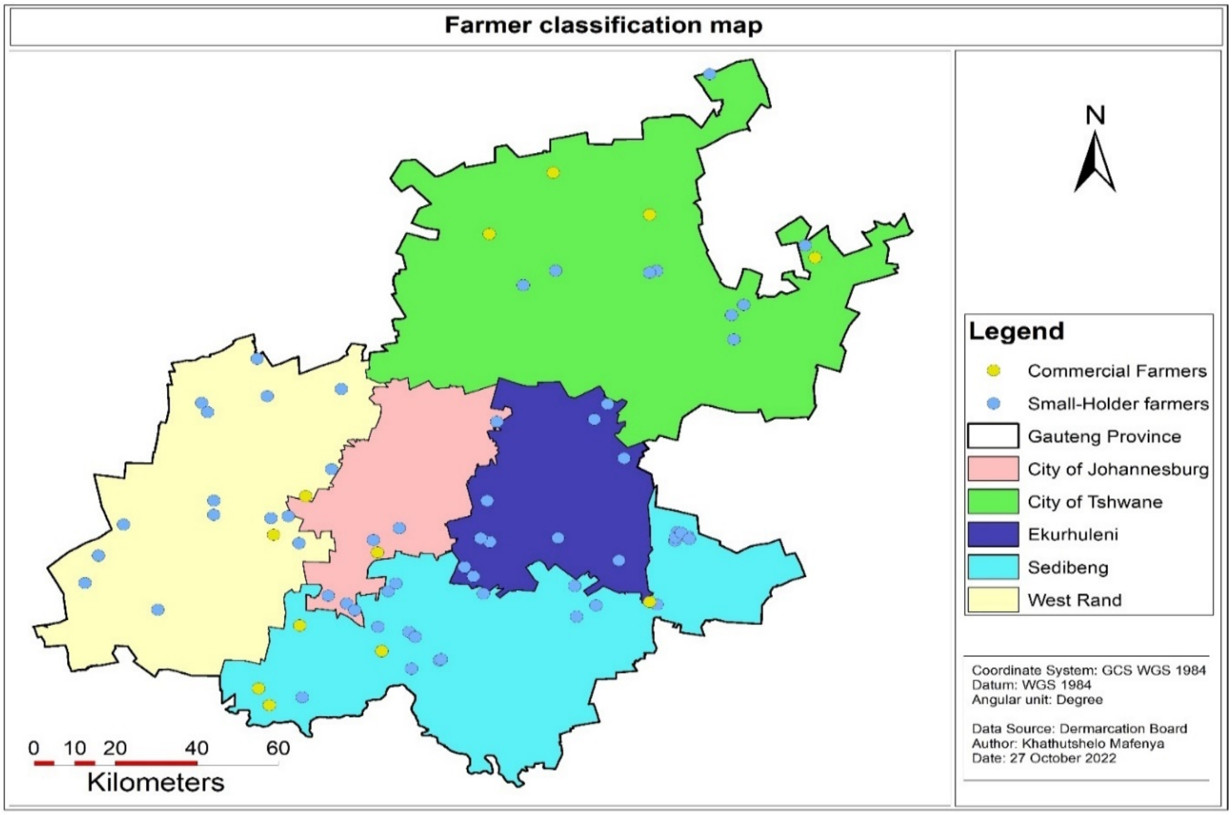


Figure 4.2. Farmer participants classification

4.5. GDARD Official Areas of Expertise

According to Figure 4.3, GDARD Agriculture and Veterinary Services officials possess a wide range of expertise, and these officials offer support to farmers. At 24%, the most participants were agricultural advisors, followed by animal health technicians at 23%, extension advisory services at 18%, and scientists, veterinary public health, and others (regional managers) at 2%. Senior agriculture advisors supervise agricultural advisors, and extension and advisory services. State veterinarians are regional managers for Veterinary services and provide supervision to animal health technicians and veterinary public health officials.

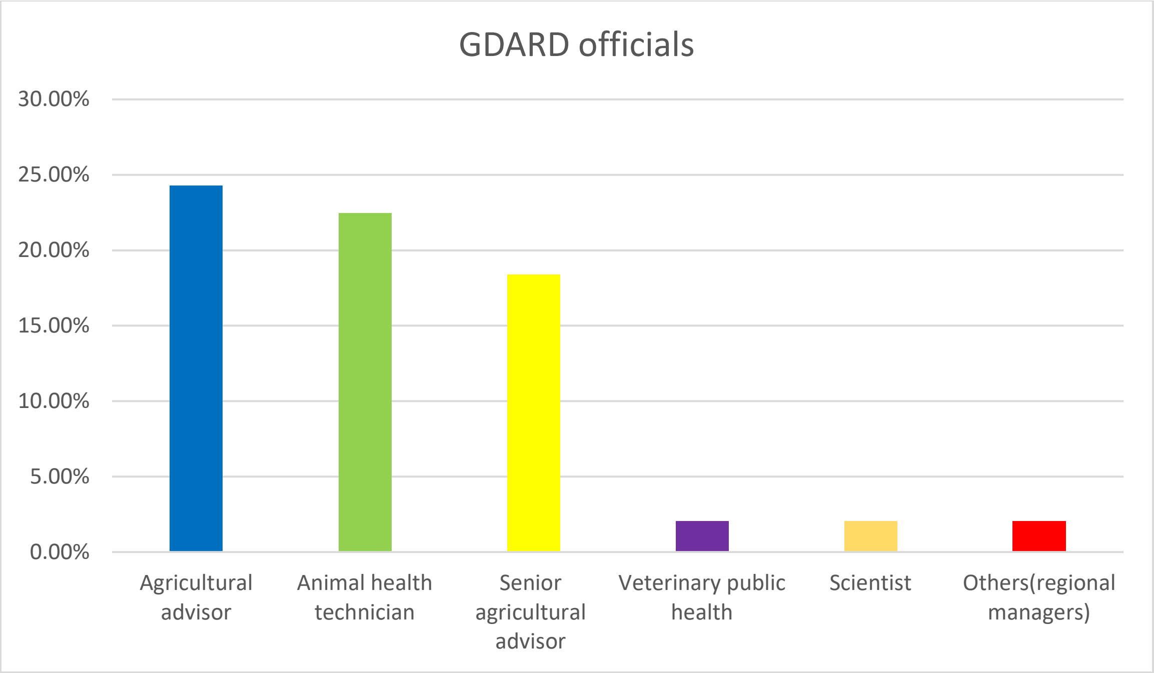
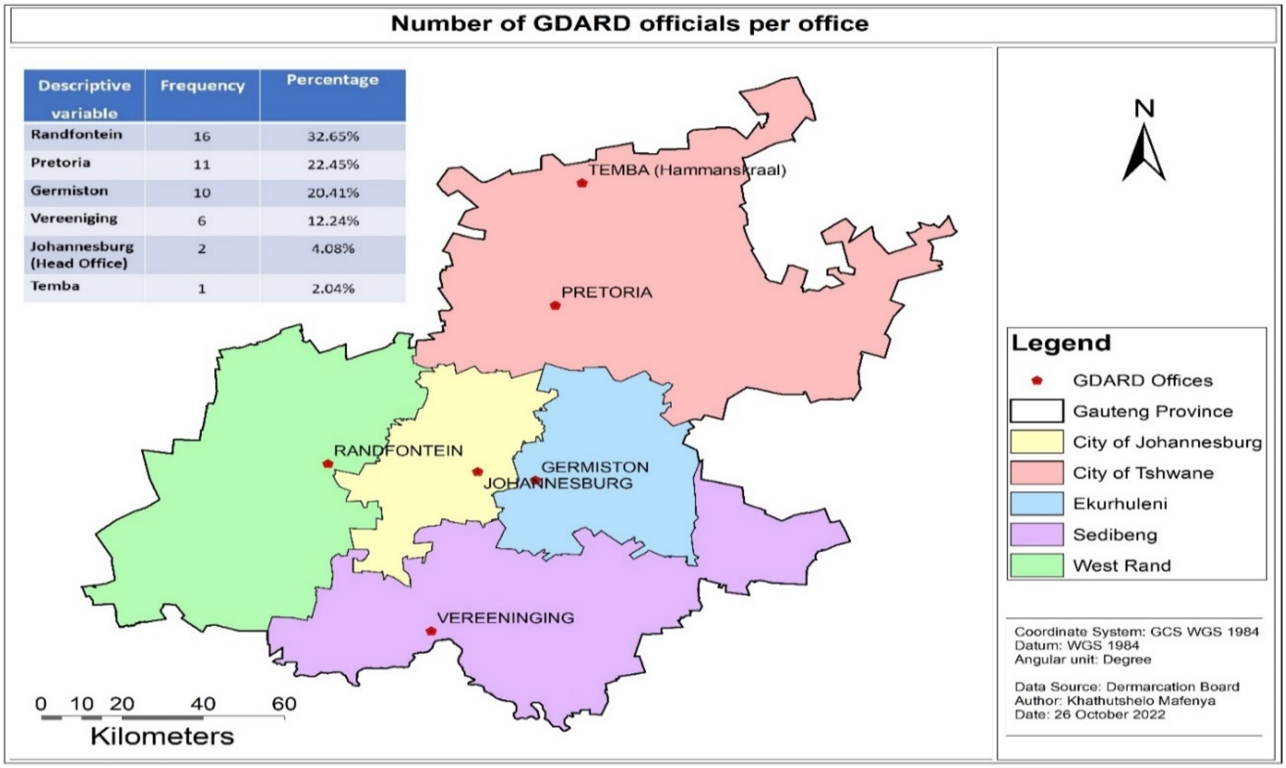


Figure 4.3. Area of expertise for GDARD participants

4.6. GDARD Offices for Extension advisory services and VETS

It is estimated that GDARD has 14 offices, with six of those being nature reserves, Johannesburg is the head office of the organisation. Most of the Agriculture and veterinarian officials are in Randfontein, Pretoria, Germiston, and Vereeniging offices, therefore primary research participants came from these locations. Randfontein has respondents 16 (33%), followed by Pretoria with 11 (22%). It is not surprising that the head office had 2 (4%) respondents, which places them second last. This is because the extension advisory and services, agriculture advisors, animal health technicians, and state veterinarians are based in regional offices that are easily accessible by farmers. The locations of these offices are shown in Figure 4.4.



Descriptive variable	Frequency	Percentage
Randfontein	16	32.65%
Pretoria	11	22.45%
Germiston	10	20.41%
Vereeniging	6	12.24%
Johannesburg (Head Office)	2	4.08%
Temba	1	2.04%

Coordinate System: GCS WGS 1984
Datum: WGS 1984
Angular unit: Degree

Data Source: Dermarcation Board
Author: Khathutshelo Mafenya
Date: 26 October 2022

Figure 4.4. GDARD participants per region

4.7. DALRRD Official Areas of Expertise

The expertise of DALRRD officials is shown in Figure 4.5, it shows that 43% of participants are involved in smallholder development, 29% in land use and soil management, 14% in information and communication technology, and 7% each in national extension support and veterinary public health.

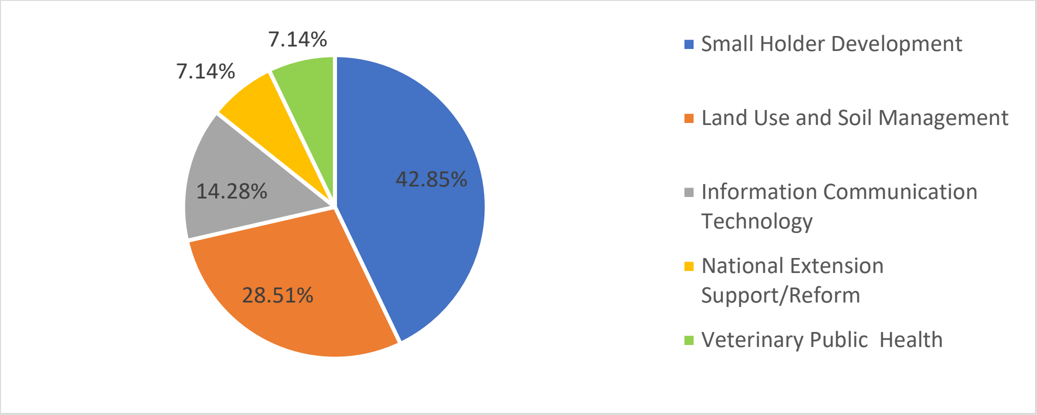


Figure 4.5. Area of expertise for DALRRD participants

4.8. GDARD and DALRRD officials' years of service in the Agricultural sector.

One participant from GDARD skipped the question, while all participants from DALRRD answered it. As shown in Figure 4.6, the trend in years of service in the agricultural sector is the same in both departments. Most participants in both departments have more than 10 years of agriculture experience, with DALRRD participants leading with 57% and GDARD participants at 47%. GDARD participants have 39% in the 5 - 10 years category, while DALRRD participants have 29%. DALRRD has 14% and GDARD has 12% of participants with less than 5 years of experience. Government agriculture personnel have a great deal of experience. These skills must be retained and transferred to agriculture personnel with less than 5 years of experience.

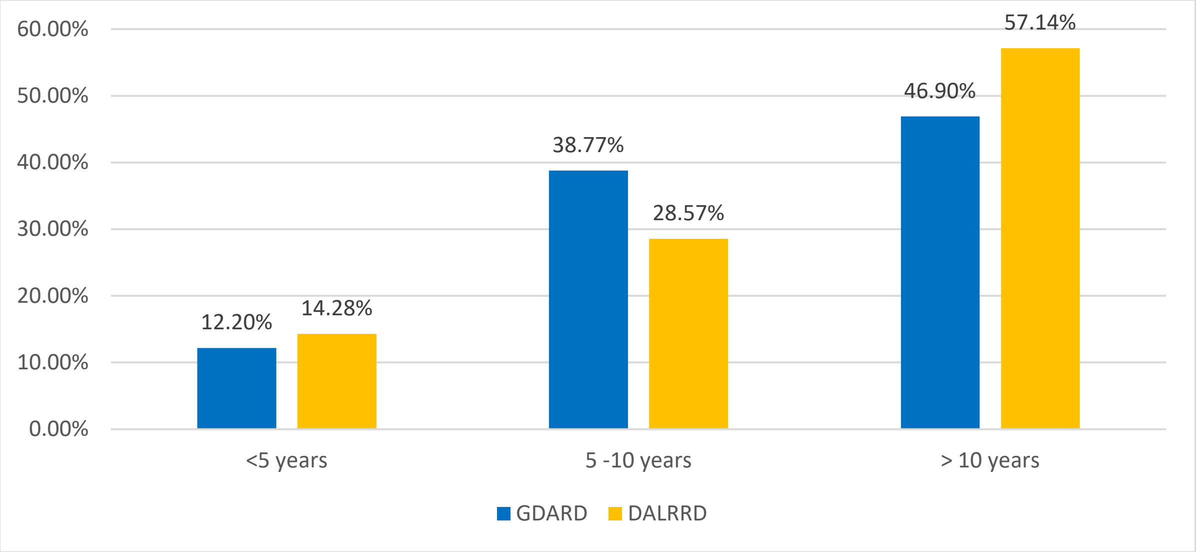


Figure 4.6 Years of service in the Agricultural sector.

4.9. DALRRD and GDARD participant's tools of the trade

Figure 4.7 shows participant' responses on whether they are receiving necessary tools of trade such as personnel, software licenses, good-enough specification listed hardware, enough mobile data from ICT, GIS, and facilities. It was interesting to note that 86% of participants from GDARD and DALRRD indicated that they are provided with enough tools for the trade, with 14% indicating that they have not been provided with all necessary tools.

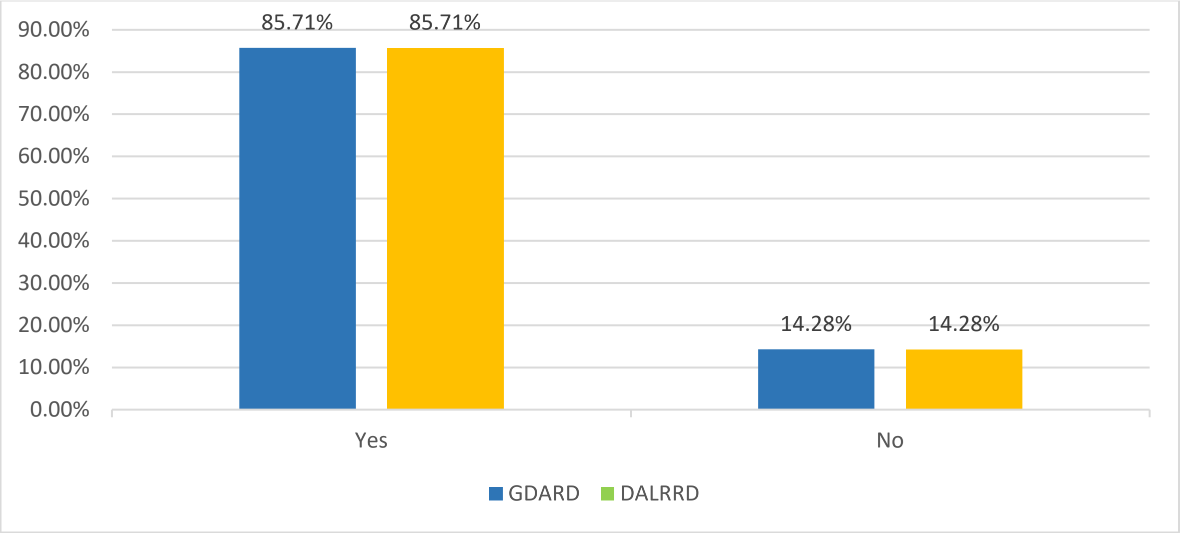


Figure 4.7. Are you provided with the necessary tools for the trade by DALRRD and GDARD ICT, GIS, and Facilities units.

The participants who said they are not getting enough support and the necessary tools of trade suggested the following:

GDARD P1 said *"they need to offer gadgets that enable us to do our work without using paper or less paperwork. design a central database where all farmer's information can be stored. engage extension practitioners on the type of gargets they prefer which enables them to best do their work".* Then P6 said "*we are always on the farms communicating with farmers, if possible, can we have unlimited airtime, also regarding software license it would be easier if we have one official who deals with it issues at our regional office no need for us to go to head office".* This the issue of data bundles was supported by P37 *who mentioned that "the data we are getting, does not last a month".*

P12 said *"Create Applications that can ease the day-to-day business operations & processes that we use in our field. Make things easier and more accessible for optimal service delivery, traceability & transparency".* This was supported by P17 *mentioning that "The world as a global village is digitizing, my work includes visiting farmer which should be reported daily manually so thereafter POE submitted monthly with a lot of paper and manual work, ICT and GIS should be enough to fill up this gap with modern systems reporting and general admin".*

DALRRD participant T9 said *“Provide the necessary infrastructure, e.g., cell phone with photographic tools, laptop to load the necessary information and photos as evidence, data to send the information to a central server that receives the information”.* Then T13 said, *“The department can review the books in the library and maybe, possibly, affiliate to certain industry bodies to somewhat make it easier for officials to have current information to better advise farmers”.* Participants from both GDARD and DALRRD raised the issue of mobile data not being enough and suggested that unlimited data could be a solution.

4.9.1 Laptop or computer usage lifespan at GDARD

All 49 participants responded to the question about the laptop or computer life span, with 63% indicating that they have been using their laptop for less than three years, 27% indicating that they have been using them for three to five years, and 10% indicating that they have been using them for more than five years.

4.9.2 Laptop or computer usage lifespan at DALRRD

In response to the question about the laptop or computer life span, all 14 participants responded, 50% indicated that they have been using their laptops or computers for more than five years. 7% replied that they had been using their laptops for at least three to five years, while 43% have been using their laptops for less than three years.

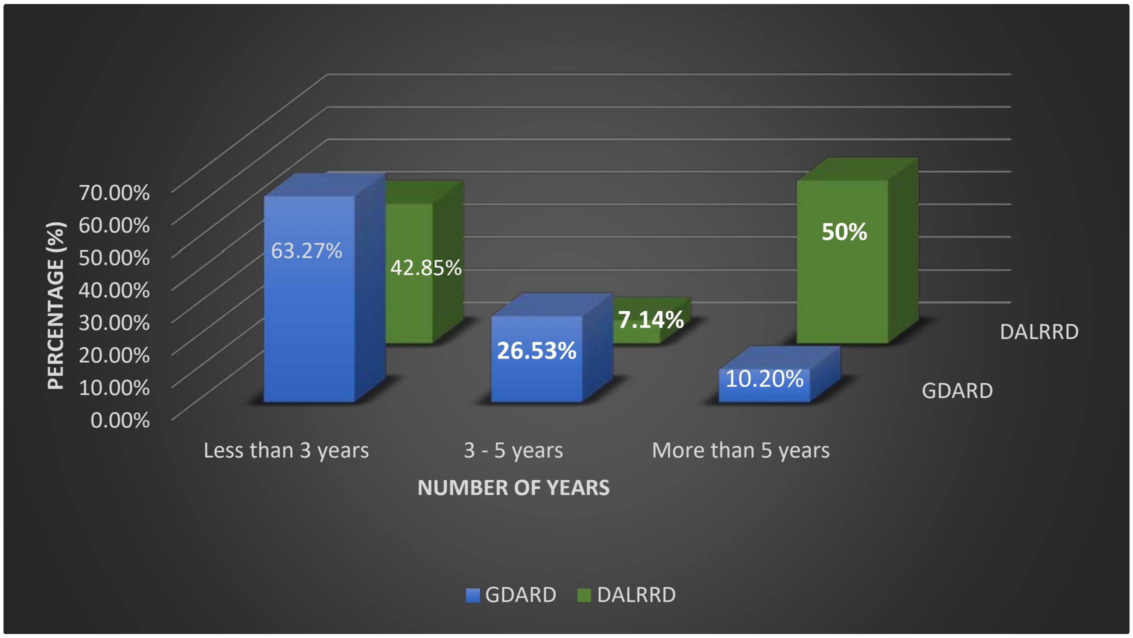


Figure 4.8. The lifespan of computers and laptops for GDARD and DARLRRD participants.

It is significant to note that most participants in both GDARD and DALRRD have laptops with a lifespan of under five years. As Sarokin (2019) points out, it is a common practice in the business world for computers to be replaced every three to five years to keep up with recent technologies. In addition to any performance issues that may be the trigger for the replacement of the computer, original service agreements for computer maintenance may have lapsed. This may lead to a replacement cycle. This provides further encouragement to purchase a new set of computers.

4.9.3 Utilisation of robust tablet and a single system integrating all systems by GDARD Participants

As displayed in Figure 4.9, the majority of GDARD participants, 96% (N=47) are of the view that using gadgets such as a robust tablet and a single system integrating all systems can make their work easier, 4% do not believe that it can make work easier. One of the participants responded by saying *“no”* said: *“The robust tablet is very slow; the touch screen is not sensitive”.*

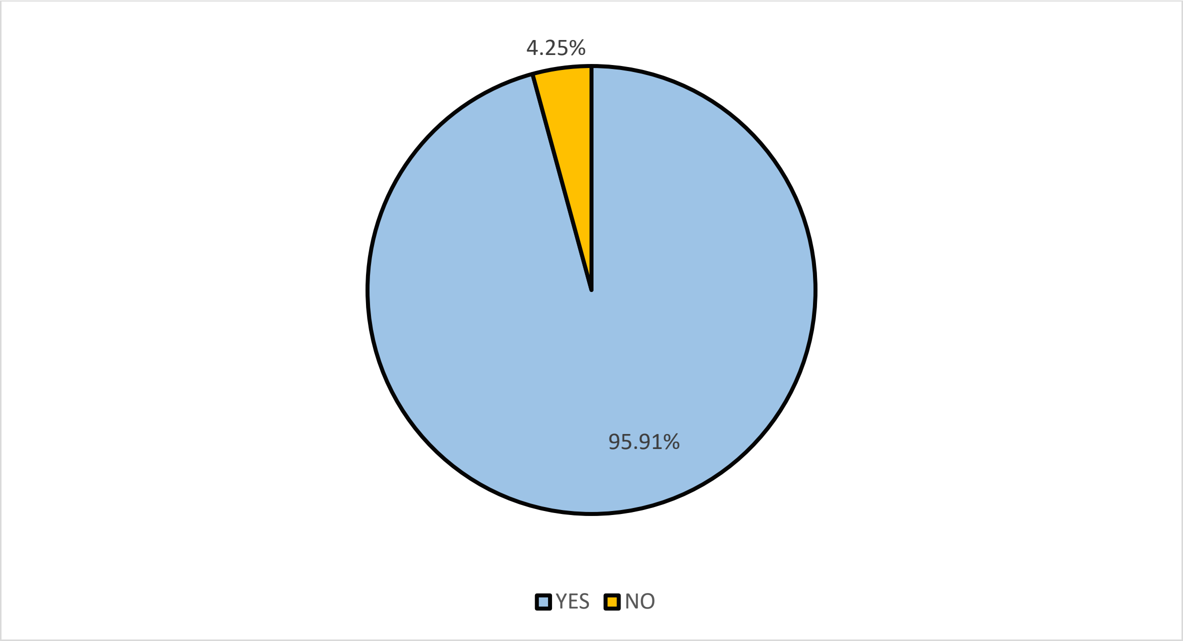


Fig 4.9. Utilisation of a robust tablet and a single system integrating all systems to make your work easier.

4.9.4 Internet connection performance at the farms

According to Figure 4.10, 71% of GDARD participants experienced internet connection challenges at the farms and 29% indicated that they are not experiencing network challenges. One of the participants experiencing challenges P24 said*: "It is difficult to find directions or for a farmer to send a location." Finding the farm takes more time".* P35 supported it by saying *"We often cannot attend to farmers because we cannot get hold of them to travel to their farm"*.

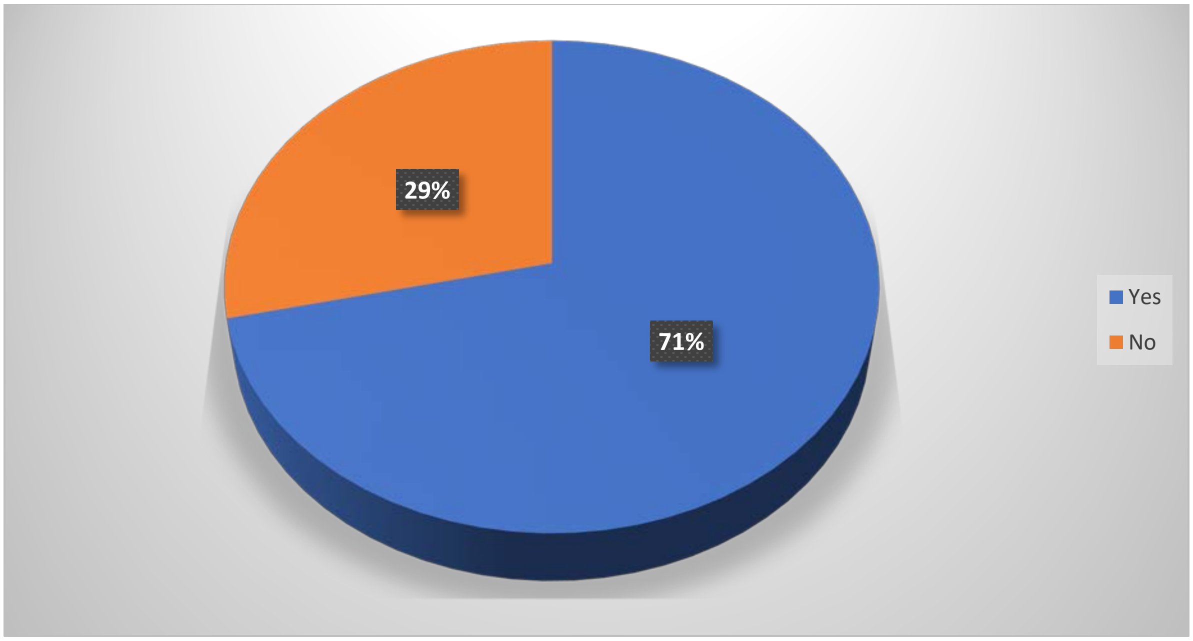


Fig 4.10. Internet connection challenges encountered by GDARD participants at the farms.

P3 mentioned that *“It is affecting service delivery because you can't access the internet on the farms to google urgent information needed by the farmer at that particular time”.* P15 said that it *"is problematic because you are unable to use the gadget".* In contrast, P5 pointed out *“Not that much as most of our work in farms is done manually even writing the visitation note”.*

4.10. Farm location of participants per local municipality

Figure 4.11 shows the number of farm participants within municipalities. The City of Tshwane Metro has the largest number of farm participants with 17 farmers. This is followed by the Ekurhuleni metro with 15 farmers. Then Lesedi Local municipality has 15 farmers, City of Johannesburg 11 farmers, Rand West City local municipality has 10 Farmers, Midvaal has 9 farmers, followed by Mogale City with 6 farmers, local municipalities with the lowest number of farmers are Merafong City and Emfuleni with 5 farmers each.

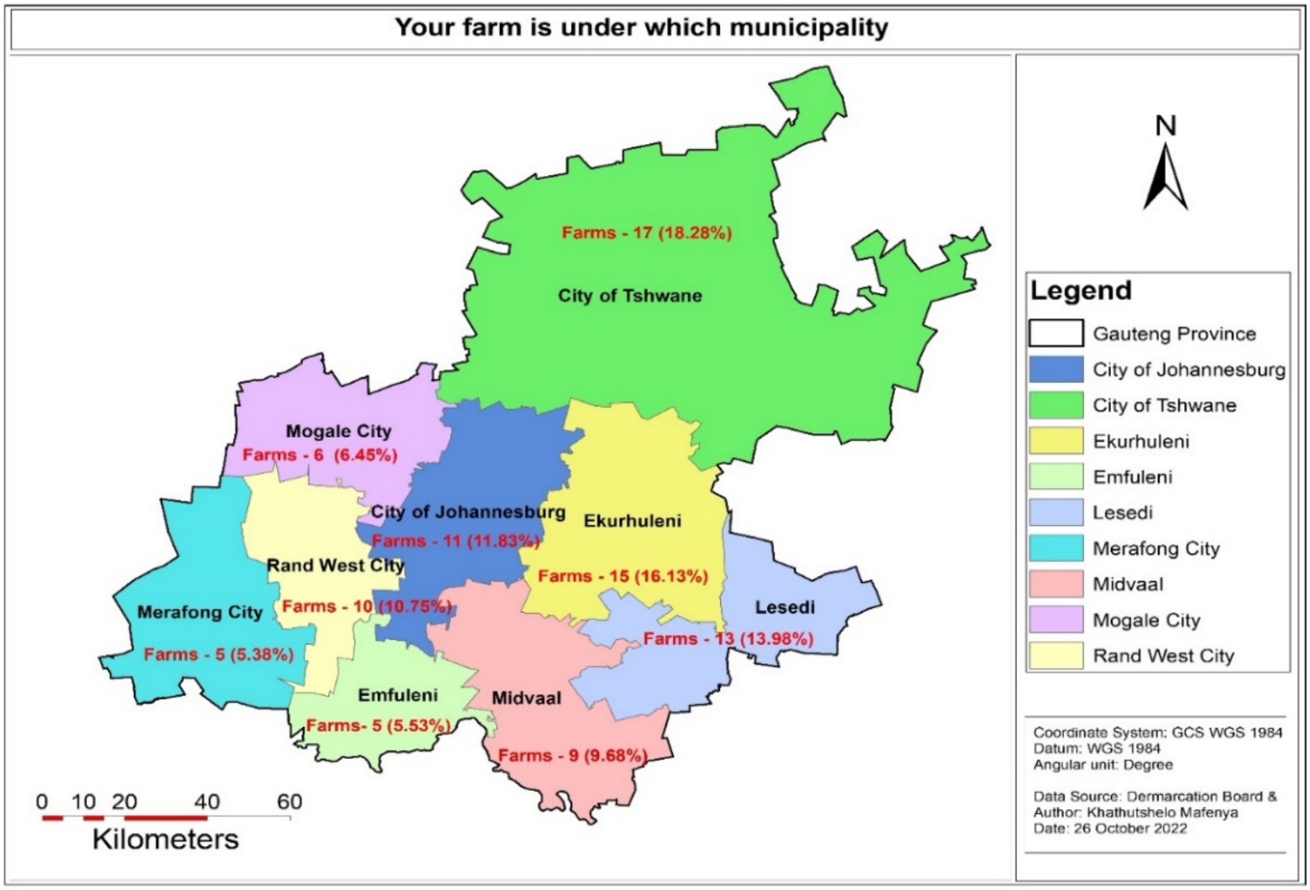


Figure 4.11. Farm location of participants per local municipality.

4.11. Farmer record keeping

Participants were allowed to select more than one method or equipment for record-keeping on their farms. A total of 100% of commercial farmers and 87% of small-holder farmers keep records. Findings show that 45% of participants used a laptop, 38% utilised a notepad, and 32% utilised a phone. There were 11% who did not keep records, 10% who used an online system, and another 10% who relied on other methods.

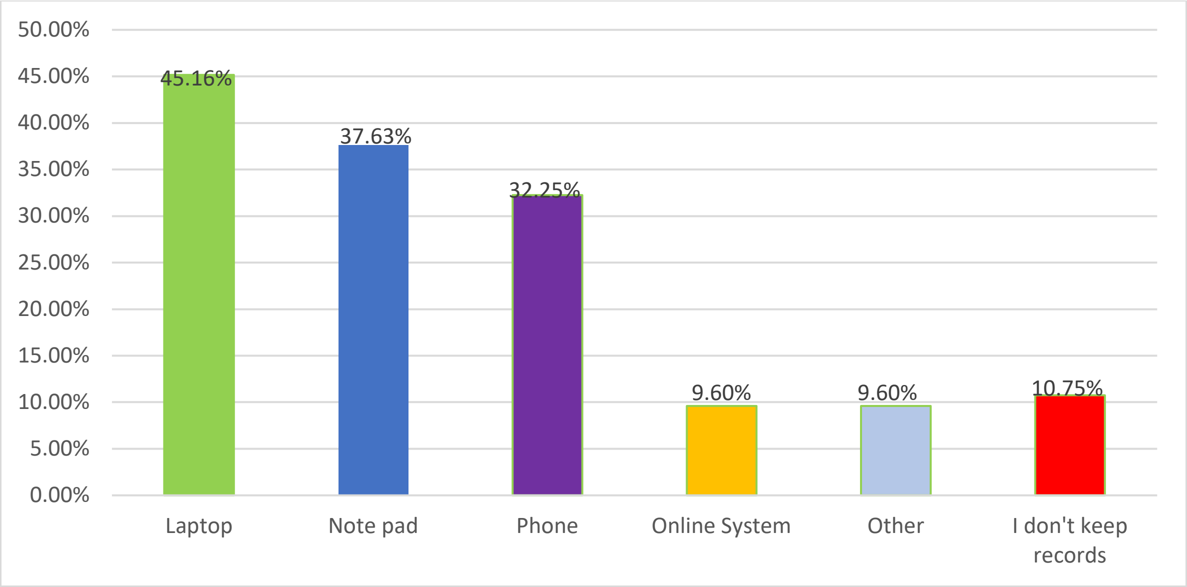


Figure 4.12. Farmer's participant Record keeping equipment or method.

According to Prajapati et al. (2020), there is less interest among farmers in maintaining business records. In the farming business, farmers deal with planting, fertilising, irrigating, protecting plants, harvesting, transportation, and various other expenses and revenue. Keeping track of every business event and transaction can be very challenging if business records are not maintained properly. A farm record-keeping process allows an individual to make business decisions based on the information gathered.

4.12. Farmer Profiling at DALRRD

T9 said "*Yes, they have a database of all farmers. The information is mainly collected by the provincial departments of Agriculture, assisted by the DALRRD officials in the provinces. This information is then drafted and loaded onto the provincial database for farmers and then shared with the National Department of Agriculture.* NES3 added by saying that "*the database only has 95 000 smallholder farmers. The data was collected using the digital pen and the hybrid model app developed by the DALRRD".* T4 also responded that "*We went province to province to register the farmers*". T1 explaining how the data was collected said: "*by conducting a farmer census".* From the responses above, it appears that DALRRD has a database of farmers. The data was gathered by extension officers within the provinces with the help of DALRRD officials using the farmer register online tool.

T7 said "*the Agriculture Statistics Directorate is in the process of developing a farmer database. However, I am not sure as to whether this database is spatially orientated for further analysis within a spatial environment or any progress thereon*" T12 said" *Yes, but not a database of all farmers, collected manually and electronically using instruments such as survey123 and farmer register*". Although there is a national agriculture database in place, there are still farmers who have not been profiled yet. It is critical to make officials in other DALRRD directorates and provinces aware of this database, as it can be of help to them.

The DALRRD has a national database of farmers, called a farmer register, which can be used to measure farmers' contribution to food security and the agriculture economy. Moreover, it will help measure progress in closing the gap between smallholder and commercial farmers (Ntombela, 2022). DALRRD Minister, Thoko Didiza launched a much-anticipated country farmer register, which should improve inaccurate and/or misrepresented statistics on smallholder and commercial farmers.

Statistics are collected on smallholder farmers, and commercial farmers, and their demographics, production activities, and infrastructure through the Producer Farmer Register (PFR). For DALRRD to plan for, among other things, the preservation of food security and the eradication of hunger, and to know the geographical location of farmers and monitor the impact of its interventions, it requires reliable data since it plays such a significant role in the economy's growth. A total of 95 501 farmers were expected to be registered on the register at the end of 2020 (South African Government News Agency, 2022).

4.13. Farmer Profiling at GDARD

P18 said, *"before, it was manual profiling. Now with GIS, this is easier."* The statement was backed up by P19, who stated, "*Animal Health Survey123 form*". *"We use the farm Ad-hoc visitation forms,"* The Ad-hoc visitation form uses digital pen and paper. Paper forms are pre-printed with specially arranged dots. A ballpoint pen with camera and electronics is used just as usual to write anything on the paper. While writing, the camera captures images of dots, which are then analysed to locate the positions of the pen. The x-y coordinate data is stored in the internal memory and sent to computers through Bluetooth wireless communication or a USB cable. Other information such as pressure, pen posture, time, and pen ID is also recorded and sent to computers (Hiromichi, et al., 2014).

P12 responded that “*We use the farm Ad-hoc, visitation forms*”. P25 then said, "*Manual, work in progress to use a paperless rugged device*." P22 mentioned the “*Agricultural Decision Support System*." Most other officials mentioned that they are utilizing farmer register, ArcGIS Survey123, and other mentioned that they are doing profiling manually.

The FAO (2020) suggests using IT for data archiving to enable the broader use of data, including historical analysis and the dissemination of information and products. In the traditional pen-and-paper collection method, handwritten paper sheets must be post-processed for the information collected to be retrieved and archived digitally. Previously, traditional paper sheets had to be digitised manually and often with problems of readability due to blurred records and to rainy conditions in the field. In some cases, even missing sheets occur when surveyors are not paying attention.

4.14. 4IR Technologies that can impact the agriculture sector in Gauteng.

Most participants (82%) from GDARD indicated that smart farming could have a positive impact on agriculture in the Gauteng province, then UAVs at 53%, vertical farming at 51%, and one participant believed blockchains could have an impact on agriculture. UAVs are used for collecting imagery, pesticide applications, fertiliser applications, safety, monitoring livestock and crop conditions, et cetera. DALRRD participants chose UAVs as the most impactful technology in agriculture, followed by smart farming at 69%, vertical farming at 62%, and blockchains at 8%. Based on these responses, both departments have smart farming, UAVs, and vertical farming as their top three technologies that may affect agriculture within Gauteng province.

Table 4.4 4IR Technologies that can impact the agriculture sector in Gauteng as per GDARD and DALRRD participants.

Descriptive variable	Department	Frequency	Percentage	Department	Frequency	Percentage
Smart farming	GDARD	40	82%	DALRRD	10	71%
UAVs	GDARD	26	53%	DALRRD	11	79%
Vertical Farming	GDARD	25	51%	DALRRD	9	64%
Artificial Intelligence	GDARD	9	18%	DALRRD	7	50%
Internet of Things	GDARD	20	41%	DALRRD	7	50%
5G network	GDARD	24	49%	DALRRD	3	21%
Sensor Technology	GDARD	18	37%	DALRRD	6	43%
Big Data	GDARD	18	37%	DALRRD	5	36%
Transport Technology	GDARD	10	20%	DALRRD	7	50%
Cloud Computing	GDARD	5	10%	DALRRD	6	43%
Bioinformatics	GDARD	4	8%	DALRRD	6	43%
Robotics	GDARD	4	8%	DALRRD	2	14%
Cyber Security	GDARD	7	14%	DALRRD	3	21%
Block Chain	GDARD	0	0%	DALRRD	1	7%

4.15. Technologies and equipment that are utilised to support farmers.

Participants had the option of choosing more than one technology or equipment. Figure 4.13 shows the technologies and equipment that DALRRD and GDARD use to support farmers. As would be expected, smartphones and laptops are at the top of this list in both departments: GDARD has 94% smartphone usage and DALRRD has 62%, then GDARD has 88% laptop usage and DALRRD has 77% laptop usage.

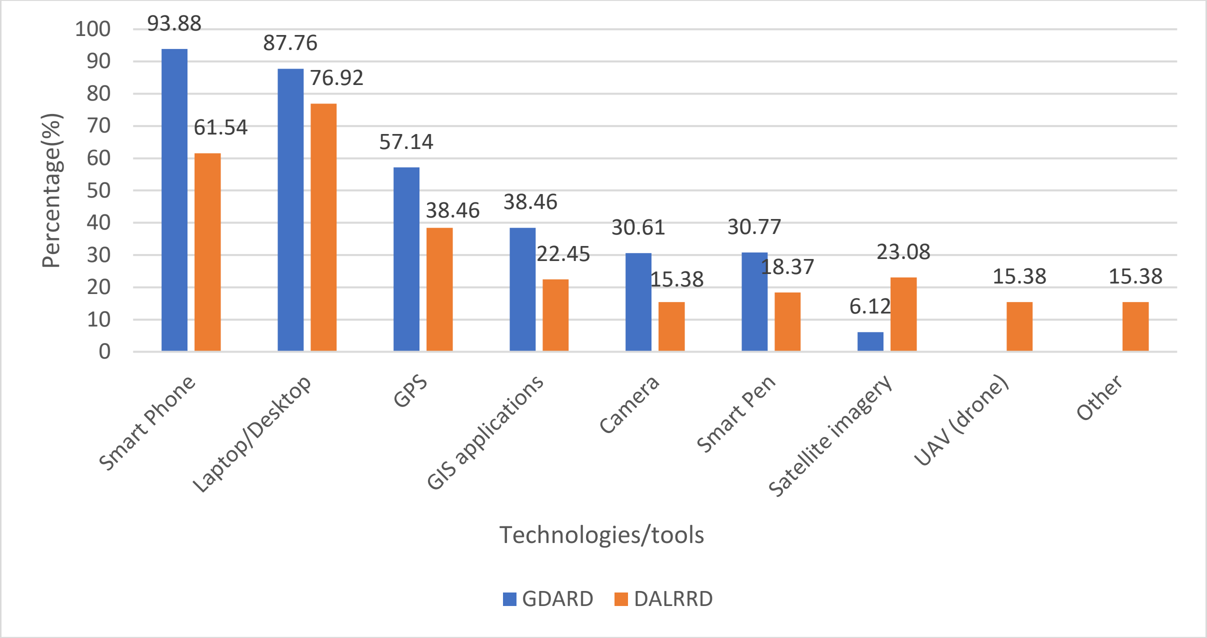


Figure 4.13. Technologies and equipment that GDARD and DALRRD participants use to support farmers.

Additionally, both departments use GPS, GIS applications, GIS software, cameras, smart pens, and satellite imagery to support farmers. It is interesting to note that 15 % of DALRRD officials use UAVs to assist farmers, whereas GDARD does not. One participant from the DALRRD mentioned that they use the Natural Agricultural Resources of South Africa Atlas. This atlas is available to the public and contains layers such as soils, geology, weather, vegetation, land cover, and use, agriculture capability and potential, and protected agricultural areas (PAA). Protected Agricultural Areas are areas of agricultural land that are protected for the purpose of ensuring long-term agricultural production and food security by protecting high potential and best available agricultural lands from non-agricultural land uses (Department of Agriculture Environment Forestry and Fisheries, 2014).

GDARD GIS professionals integrate a variety of spatial data types, such as satellite images, topography, soil characteristics, weather data, and land use information. By combining these datasets together, officials create comprehensive maps for farmers to help them plan planting and harvesting. GIS officials also process satellite imagery using remote sensing software such as ENVI and ERDAS to predict crop yields and farmers use this information for harvest planning, storage, and market forecasting.

4.16. DALRRD programs to equip the officials with skills to use new technologies at Agriculture national and provincial departments.

Out of 14 participants who responded to this question, 11 participants indicated that there are programs to equip them and training that they attend, one participant responded by saying partly yes, and two participants indicated that there no programs to equip them.

P4 mentioned that *"there is training which is arranged to help officials to use new applications"* P6 said *"Yes, we attended the 2019 Living Planet Symposium in Milan and received intensive R programming language training for six months in Germany for geospatial analysis. The Department also planned for us to go to Stellenbosch to attend the Drone Users Conference."* P12 said *"Yes, technology such as Survey123".*

P5 indicated: *"Partly yes. We are funded to attend conferences. Within our work environment, we are allowed to allocate time to learning and self-development, but this is limited. Can the employer do more; I would say yes, I have not attended a GIS-related course in more than 5 years. Also, there is limited opportunity to go to open-source training courses."* On the other hand, P11 mentioned that *"No none since I started in the public sector, I have never been offered any skills to use new technologies at the agricultural national department".*

The researcher concluded that the last comment by P11 is the true reflection of what is happening at the Department, DALRRD is having a program in place to equip their officials with new technology in national and provincial agricultural departments, however, the department can still do more as the technology is evolving fast. When the officials are equipped, they will be able to share information about these recent technologies with provincial departments and the information will cascade down to farmers.

4.17. ICT applications used by GDARD to alert farmers about disasters and diseases

Figure 4.14 shows that 31% of GDARD participants indicate that there is no system in place to notify farmers about disasters and diseases. The researcher deduced that there is a need to train or induct GDARD officials about available systems or platforms that can be used to disseminate information to farmers. For instance, only 31% of participants utilised email. This was followed by

14% who use a telephone and (or) cell phone. Then, 12% use WhatsApp, 8% use the South African Weather Service system, 4% use SMS, 2% use the early warning system and 6% mentioned that they use other methods.

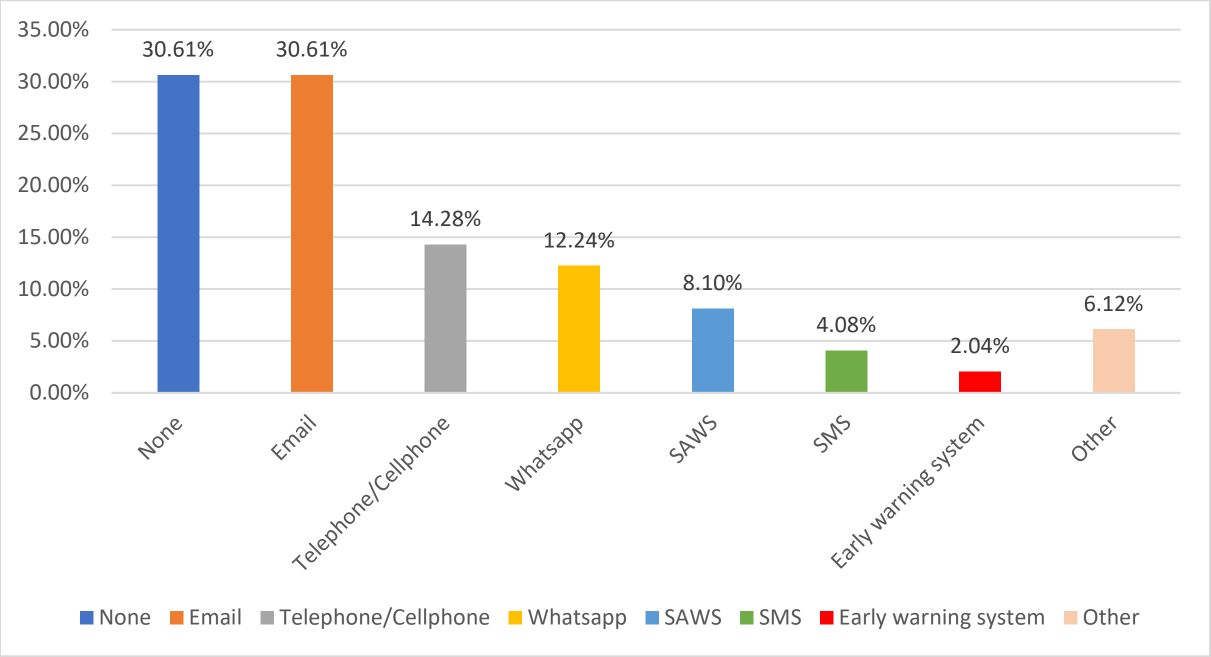


Fig 4.14. The ICT applications that GDARD is using to alert the farmers about disasters and diseases.

In a similar fashion to GDARD, as per Figure 4.15, 13. 36% of the participants indicate that there are no systems, or they are not aware of any system that alerts farmers to disasters and diseases. A total of 29% reported that the department has an early warning system, 15% reported that farmers are informed via DALRRD's website, 14% mention other media, and 7% mention social media.

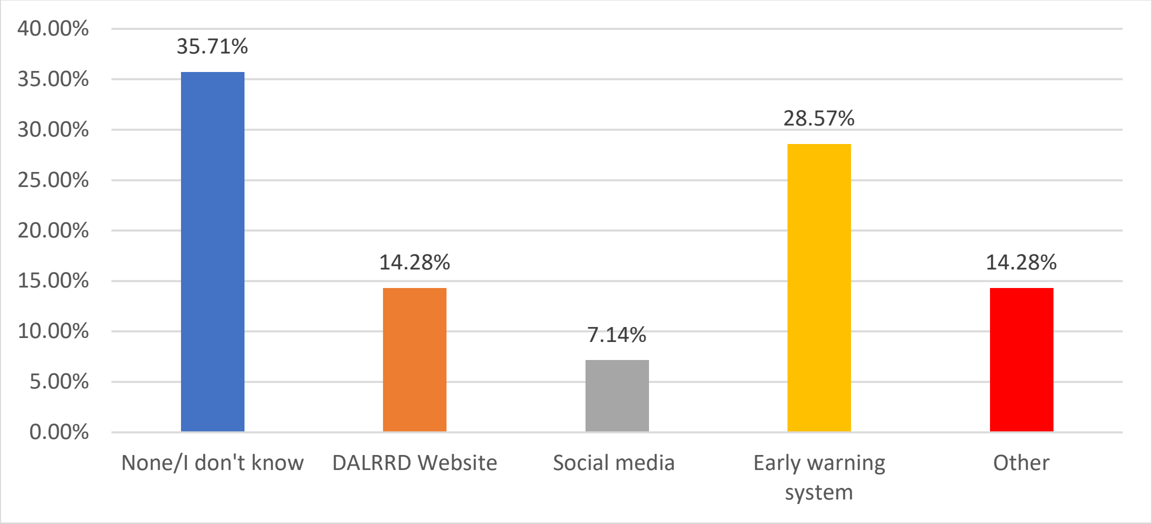


Figure 4.15. The ICT applications that GDARD is using to alert the farmers about disasters and diseases.

As per Figure 4.16, 93% of respondents indicated that they are getting support from the government and 7% indicated that they are not getting any support from the government. Commercial farmers who are getting support mention that the support they are receiving is as follows (1) extension services, (2) agriculture inputs, (3) infrastructure, (4) livestock vaccination, (5) animal inspection, (6) soil testing, and (7) removal of alien species. In addition, commercial farmers mentioned that they are provided with farming training, information on how to access agriculture funds, and the opportunity to attend farming conferences.

4.18. Government support and services for commercial farmers'

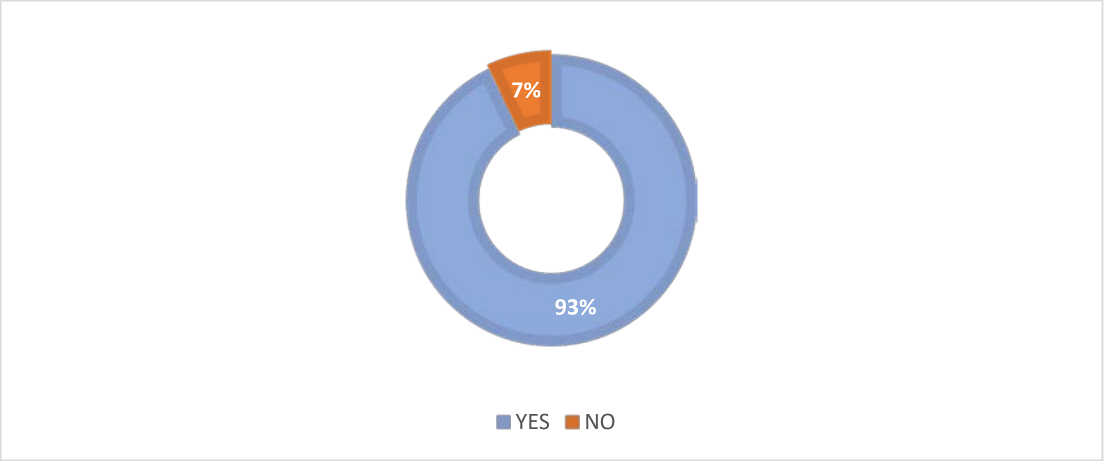


Figure 4.16. Government support and services for Commercial Farmers'

The commercial Farmer who indicated that he is not getting support from government mentioned that they will appreciate it if they can receive 2 tractors, combine harvester, sprayer, plougher, planter, ripper, 12-ton truck, fertilizer broadcaster, heavy harrows, 20-hectare center pivot, and silos.

4.19. Government support and services for Smallholder Farmers

As reflected in Figure 4.17, 61% of respondents indicated that they are not getting support from government, 38% indicated that they are getting support from the government and 1% skipped the question.

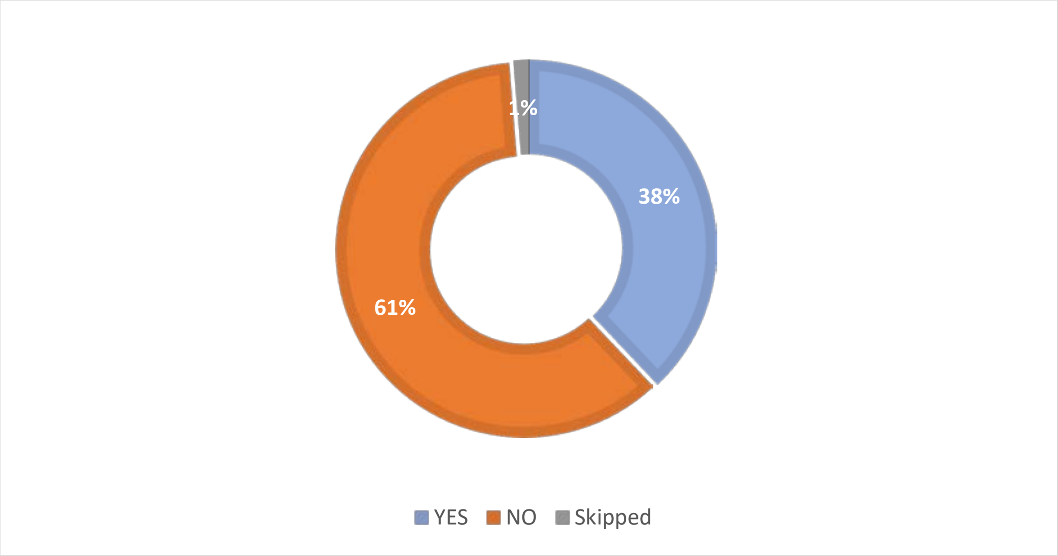


Figure 4.17. Government support and services for smallholder Farmers'

Those smallholder farmers who are getting support mention that the support they are receiving is as follows (1) extension services, (2) agriculture inputs, (3) infrastructure, (4) livestock vaccination, (5) animal inspection, (6) animal c-section, (7) soil testing, (8) removal of alien species, (9) Farming equipment, and (10) alert on disease outbreak. In addition, smallholder farmers stated that they have access to workshops where information is shared regarding farming and how to access agriculture funds, Extension officers organize study groups and development programs such as attending Tshwane University of Technology short courses.

Farmer F69 responded by saying "*Only Seeds, then sometimes they come check the farm",* Then F36 mentioned that "*They only support by removing the dead livestock since the disease strike in December".* F13 said "*Got seeds once and a soil test done*". F89 replied that "*Seeds and fertilizers, government should do more to help farmers*".

Farmers who indicated that they are not getting support from government mention that they will appreciate it if they can receive infrastructures such as tunnels, automatic irrigation systems, fencing, cold room, and chicken houses. Lack of, or inadequate infrastructure leads to loss of productivity due to underdeveloped crops (poor irrigation) and crop theft. This, in turn, leads to loss of profit, making it almost impossible for a smallholder farmer to continue their business.

Farmers further mention that they need agriculture funding, farming equipment, land to lease for farming purposes, livestock vaccination, and to receive information about vaccination periodically. Agriculture inputs and costs such as livestock feed, as the cost of feed, fertilizer, and can normally destroy an emerging farmer if not advised and managed properly.

Farmers also mentioned that they need government to assist them to market their agriculture products. Moreover, farmers need a workshop on how to care for their farms and market the product, training on 4IR technologies, and extension support services. Smallholder farmers were not happy that government officials just visit their farms and promise that they would come back. One smallholder farmer mentioned he knocked at several government doors, with no luck. Lastly, smallholder farmers stated that they need government officials who have a passion for agriculture.

4.20. Government services rating by commercial farmers

Commercial farmers (13) who indicated that they receive support and services from the government, were further asked to rate the services received from government. The rating was from 1 to 5, with 1- poor, 2- average, 3 - good, 4 - very good, and 5 – excellent. As demonstrated in Figure 4.18, 31% of farmers feel that they are receiving excellent support and services from the government, with 38% indicating that the services are very good, 23% receive good service. 8% mentioned that the support and service they receive is average and lastly, none of the participants indicated that they are receive poor services.

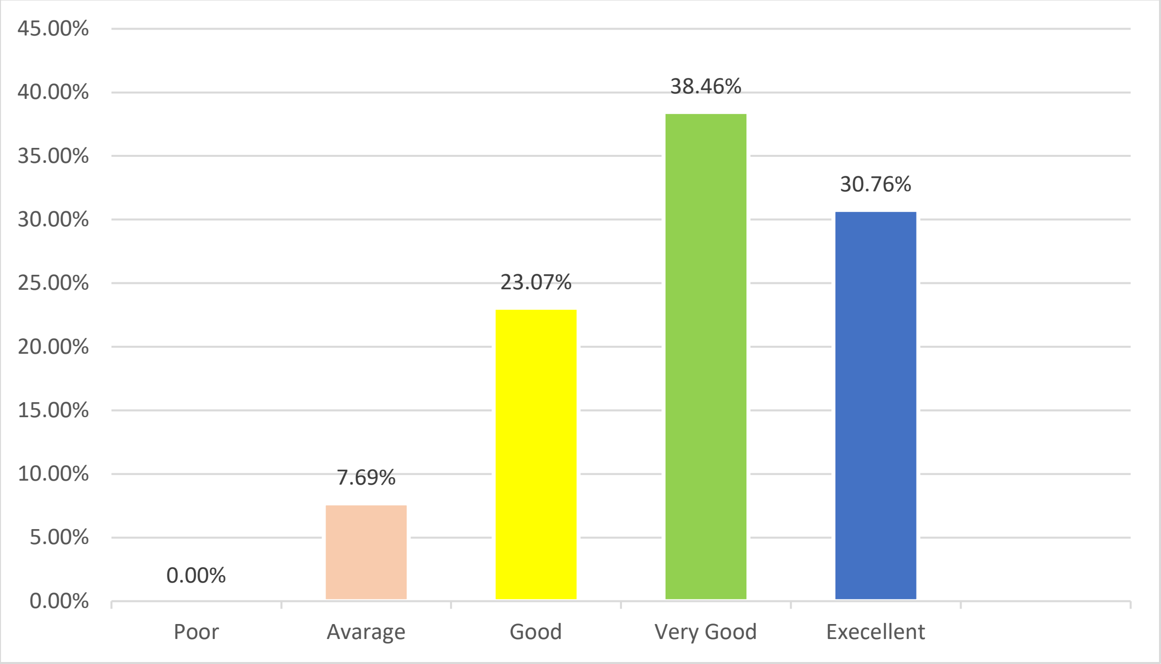


Figure 4.18 Government services rating by commercial farmers

4.21. Government services rating by smallholder farmers

The 42 smallholder farmers who indicated that they receive support and services from the government, were further asked to rate the services they receive from the government. The rating was from 1 to 5, with 1- poor, 2- average, 3 - good, 4 - very good, and 5 – excellent. As demonstrated in Figure 4.19, 21 % of farmers feel that they receive excellent support and services from the government, with 38% indicating that the services are very good, 21% receive good service.17% mention that the support and service they receive is average and lastly, 2 % indicate that the service they receive is poor.

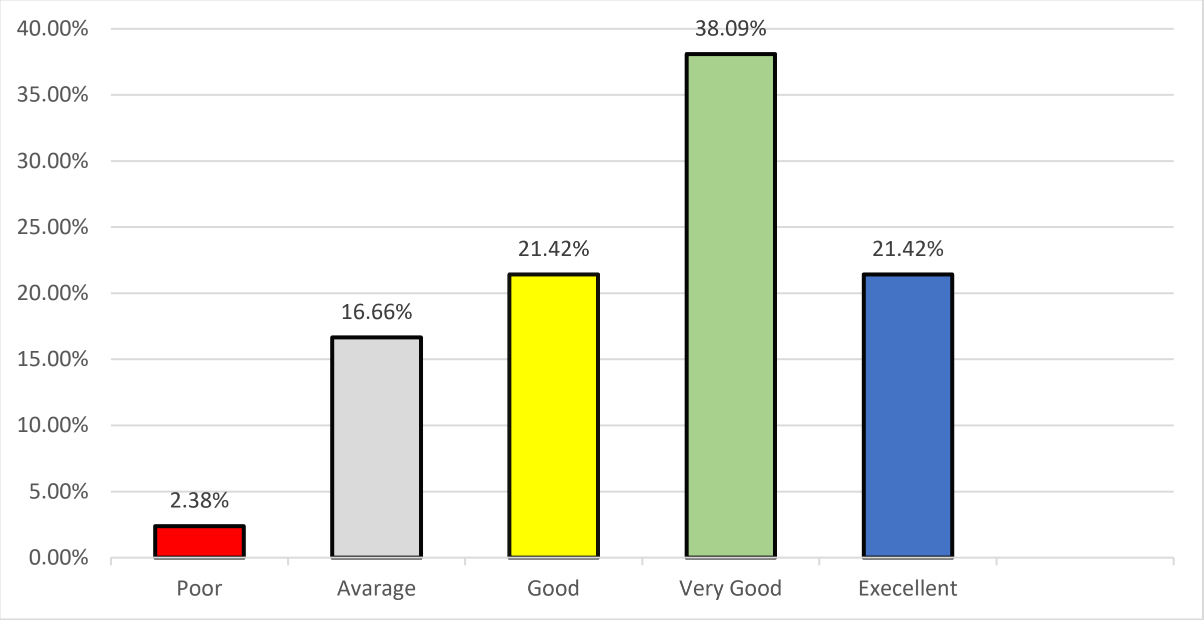


Figure 4.19 Government services rating by smallholder farmers

4.22. Farmers' Utilization of E-Services, GIS (Maps), GPS, RS (Satellite Images), and ICT for Mapping, Marketing Products, and Monitoring Issues such as Drought

12 farmers did not respond to this question. 57 indicated that they were not using technology to monitor crops or livestock. Whereas 92% of commercial farmers and 38% of smallholder farmers mentioned that they are using GIS, GPS, RS, and ICT technologies. Some of the technologies mentioned by 24 respondents are cameras, GPS ear tags, UAVs, temperature sensors, humidity sensors, smartphones, biometrics, and security systems that send alerts if something seems wrong. Berckmans (2017) points out that through precision farming, individual animals' health, welfare, reproduction, and environmental impact are continuously monitored and managed. GPS-based animal tracking technologies have advanced in recent years, but several constraints limit their use as Precision Livestock Farming (PLF) tools on commercial farms, especially in large production systems. The first challenge is wireless data transmission in rural areas (Nobrega et al. 2018). Further, GPS tracking systems are costly, which prevents widespread adoption (Davis et al., 2011). Crops and soil can be monitored from the air using UAVs. These devices provide images with a higher resolution than satellite imagery (Velusamy, 2022). Revenue can be increased, costs reduced, and business efficiency can be improved through drone outputs (Radoˇcaj, 2022).

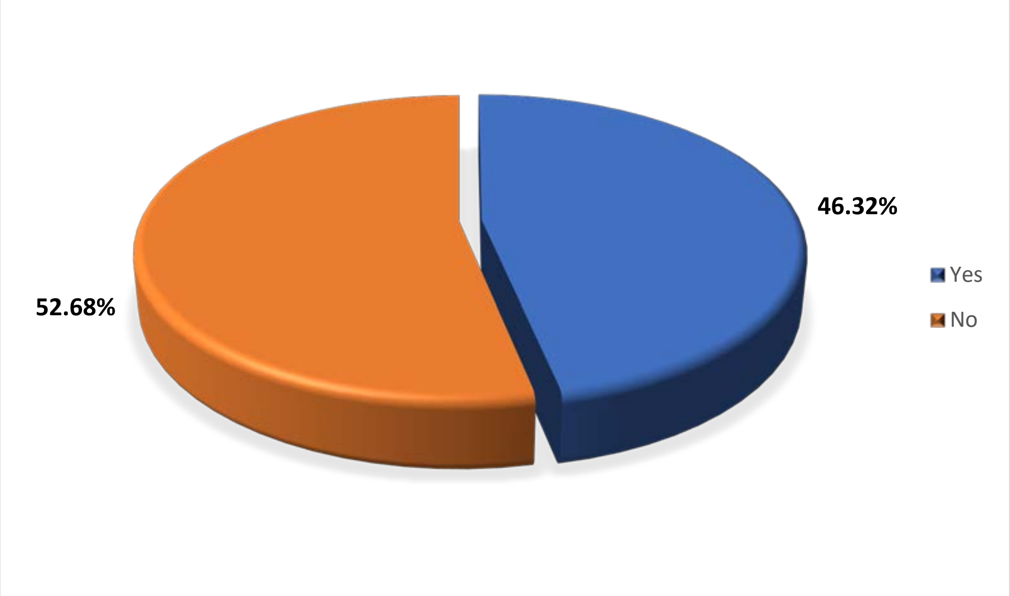


Fig 4.20. Farmer’s utilization of E-services, GIS, GPS, RS, and ICT Technologies

4.23. Participant Farmers' Views on the Impact of 4IR in the Agricultural Sector of Gauteng Province

This question was answered by 76 out of 93 participants. 16% of participants mentioned that they do not know, or they are not sure which 4IR technologies will impact the agricultural sector in Gauteng Province. Some participants believe that this 4IR technology will only benefit commercial farmers as smallholder farmers cannot afford it.

F58 said: *“I think it will benefit big farms that can afford those expensive tools”.* Then, F86 said: “*It will benefit the farmers with big farms and money*”. According to Christiaensen, et al. (2021), despite new technologies' bright future, smallholder farmers in South Africa face poverty, drought, hunger, and inadequate compensation.

Farmers are of the view that drones can play a vital role in monitoring crops and the farm. F52 responded by saying “*The use of drones technology is one that farmers in Gauteng can highly benefit from because drones can be used for daily functions on the farm such as crop monitoring, crop inventory inspection of farm infrastructure, and making crop damage assessment, Furthermore the use of drones can negate the need for physical inspections thus saving time and security cost.”* F87 mention that *“if implemented well livestock theft will decrease, using tags,* *sensors and drones",* then F19 said*, "Drones will assist a lot to spray and monitoring crops".* Garg, et al. (2018) indicated that with drone monitoring systems, farmers can observe the aerial view of their harvest. It provides information about the water system, soil variety, pests, and fungus infestations. Images can be analysed to extract features that provide information about the health of plants in a way that is not visible to the naked eye. In addition, this technology is capable of monitoring yield regularly.

F84 indicated that *"Real-time information. Historical data to use for future predictions, link with markets, suppliers, other farmers, on-point weather reports".* F78 said: *"Technology will make it easy to monitor crops, assist on what to plant and when"*. F17 mentioned that "*Taking advantage of 4IR will help farmers, better plan, and anticipate adverse weather patterns, to always recover from unreasonable, or unexpected weather conditions brought on by global warming and finding innovative ways of farming, whether remotely or using technology to monitor growth"*. As cited in Lassuoed (2021) big data is generated during the production process when GPS, RS, and UAVs are integrated into farming practices and equipment. By using big data technology, farmers can make better decisions regarding production, procurement, human resources, and financial management. Farmers can make better decisions and act more efficiently when they have real-time data on soil characteristics and climatic conditions.

F52 indicated that *"the fourth industrial revolution covers exciting technologies that black farmers in Gauteng would benefit from if they had the knowledge of and or access to technologies. For example, the use of artificial intelligence could give farmers access to complex information that can greatly influence farm management decision-making. Artificial intelligence can assist in improving costs because it can improve the allocation of inputs such as fertilizer and chemical applications. Blockchain can be used to increase a farmer's earnings*". F76 said: *"Technologies such as artificial intelligence can help farmers to analyse data and predict which product will do well and is in demand that year".* Geetharamani & Pandian (2019), state that the decision-making capabilities of AI systems have made them useful for real-time data analysis.

F43 indicated that *"It will have a positive impact on the availability of data that will make it possible to plan better. One such example is consumption patterns. With this data, farmers can determine what consumers' needs are and plant, accordingly, reducing the cost of producing crops that are not in demand. On the flip side, the use of technology and heavy machinery to produce crops can lead to job losses, upping the unemployment rate."* F53 argued that "*Labour cost will be reduced,* *technologies help will farmers to harvest more crops.”* F81 said: *“If adopted well it can help farmers increase productivity and minimize loss”*. The use of UAVs, electronics, tractors, and other 4IR technologies has replaced humans in agriculture. In the farming industry, technologically advanced and powerful agricultural materials have a significant impact on job losses (Moloi & Marwala, 2020).

4.24. Participant Farmers' Perspectives on ICT, GIS, and Remote Sensing Technologies and Trends Impacting the Agricultural and Agri-Processing Industry in Gauteng Province

33 participants skipped the question. 25 people did not know or had no idea what ICT, GIS, and RS technologies and trends could have an impact on the Gauteng Province agricultural and Agri-processing industries. Then F27 highlighted *that "Land Management and Livestock Management for electronic databases, financial systems and drones, machines, labelling and packaging, security systems, crop management, and monitoring systems to indicate if an animal is sick or giving birth".* F52 mentions *"drones, satellite technology, cloud computing, and data analytics. Access to smart gadgets such as cellular phones and tablets and the internet assists in delivering timely, convenient information like climate changes and market trends cost-effectively”.*

F34 briefly explained that *“GIS is helping farmers to conduct crop forecasting and manage their agricultural production by utilizing imagery collected by satellites also helps analyse and visualize agricultural environments and workflows, which has been very beneficial for those involved in the farming industry. GIS can analyse soil data and determine which crops should be planted. ICT farmers can stay updated with all the latest information. ICT has made it possible to facilitate better communication and ensure the delivery of services*”. F53 is using GIS for Farm maps, Google Earth, and weather applications.

F84 is using drones, Online marketing software, and data storage applications, then participant F40 is using motion sensing and drone technology. F66 said: *“Well honestly I need to do my research as it's my first-time hearing of such technology”.*

4.25. Assessing and mapping of 4IR technologies uptake by commercial and smallholder farmers.

a). 4IR technologies uptake by commercial farmers.

Table 4.5 indicates that it is mainly smart farming and the Internet of Things that are used by commercial farmers, followed by sensor technology and transportation technology. Additionally, commercial farmers are using UAVs, robotics, and vertical farming. Big data and artificial intelligence are not used by any commercial farmers. furthermore, commercial farmers mentioned they use other digital technologies, such as GPS, geological apps, Google Earth, wireless security cameras, and sensors.

Table 4.5. List of 4IR technologies uptake by commercial farmers.

Answers	Count	Percentage
UAVs	3	7%
Big Data	0	0%
Vertical Agriculture	2	5%
Smart Farming	10	23%
Artificial intelligence	0	0%
Robotics	1	2%
Internet of things	10	23%
Bioinformatics	1	2%
Sensor technology	8	19%
Transport Technology	4	9%
Other	4	9%

According to Figure 4.21, there is a high density of adoption of 4IR technologies by participants in the southwestern part of Gauteng. However, there is a contrast, there is moderate adoption in the north. The south-eastern part of Gauteng has low adoption rates. In the central part of Gauteng, 4IR technology has not been adopted, as there were no participants. All participants who have adopted 5 different technologies are from the southwestern part of Gauteng.

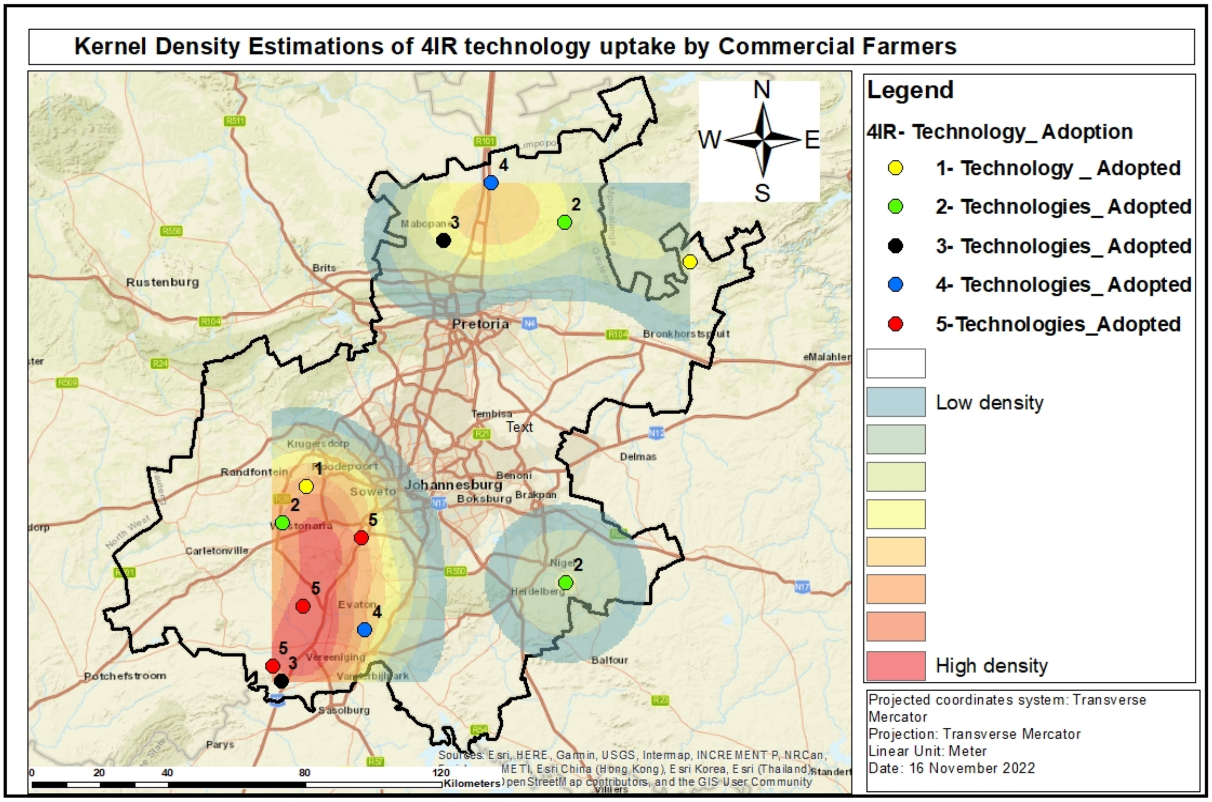


Figure 4.21. 4IR technologies uptake by commercial farmers

b). 4IR technologies uptake by Smallholder farmers.

For smallholder farmers as shown in table 4.6, the most used technology is the Internet of Things, followed by smart farming, and big data. Smallholder farmers also use vertical farming, transportation technology, UAVs, and artificial intelligence. Robotics are not used by smallholder farmers. Then 17% of smallholder farmers said that they were using other digital technologies such as GPS, Google Earth, wireless security cameras, and another mentioned sensor.

Table 4.6. List of 4IR technologies uptake by smallholder farmers.

Answers	Count	Percentage
UAVs	1	1%
Big Data	6	6%
Vertical Agriculture	5	5%
Smart Farming	19	18%
Artificial intelligence	1	1%
Robotics	0	0%
Internet of things	49	47%
Bioinformatics	1	1%
Sensor technology	0	0%
Transport Technology	5	5%
Other	18	17%

According to Figure 4.22, there is a high density of adoption of 4IR technologies by participants in the eastern part of Gauteng. Then, there is moderate adoption on the Southern side. The Western, central, and Northern part of Gauteng has low adoption rates. Of the smallholder participants, there is one farmer who has adopted more than 4 technologies, many farmers have adopted one technology followed by those who are not using any 4IR technology, and then those who are using two technologies.

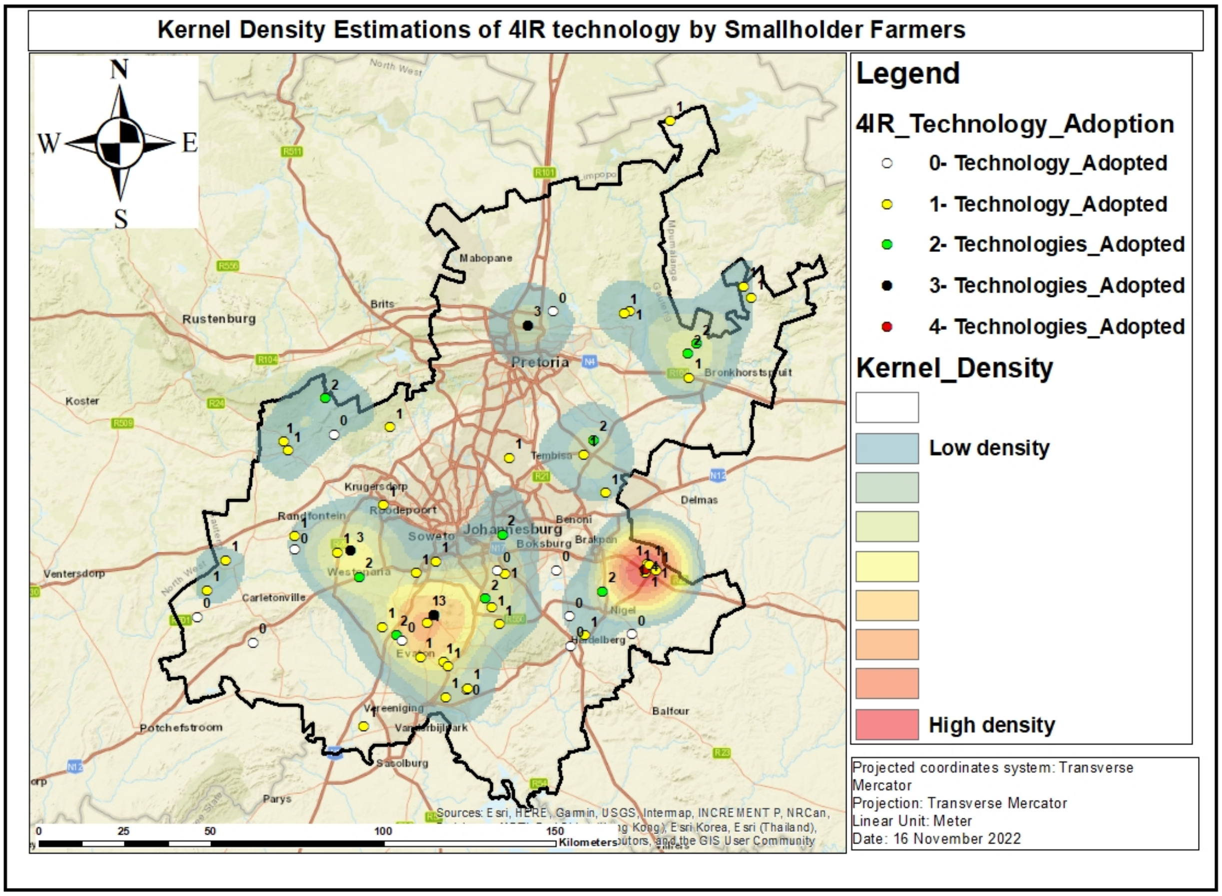


Figure 4.22. 4IR technologies uptake by smallholder farmers.

4.26. Assess and map the underlying conditions that promote or discourage the uptake of ICT, GIS, RS, and 4IR technologies by farmers in Gauteng.

4.26.1 Affordability by commercial and smallholder farmers.

In commercial farms, 93% (N=13) have implemented some form of 4IR technology and 7% (N=1) do not use any form of 4IR technology. In total, 81% of smallholder farmers (N=64) have embraced more than one technology. 19% of smallholder farmers (N=15) have not adopted any technology. As shown in Figure 4.23, many commercial farmers have adopted 4IR technologies, possibly because they can afford them. The reason for low uptake by smallholder may be due to a lack of funds.

Figure 4.23 shows how many commercial and smallholder farmers have implemented 4IR technologies and how many have not. Among smallholders, the majority have only adopted one technology, and the most popular technology is the Internet of Things such as smartphones, thermostats, home security systems, and RFID tags. Followed by those who have not implemented any technology, one farmer is using four technologies, and there is no one who uses five technologies. In contrast, commercial farmers adopt up to five technologies. Due to commercial farmers' financial capabilities, the researcher concluded that they could afford 4IR technologies. Owing to smallholder farmers' financial constraints, the government should provide 4IR services where possible.

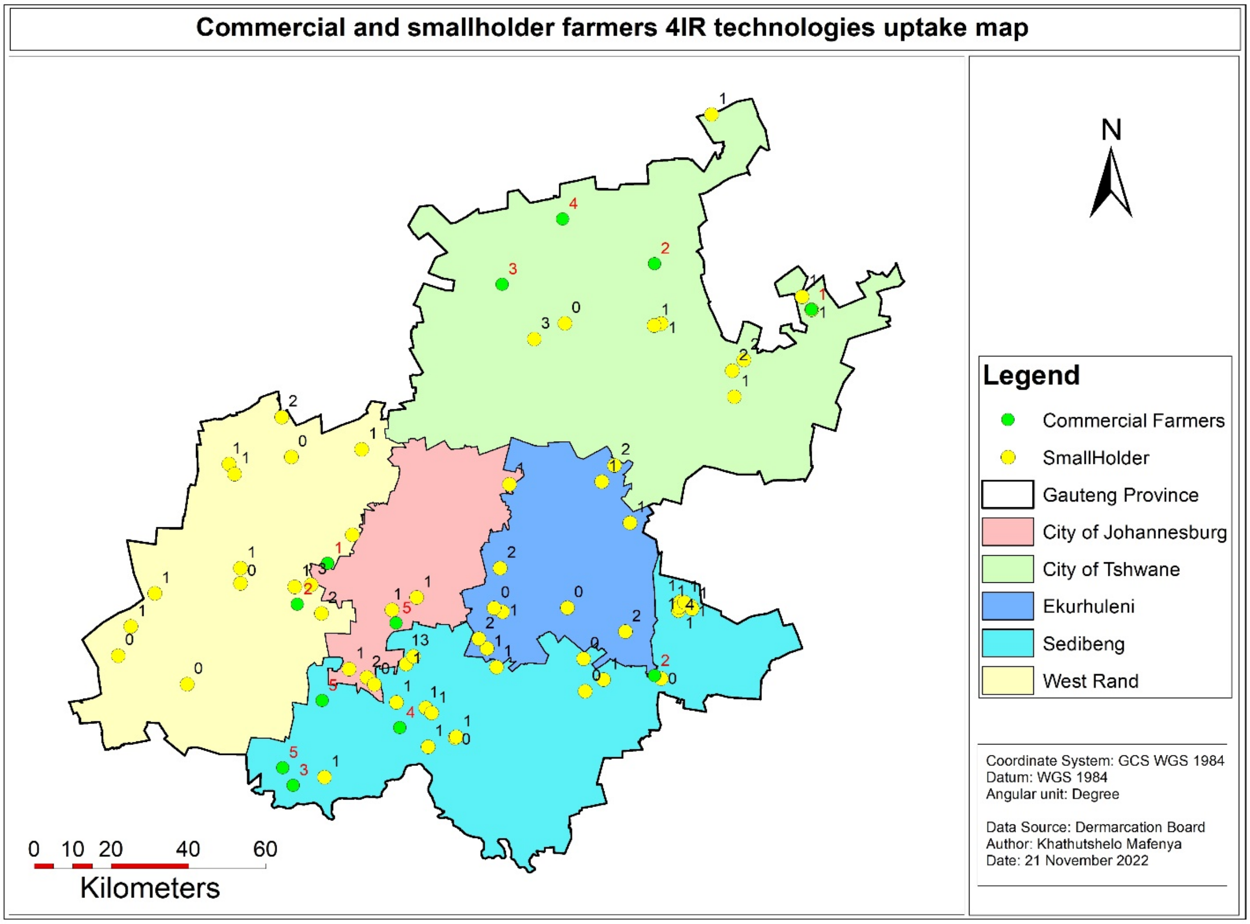


Figure 4.23. Farmer’s 4IR technologies uptake

The adoption of ICT, GIS, and RS technologies by commercial and smallholder farmers is illustrated in Figure 4.24. There are 67% smallholder farmers (N=43) who do not use ICT, GIS, and RS technologies on their farms, followed by 31%, (N=20) who are using the technology, and 2% (N=1) who skip the question. 92% of commercial farmers use ICT, GIS, and RS technologies, while 8% (N=1) do not. Maps from the Surveyor General and Agriculture departments as well as satellite images from Google Earth are used by commercial and smallholder farmers. These tools provide farmers with valuable insights into their fields and operations. With maps, farmers can allocate resources and make informed decisions about soil quality, topography, and land potential. Farmers use Google Earth satellite images to monitor changes on their farms, identify potential problems, and plan planting and harvesting times.

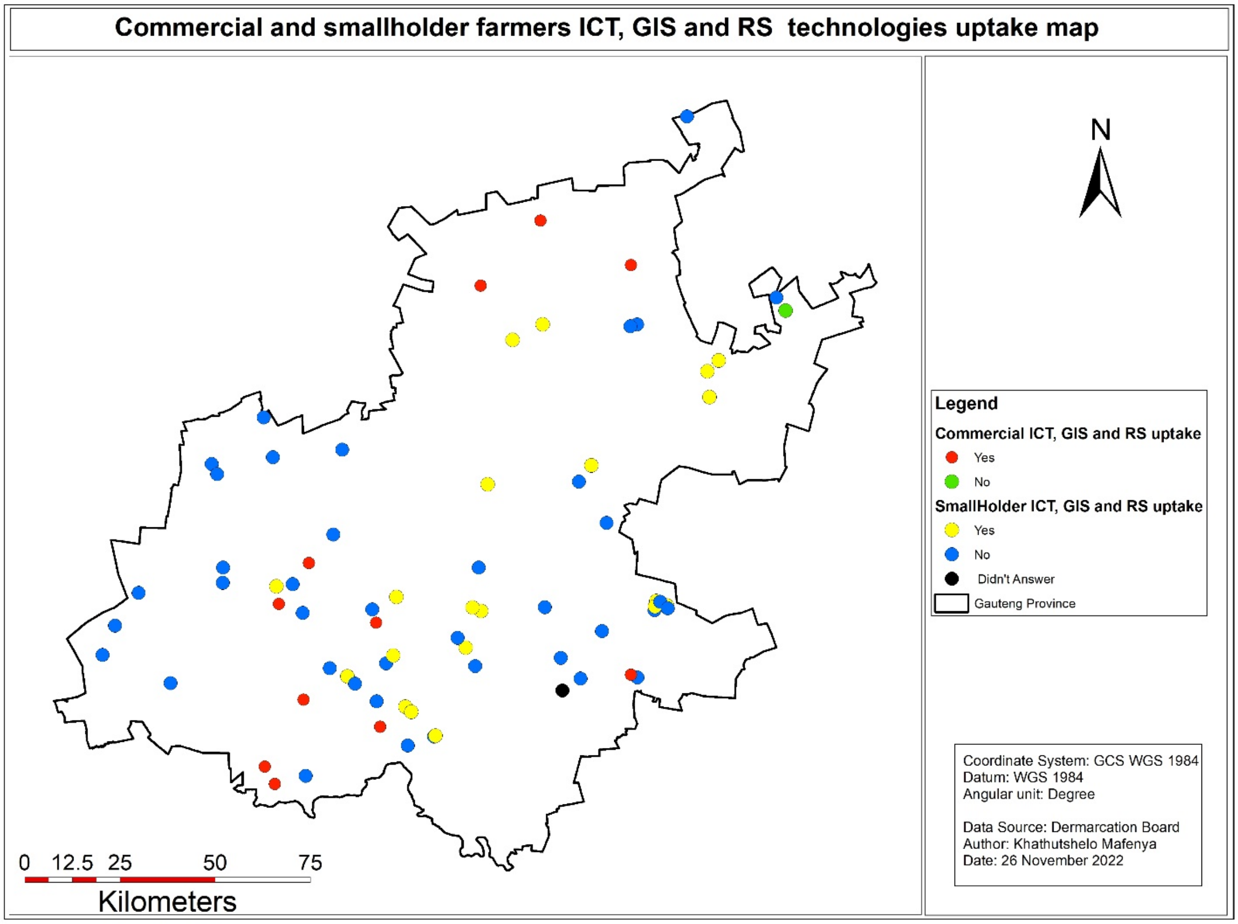


Figure 4.24. Farmer's ICT, GIS, and RS technologies uptake

Digital technologies are viewed as expensive, which causes a digital divide, moreover, farmers have little knowledge of them despite their potential (Dlamini and Ocholla, 2018; Mabaya and Porciello 2022 & Bontsa et al., 2023). Strydom (2021) concludes that in developing countries, including Africa, some digital technologies require access to internet connectivity, which has cost implications. This is disadvantageous to smallholder farmers, making it difficult for them to compete, which exposes them to risks of takeover by large corporations (Jeanneaux, 2018). Like in the uptake of 4IR, affordability might have contributed to commercial farmers adopting more ICT, GIS, and RS technologies than smallholder farmers, where only a few farmers utilize these technologies.

4.26.2 Level of education

Most commercial and smallholder farmers 59% (N=55) who adopted 4IR technologies have postgraduate matric qualification, whereas 29% (N=27) have grade 12 or standard 10 qualifications. 4IR technologies are used by 2% (N=2) of farmers without formal education. Farmers with ABET are 2% (N=2), and those with Grade 7 or Standard 5 are 7% (N=6). Based on these results, the education level influences the uptake of 4IR technologies. This indicates that a farmer’s educational background plays a role in determining their adoption of 4IR technologies. Mashaphu (2022) argued that education significantly influences a farmer’s decision-making processes by shaping the awareness, perception, and adoption of innovations. Singh and Kaur (2021) agree that factors such as education strongly influence farmers' perceptions of digital technologies. Schulze Schwering et al. (2022) also support this view when they claim that openness to technologies is related to educational levels.

4.26.3 Potential Agriculture Land

Figure 4.25 illustrates the uptake and non-uptake of 4IR technologies in areas with low and high agricultural potential. This map does not indicate whether there will be uptake or non-uptake based on the potential of the land. For example, in the Southwestern part of Gauteng province, there is high agricultural potential land and there are farmers using 4IR and those who are not. Smallholder farmers are mostly located in built-up areas. Built-up areas dominate the central part of Gauteng, which includes the cities of Johannesburg, Tshwane, and Ekurhuleni.

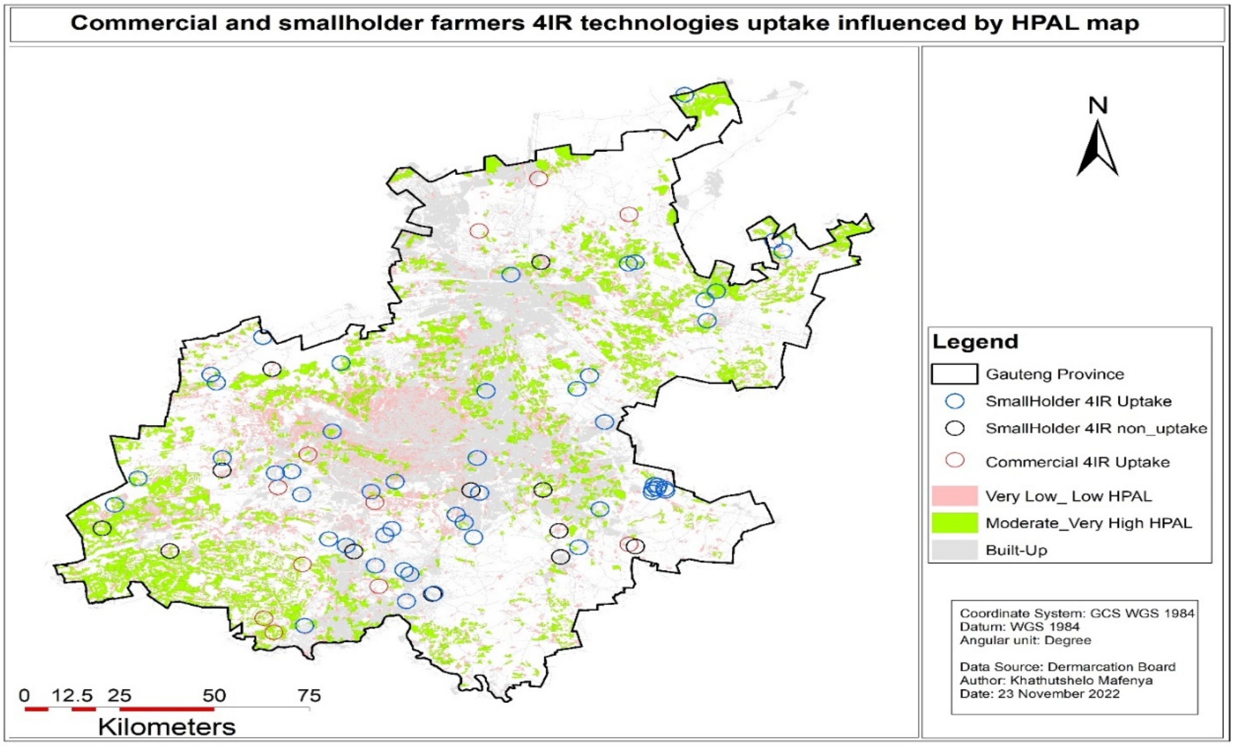


Figure 4.25. commercial and smallholder farmers 4IR uptake and non-uptake in High Potential Agricultural Land (HPAL).

4.27. Farms observations

The researcher used the Convert observation method in eight farms within the Gauteng province, as shown in Figure 4.26. In convert observation, participants are not aware they are being observed (George, 2023). Geospatial data was collected using ArcGIS Collector as points, and polygons. To map the area, researcher had to drive around the farm with the farmer to identify certain farm features. Six of those farms were involved in mixed farming and two were dealing with crop farming. The first thing the researcher noted was that it was challenging to get the coordinates of their farm from some of the farmers, however, most of the farmers were using a smartphone and they knew how to send the coordinates. Half of the farmers have maps of their farms which they received from GDARD and DALRRD. These maps help them to know their farm boundaries and to be able to plan the areas they can plough and plant.

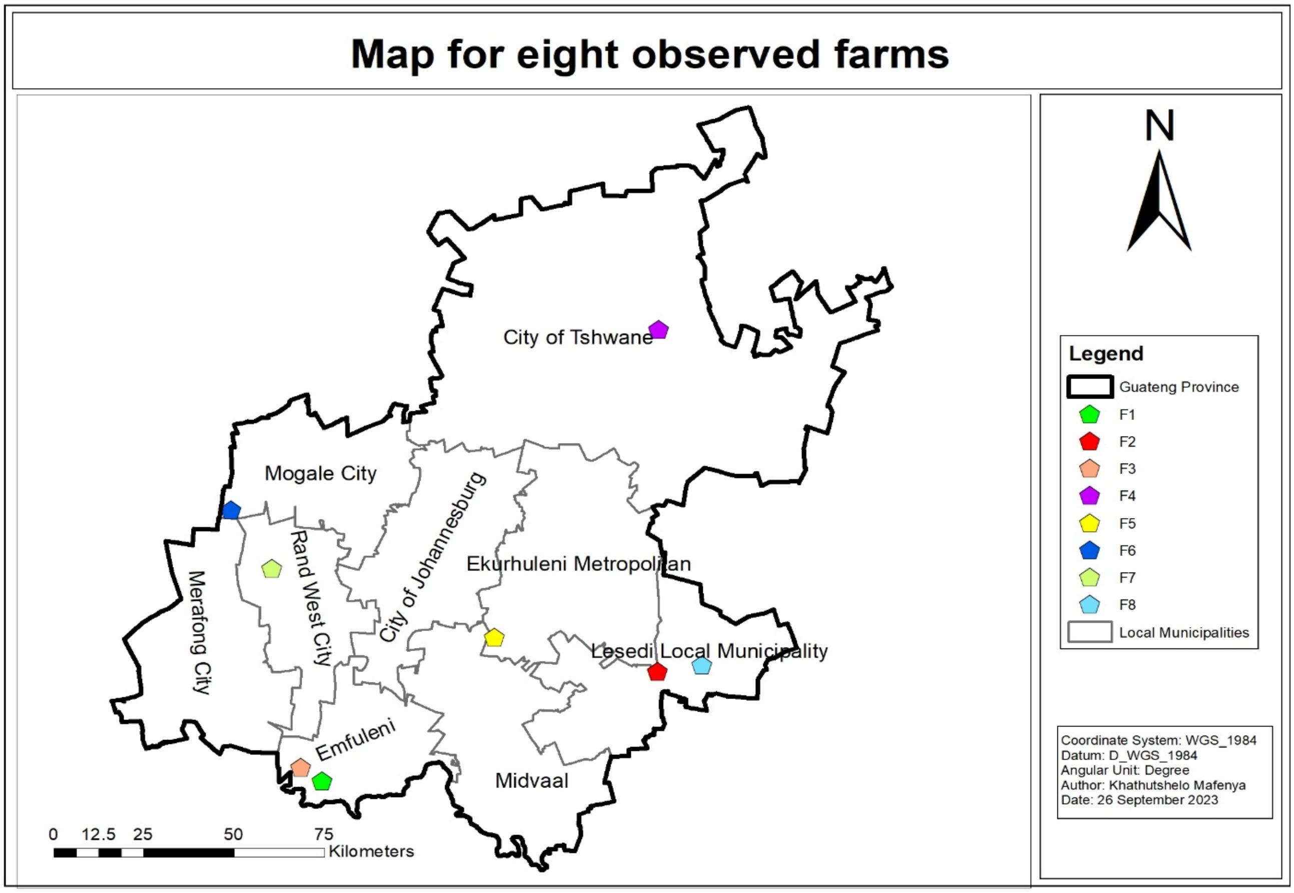


Figure 4.26: Map of eight farms visited.

Farm One (F1) is in Emfuleni local municipality, an area known for producing some of the highest maize yields in South Africa. On this commercial farm of 500 hectares, there are four farm portions, one of which is Kaalplaats 577IQ, portion 106. The farm is primarily used for cultivation and grazing. Mixed farming is practiced by the farmer, which includes producing maize and keeping cattle, goats, and pigs. Farmer use tractors, laptops, smartphones, maps, and Google Earth imagery. The farmer identified the farm boundary and ground features using a farm map. Additionally, she was able to take coordinates using Google Earth imagery. The blue gum trees are an alien species which needs to be eradicated over time by the farmer and GDARD through the land care project.

Figure. 4.27a shows how Kaalplaats 577IQ farm, portion 106 looks and what activities are currently taking place there. On the Kaalplaats 577IQ farm, portion 106, B represents four boreholes, S2 represents the storages, S3 represents the training and workshop center, and S4 represents the cattle kraal.

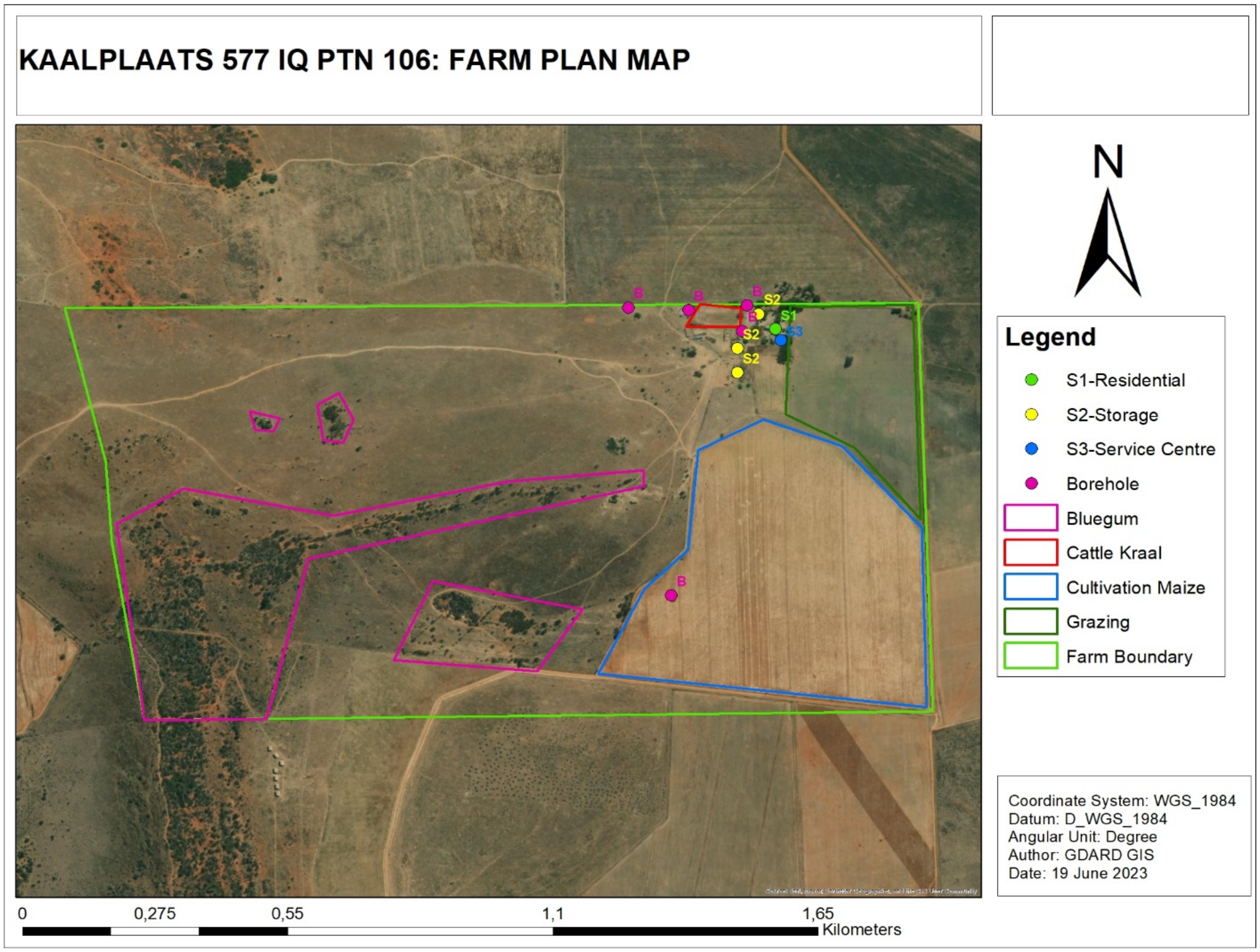


Figure 4.27a. Kaalplaats 557IQ, portion 106 farm map

Figure 4.27b shows the Kaalplaats 557IQ, portion 106 farm zoomed-in map. The zoomed map was created to show the five boreholes, three storages, residence, and a service center.

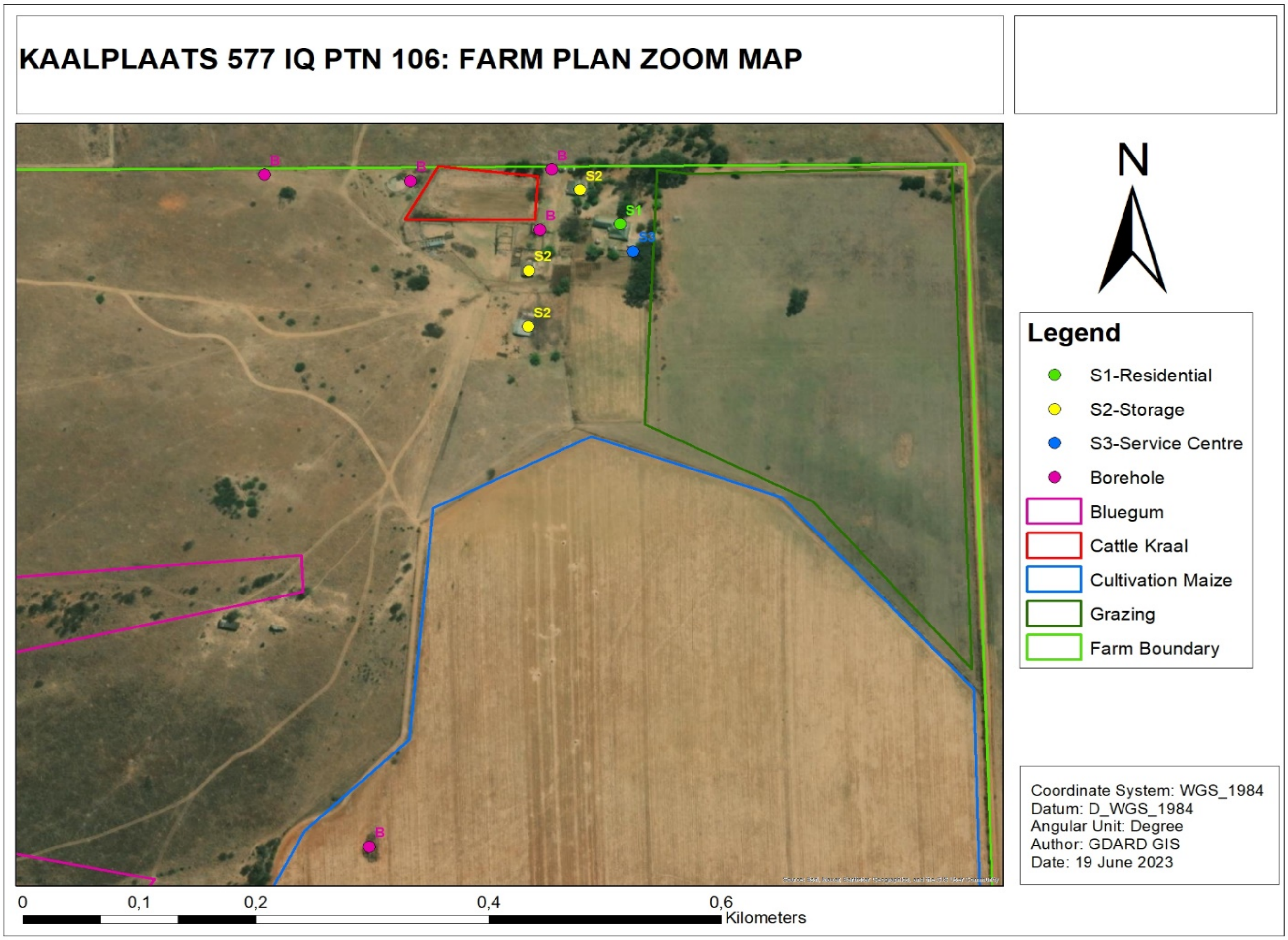


Figure 4.27b. Kaalplaats 557IQ, portion 106 farm zoomed-in map.

Figure. 4.28 shows what has been implemented to date and what still needs to be done at Kaalplaats 577IQ farm, portion 106. There is a cultivated area of 31.33 Hectares, which has been planted with maize by the farmer. In I2, blue gum trees cover 28.41 HA, and this needs to be eradicated over time by the farmer and GDARD through the land care project. The grazing area for cattle is shown in I3.

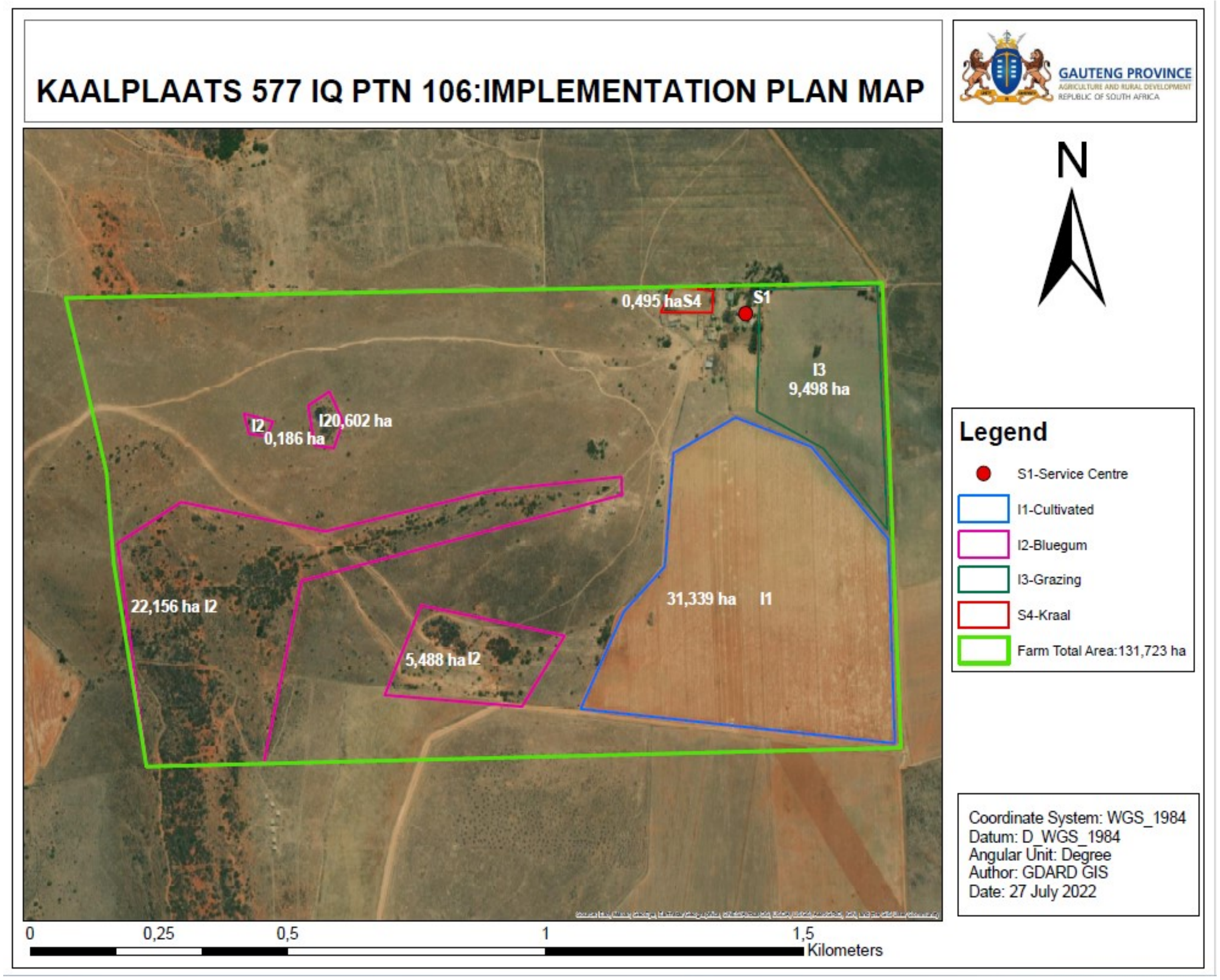


Figure 4.28. Kaalplaats 557IQ, portion 106 implementation plan map

Two maps are shown below, one showing the farm plan of Farm Two (F2) which consists of three farms, namely Bultfontein 192 PTN 15, Rietpoort 193 PTN 26, and Uitkyk 329 PTN 0 in Figure 4.28a and Figure 4.28b. Then Figure 4.29 shows the land care project's implementation plan of these three farms in Ekurhuleni metropolitan municipality. The total area these three farms is 524 hectares. The farmer produces crops such as maize and soya beans, as well as livestock such as goats and cattle. Black wattle and slangbos alien species grow on the farm, which the farmer harvests and sells it as firewood.

Figure 4.29a shows how the farm looks and what activities take place there currently. On the map, B is the location of two boreholes on the farm. On the farm, there is an earth dam (S2) for livestock to drink water.

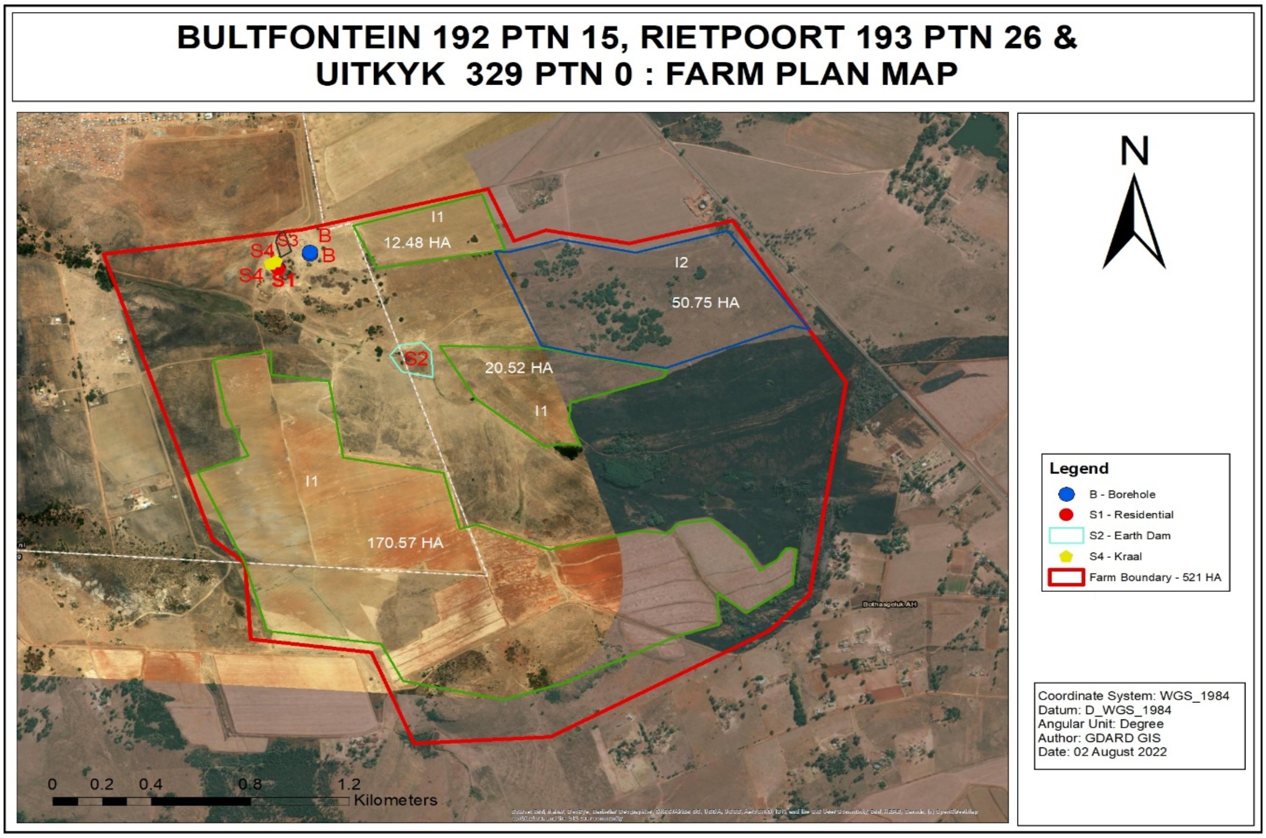


Figure 4.29a. Bultfontein, Rietpoort and Uitkyk farm map

Figure 4.29b shows the Bultfontein, Rietpoort, and Uitkyk farm zoomed map. B indicates two boreholes at the farm, while S1 displays the structure used for residential purposes. On the farm. S3 is showing the kraal structures for the livestock. S4 is showing the other two kraals and one of the kraals is used for calves, young goats, or heavily pregnant livestock.

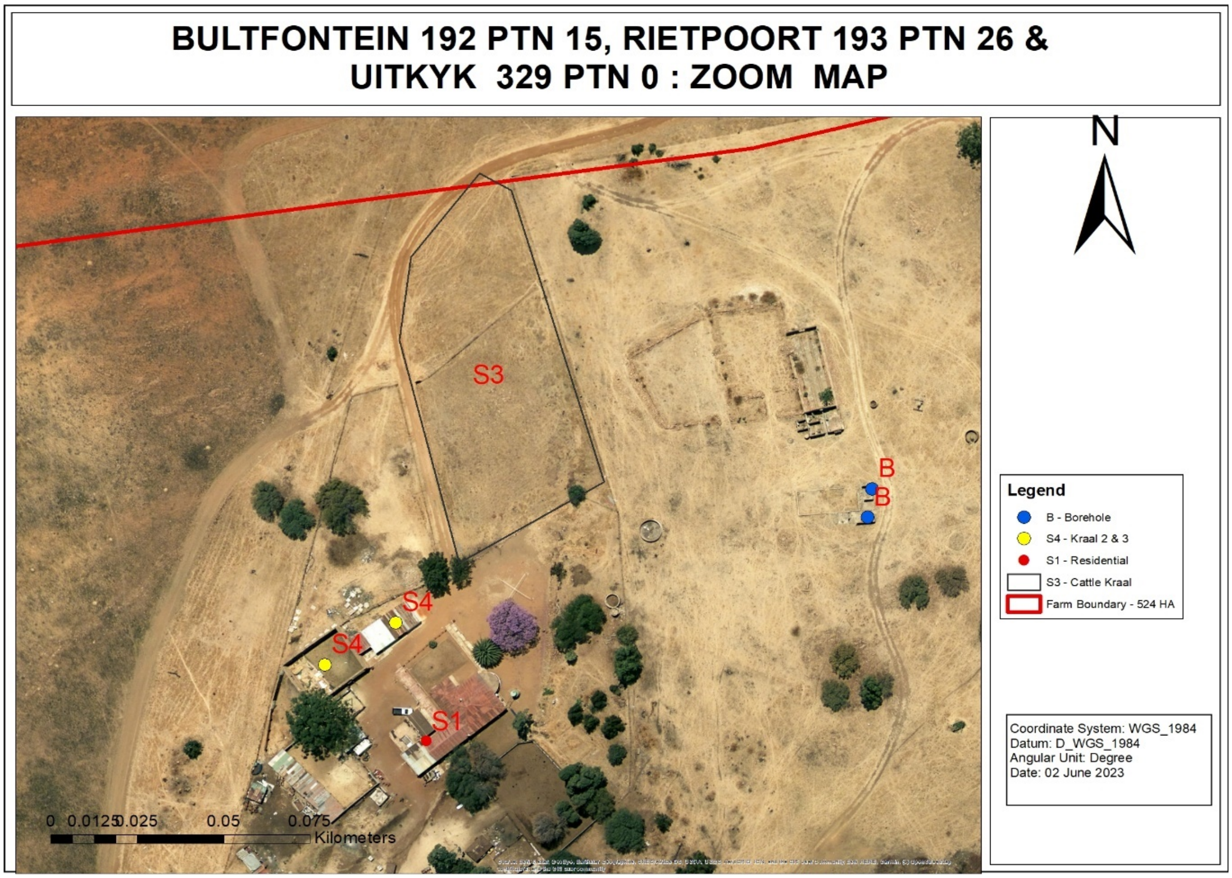


Figure 4.29b. Bultfontein, Rietpoort and Uitkyk farm zoomed-in map.

Figure 4.30 illustrates what has been implemented so far and what still needs to be implemented. The service center is where farmers will receive training. I2 is the black wattle and slangbos alien species covering 50.75 HA and this will have to be eradicated. I1 shows showing the cultivated area is 183 Hectares, on which the farmer planted maize and soya beans.

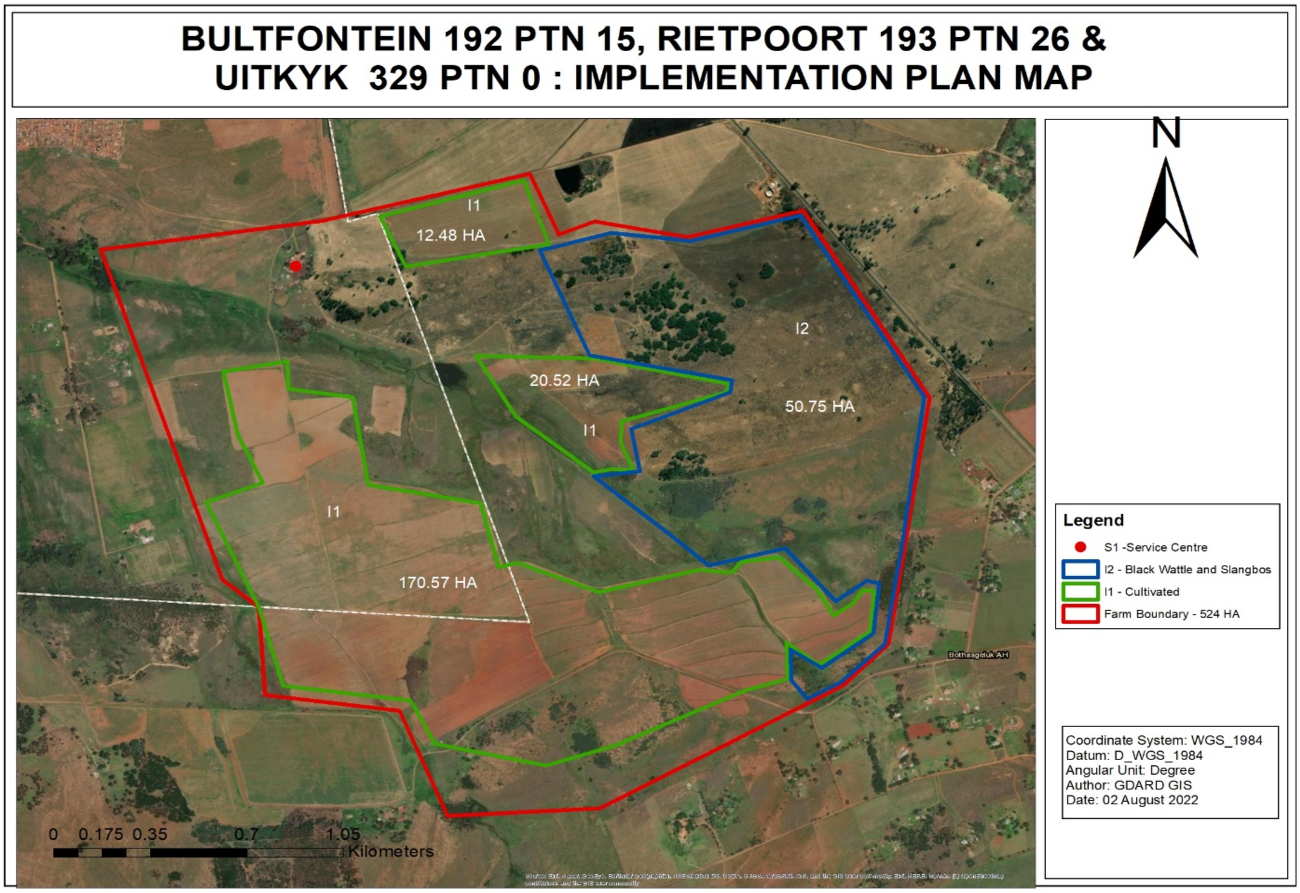


Figure 4.30. Bultfontein, Rietpoort and Uitkyk Implementation map

There is a commercial farm of just over 700 hectares on Farm Three (F3). The farm in Emfuleni local municipality is also located in South Africa's maize triangle area. Grazing and cultivation are the main uses of the farm. The farmer practices mixed farming, which involves growing maize, soya, and sunflowers, as well as raising livestock. The farmers use technologies and equipment such as a tractor, harvester, smartphone, the internet, and maps. On the farm, signal reception was poor. Blue gum trees and slangbos are alien species that need to be eradicated over time by the farmer and GDARD through the land care project.

It was interesting to observe that the farmers were conducting a study group during the farm visit. Ankiewicz (2022) explains an Agri-community study group is a gathering in which growers, producers, and others discuss challenges and strategies related to the industry. Through interaction with industry experts and fellow training participants, education and learning can build capacity within communities by sharing relevant knowledge and skills. Therefore, study groups provide farmers with the opportunity to share information and resources for farming and to keep up with market trends relevant to farming.

Farm Four (F4) is a smallholder farm located within the Tshwane metropolitan municipality and has a total land area of 24 hectares. Maize crops are cultivated by the farmer. On the farm, the farmer uses only a hired tractor. Furthermore, the farmer was dissatisfied with the fact that the fence promised by the government official had not yet been built. Due to the lack of a fence, maize cobs are stolen.

Farm Five (F5) is a smallholder farm in Ekhurhuleni metropolitan municipality. Mixed farming is practiced by the farmer, who produces maize, vegetables, and goats for livestock. The farmer uses only mobile phones and the internet on the farm. Neither of these smallholder farmers had a map of their farms. There is no smartphone available to the owner of F4. F5 has a smartphone but having trouble obtaining the Google Earth coordinates of the farm.

Farm Six (F6) is in Mogale City local municipality. This commercial farm consists of 677 hectares. Besides producing maize, the farmer also has cattle and goats. Maps showing the cultivated and grazing areas of the farm were available to the farmer. There was a battle wattle challenge on the farm. Among the technologies used by the farmers in the area, 4IR technologies are not widely adopted. Despite this, farmers used 2nd and 3rd industrial technologies such as tractors, laptops, smartphones, the internet, Google Earth imagery, and maps.

The farm seven (F7) is in Rand West City local municipality. It is a commercial farm that covers 124 hectares. Mixed farming is practiced, including the production of crops (maize and soya), as well as livestock (chicken). During the research visit to the farm, alien poplar species growing in the wetlands were noticed. The farm did not use much technology other than a laptop, smartphone, internet, and Google Earth imagery. Despite the lack of a farm map, the farmer was able to take the coordinates of the features on the ground, such as boreholes, residential buildings, and chicken houses.

Farm Eight (F8) is a commercial farm with a size of 102 hectares located in the Ekurhuleni metropolitan municipality. The farmer is farming maize and there was a blackjack invasion in the maize field at the time of the visit. Technologies such as harvesters, smartphones, the internet, Google Earth imagery, and a map are used by the farmer.

4.28. A comparison of the results of this study with those of other studies

The disparities in the uptake of 4IR technology, ICT, GIS, and RS technologies by smallholder and commercial farmers was indicated by Engås et al. (2023), the digital divide led to low adoption of digital technologies. Moreover, FAO (2020) points out that to maximize the benefits of digital technologies, it is crucial to consider the digital divide in capacities, competences, and access in all three levels. 4IR has been adopted by most farmers with post-matriculation qualifications, followed by those with grade 12 or standard 10 qualifications. Consequently, 4IR technology uptake is influenced by education level. Singh and Kaur (2021) conclude that farmers' perceptions towards digital technologies are strongly influenced by factors such as their education. Moreover, Schulze Schwering et al. (2022) attests that openness to technologies is related to educational levels.

In this study, commercial farmers were able to afford more 4IR technologies than smallholder farmers. This was supported by several other authors who mention that income plays a role in technology adoption and that digital technologies are expensive. Higher income allows access to improved digital technologies, which in turn leads to positive perceptions of digital technologies (Bontsa et al., 2023). Digital technologies were deemed expensive, causing a digital divide, and farmers had little knowledge of them despite improving agricultural productivity (Dlamini and Ocholla, 2018; Mabaya and Porciello 2022 & Bontsa et al., 2023). Strydom (2021) concludes that in developing countries, including Africa, some digital technologies require access to internet connectivity have increased their costs. In some cases, this is disadvantageous to smallholder farmers, as it can lead to large corporations taking over smaller farms and consolidating them (Jeanneaux, 2018).

4.29. Comparing the results of this study with other African countries and the world.

There is a growing recognition that 4IR-based devices and applications like mobile phones, radios, computers, UAVs, cloud computing, and the Internet have the potential to significantly improve farm operations for smallholder farmers (Farayola et al., 2020). In addition to land preparation, crop management, the sourcing of inputs, harvesting, and postharvest management, these technologies can revolutionize smallholder farming (McFadden and Griffin, 2022). As far as smallholder farming is concerned, digitalization services range from simple advisory communication between farmers and experts, such as extension officers using mobile phones, which was also the case in this study, to sophisticated farming management using UAVs and satellites (Tsan et al., 2022). Smallholder farmers can also benefit from the deployment of smart technologies by gaining access to important information, in addition to improving productivity and smoothing operations (Mukhamedova et al., 2022).

Despite the transformative potential of smart technologies, smallholder farmers, particularly in developing countries, particularly in sub-Saharan Africa, have been slow to access and use smart technologies (Nyaga et al., 2021). A wide range of factors have contributed to this, including a lack of finance, limited government support, inadequate education, and inadequate research and development facilities, as well as collateral challenges and cultural and social practices resisting or reluctant to accommodate transformation (Nyaga et al., 2021; FAO, 2022). In this study, affordability and insufficient education also contributed to the low adoption of 4IR by smallholders.

Also in Brazil, many smallholders, a lack of digital skills and a limited ability to use digital tools will remain an obstacle to adoption and it needs to be addressed. While almost 96% of rural producers use cell phones across different states, only 46% use them for Internet access (SEBRAE, 2017). A program that provides low-cost digital devices and locally based Internet access, such as working with cooperatives, along with local training on the use of basic digital tools, might be an effective way of increasing the productivity of poor Brazilian farmers (Welthungerhilfe, 2018).

Due to the difference in scale, western technology and business models do not apply to India. Although there are fewer farmers in the West, they typically own over 1,000 acres of land. A typical Indian farm size of 2 acres does not require products that make sense for such large farmers. A barrier to making small rural farms more efficient and profitable in India has been the cost of mechanizing agriculture. The delivery of technology will be a major challenge for Indian farmers. Due to the high number of small and marginal farmers in India, the government should engage in public-private partnerships with innovative technology providers that follow the build, own, operate, and transfer (BOOT) model to promote the adoption and scale-up of mechanization (World Economic Forum, 2023).

4.30. Summary

The chapter discusses findings from the data collected through survey questionnaires, interviews, and observation. People who participated in the study are farmers from the Gauteng province, as well as officials from GDARD and DALRRD. Both quantitative and qualitative findings were presented, analysed, and interpreted by the researcher. Findings were presented in accordance with the study's objectives. The study's major findings and recommendations are outlined in Chapter 5.

CHAPTER 5: SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

5.1. Introduction

This chapter presents the summary, concluding remarks, and recommendations from this study as well as some suggestions for further research. The aim of study was to evaluate the uptake of ICT, GIS, remote sensing, and 4IR technologies by the agricultural sector in improving food security in the Gauteng province of South Africa. A mixed methods approach (qualitative and quantitative) was employed in this study. This research work was conducted in the Gauteng province, and 156 individuals participated in the study made up of 93 farmers, 49 Agriculture Extension officers, and VETS (Animal Health officials) from GDARD, and 14 DALRRD personnel from Agriculture (Smallholder Development, National Extension Support, and Veterinary Public Health), ICT Development solutions, and Land Use and Soil Management (GIS unit).

The data for the research was collected through survey questionnaires, interviews, and observation. Kernel density estimations (KDE) statistical method and descriptive statistics were used to analyse quantitative data and content analysis was used to analyse qualitative data. Results shows that most commercial farmers have adopted some 4IR technologies while there is a low uptake by smallholders. Another observation is that farmers keep records on their farms both digitally and manually. Officials from GDARD and DALRRD indicate that they have enough tools to assist farmers. The DALRRD has a database of farmers, known as a farmer register. The majority of GDARD officials reported that they experience internet connection challenges when they visit farms in remote areas.

5.2. Summary of key findings

5.2.1 Objective A) To investigate the uptake of ICT, GIS, and 4IR technologies by agricultural support divisions in the government

Officials from both GDARD and DALRRD reported that they receive enough tools to assist farmers; however, they experience challenges with mobile data provided which is not enough for the work they do. From the officials interviewed, 63% of GDARD officials have been using their laptops for less than three years, while 50% of DALRRD have used their laptops for more than five years. A majority of GDARD participants (N=47) feel that gadgets such as robust tablets and a single system integrating all systems can simplify their work.

Both DALRRD and GDARD support farmers with smartphones and laptops, among other technologies and equipment. UAVs are used by 15.38% of DALRRD officials to assist farmers, although GDARD currently does not make use of this technology. Moreover, 71% of GDARD employees experience internet connection challenges when they visit farms, and they are unable to use a tablet or phone to capture information when they visit remote areas. Furthermore, DALRRD has a database of farmers, known as a farmer register. It is collected primarily by the province's agriculture departments, with assistance from DALRRD.

GIS applications, GIS software, GPS instruments, and satellite images are used by DALRRD and GDARD officials. Participants indicate that they also make use of the Natural Agricultural Resources of South Africa Atlas. This atlas is available to the public and contains layers such as soil, geological, weather, vegetation, land cover and use, agriculture capability and potential, and protected agricultural areas (PAA). GDARD GIS professionals integrate a variety of spatial data types, such as satellite images, topography, soil characteristics, weather data, and land use information. By combining these datasets together, officials create comprehensive maps for farmers to help them in their planning of planting and harvesting operations. The DALRRD and GDARD GIS officials also process satellite imagery using remote sensing software such as ENVI and ERDAS to predict crop yields and farmers use this information for harvest planning, storage, and market forecasting.

5.2.2 Objective B) To assess and map the uptake of ICT and 4IR technologies by smallholder farmers.

There is a high adoption rate of 4IR technologies by participants in the eastern part of Gauteng, there is moderate adoption rate on the Southern side. Western, central, and Northern parts of Gauteng have low adoption rates. From smallholder participants, one farmer has adopted more than four technologies, whereas most farmers adopted a single technology followed by those who are not using any 4IR technology, and those who are using two technologies.

For smallholder farmers, the most used technology is internet of things such as IoT sensors (electrochemical, temperature, and humidity), wireless security systems, and smartphones with 5G and WIFI connectivity, followed by smart farming, and then big data. Vertical farming, transportation technology, UAVs, and artificial intelligence are also used by smallholder farmers. Results further show that robotics are not yet used by smallholder farmers. There were 22% of smallholder farmers who said that they were using other technologies such as GPS and Google Earth, however, most farmers did not specify which other technologies they were using.

Two smallholder farms were observed, in one of the farms there was no ICT and 4IR technology which was being used. The farmer did not have a smartphone and it was difficult to navigate to the farm as the farmer was unable to share the farm location. On the other farm, the farmer was using smart phones and the internet. Findings from the survey and observation had similarities, they both indicate that fewer smallholder farmers use 4IR technologies.

5.2.3 Objective C) To assess and map the uptake of ICT and 4IR technologies by Large- scale farmers.

There is a high adoption rate of 4IR technologies by participants in the southwestern part of Gauteng. In contrast, there is moderate adoption rate in the north. The eastern part of Gauteng has low adoption rates. Commercial agriculture dominates the southern sectors of the province (part of South Africa's maize triangle), while cotton, groundnuts, and sorghum are grown near Bronkhorstspruit (east) and Heidelberg (south) (Global African Network, 2021). Agricultural technologies, such as precision agriculture, can increase yields on major crops such as maize. It is possible that cotton, groundnuts, and sorghum require different growth conditions. 4IR technologies have economic viability depending on crop profitability in a region. In some cases, farmers may invest in advanced technologies because maize has a higher market demand and a better return on investment. The general observation is that 4IR adoption rates can be affected by farmers' awareness and familiarity with the technologies.

In the central part of Gauteng, 4IR technology has not been adopted, this could be attributed by the fact that there were no participants from this region. All participants who have adopted five different technologies are from the southwestern part of Gauteng. It is mainly smart farming and internet of things that are used by commercial farmers.

The Internet of Things (IoT) such as smartphones, thermostats, home security systems, and RFID tags are mainly used in the southwestern part of Gauteng. To control greenhouses, livestock, or warehouse temperatures, farmers use thermostats. Farmers use home security systems to restrict and monitor access to their farms. Agricultural assets such as livestock, packaging, and trucks are tracked and monitored through RFID tags. The use of smartphones by farmers includes tracking equipment, crops, and livestock remotely, as well as collecting statistics on feed and produce for the livestock.

Other technologies that are being used in the southwestern and north part of Gauteng includes sensor technology (irrigation, soil moisture, and weather sensors), transportation technology (self-driving tractors), UAVs, robotics, and vertical farming. Big data and artificial intelligence are not used by any commercial farmers. Farmers use UAVs to survey their lands, conduct field analyses, and generate real-time data. Furthermore, commercial farmers mentioned they use other technologies, such as GPS, geological apps, Google Earth, and wireless security cameras. Of the six commercial farms observed the researcher did not notice any 4IR technologies being used by the farmers, however, farmers were using 2nd and 3rd industrial technologies such smartphones, laptop, internet, tractors, harvester’s, Google Earth images, and maps.

5.2.4 Objective D) Assess the implementation of GIS and RS in local farms including support.

92.85% of commercial farmers reported that they use GIS and RS technologies, and only 38% of smallholder farmers use these geospatial technologies. Commercial and smallholder farmers use GIS and RS, such as maps from the Surveyor General’s office and Agriculture departments, and satellite images from Google Earth. As a result of these tools, farmers are gaining valuable insights into their fields and operations. Reportedly, the information provided by maps is used to allocate resources and make informed decisions based on soil quality, topography, and land potential. Satellite images from Google Earth help farmers monitor changes on their farms, identify potential issues, and plan the best time to plant and harvest. Some of the technologies that are being used by commercial and smallholder farmers are cameras, GPS ear tags, UAVs, temperature sensors, humidity sensors, and smartphones. Eight farms were observed within the Gauteng province by the researcher.

The researcher noted that some of the farmers found it difficult to provide their farm coordinates, but most of them were using smartphones, so they knew how to do so. About half of the farmers had maps of their farms, which they received from GDARD and DALRRD.

Thirteen commercial farmers reported that they are getting support from the government. Despite this, no commercial farmers reported receiving government support for 4IR technologies. Currently, commercial farmers only receive extension services, veterinary services, agriculture workshops, and the opportunity to attend farming conferences. A majority (61%) of smallholder farmers reported that they do not receive any government assistance, 38% said they did receive assistance, and 1% did not answer. Results show that smallholder farmers also do not receive government support for 4IR technologies. They receive support for extension and veterinary services, agricultural workshops, disease outbreak alerts, study groups, and development programs.

Moreover, farmers need a workshop on how to care for their farm, market the product, and training on 4IR technologies. Small holder farmers were not happy that government officials just visit their farms and promise that they will come back. During observation, one small holder farmer was unsatisfied with the fact that the government official promised a fence for his farm, but it has not yet been erected. Small holder farmers also reported that they need government officials who have a passion for agriculture.

5.2.5 Objective E) To assess and map the underlying conditions that promote or discourage the uptake of ICT, GIS, RS, and 4IR in Gauteng.

Many commercial farmers have adopted 4IR technologies, perhaps due to their ability to afford them. Lack of funds may explain the low uptake by smallholder farmers. Out of the 77 farmers who reported using 4IR technologies, 47 of them had post-matriculation qualifications. According to some farmers, this 4IR technology will only benefit commercial farmers since smallholders cannot afford it. A recurring observation from this study was that a lack of training and exposure on the use of e-service marketing apps, interpret maps, Google Earth Pro applications, and satellite images analysis may also discourage the uptake of ICT, GIS, RS, and 4IR by farmers in general.

5.3. Concluding Remarks

5.3.1 Objective A) To investigate the uptake of ICT, GIS, and 4IR technologies by agricultural support divisions in the government.

Findings from this study show that the GDARD and DALRRD departments provide their officials with 4IR enabling tools such as smartphones, robust tablets, and laptops. However, mobile data provided to GDARD officials is not enough to last them a month. Although officials complain about poor internet connectivity when they visit farms located in remote areas, the systems they are using to capture information can work offline, they can sync the data when they re-connect to the internet upon arriving back to their offices. The GDARD officials are using too many systems, which leads to duplication of information and efforts since some systems are rolled out to provinces by DALRRD. The DALRRD's farmer register roll-out was a positive step. Now there is a national farmer database, although many farmers still need to be added to this database. With the help of the farmer register information, the departments will be able to plan their support for farmers and allocate resources accordingly. Another interesting fact is that farmer register data was collected electronically.

The use of ICT, GIS, and 4IR technologies by GDARD and DALRRD officials is very low. For instance, GDARD does not use drone technology in agriculture, which is essential for monitoring farms and spraying crops. Agricultural officials cannot assist farmers with 4IR technologies if they themselves do not use them or have no knowledge about them. There are some officials at GDARD and DALRRD who are not aware of systems available for profiling farmers and sending alerts to farmers about diseases or disasters. This is just an indication that induction and system awareness are not being done in these departments.

5.3.2 Objective B) To assess and map the uptake of ICT and 4IR technologies by smallholder.

In Gauteng, most smallholder farmers use 2nd and 3rd industrial technologies instead of 4IR technologies. There is high adoption rate of 4IR technologies by participants in the eastern part of Gauteng and a moderate adoption rate on the Southern side part of the province.

The Western, central, and Northern part of Gauteng has low adoption rates. Of the smallholder participants, there is one farmer who has adopted more than 4 technologies, many farmers have adopted one technology followed by those who are not using any 4IR technology, and those who are using two technologies. For smallholder farmers, the most used technology is the internet of things such as smartphones, and network connectivity such as 5G and WIFI, wireless camera system, and IoT Sensors (electrochemical, temperature, and humidity). Followed by smart farming, and then big data. Many smallholder farmers are not aware of how 4IR technologies can impact agriculture. This just shows that the government is not investing in 4IR technologies for the smallholder farmers to benefit from using these technologies. There were similarities in findings from the survey and observation. Smallholder farmers are still lagging when it comes to technology, as some cannot afford smartphones and tractors.

5.3.3 Objective C) To assess and map the uptake of ICT and 4IR technologies by commercial farmers.

There is a high adoption rate of 4IR technologies by participants in the southwestern part of Gauteng and this area is known as South Africa's maize triangle. These commercial farmers could be using these 4IR technologies to increase the production of maize. However, there is a contrast, there is moderate adoption rate in the north. The south-eastern part of Gauteng has low adoption rates. In the central part of Gauteng, 4IR technology has not been adopted, as there were no participants, but this could be attributed to the fact that as there were no participants from this region. All participants who have adopted 5 different technologies are from the Southwestern part of Gauteng.

The Internet of Things (IoT) like smartphones, thermostats, home security systems, and RFID tags are mainly used. Other technologies that are being used include sensor technology (irrigation, soil moisture, and weather sensors) and transportation technology (self-driving tractors). Additionally, commercial farmers are using UAVs, robotics, and vertical farming. Big data and artificial intelligence are not used by any commercial farmers. Furthermore, commercial farmers mentioned that they use other technologies, such as GPS, geological apps, Google Earth, wireless security cameras, and sensors. In the six commercial farms observed, the researcher did not see any 4IR technology being used by the farmers, but he did see them using 2nd and 3rd industrial technologies such as smartphones, laptops, internet, tractors, harvesters, Google Earth images, and maps.

It is possible that the results differ from the research questionnaire because the researcher was only observing, and the farmers could be using other 4IR technologies which the researcher is not aware of.

5.3.4 Objective D) Assess the implementation of GIS and RS in local farms including support.

Both departments do not have GIS and RS systems in place that can provide farmers with information to help them improve their harvest. This shows that in South Africa the adoption of 4IR by departments is moving at a slower pace, by now there should be GIS and RS applications that farmers can use in their farms. However, farmers do receive updates from GDARD and DALRRD about drought, floods, and storms, which are gathered from SAWS. VETS and extension officers also inform farmers about disease outbreaks.

92.85% of commercial farmers mention that they are using these GIS and RS technologies, and only 38% of smallholder farmers use it. Small and commercial farmers both use GIS and RS, like maps from Agriculture departments and satellite images from Google Earth. Using these tools, farmers gain valuable insights into their fields and operations. Based on soil quality, topography, and land potential, maps can be used to allocate resources and make informed decisions. Farmers use Google Earth to monitor changes on their farms, identify potential issues, and plan planting and harvesting times.

Most commercial farmers receive support from the government, but only a few smallholder farmers do. Government is neglecting smallholder farms, those who need the most help to expand their farming business and improve their productivity. It is evident that the government still has much work to do for smallholder farmers. In some cases, government officials visit the farms, make promises, and fail to fulfil them, leading to dissatisfaction among smallholders. Smallholder farmers are also dissatisfied because some officials do not seem passionate about farming.

5.3.5 Objective E) To assess and map the underlying conditions that promote or discourage the uptake of ICT, GIS, RS, and 4IR in Gauteng.

Affordability could be one of the main reasons for the higher adoption of 4IR technology, ICT, GIS, and RS technologies by commercial farmers compared to smallholder farmers. Smallholder farmers who do not use any technology on their farms may not even have smartphones. Furthermore, they lack access to internet-based farming information.

4IR has been adopted by most farmers with post-matriculation qualification, followed by those with grade 12 or standard 10 qualifications. The results above indicate that education level influences the uptake of 4IR technologies. An assessment was conducted to examine the adoption of 4IR technologies in areas with low and high agricultural potential. Based on the results it is not possible to tell whether there will be uptake or non-uptake based on the potential of the land. The researcher noticed that smallholder farmers are mostly located in built-up areas.

During observation, the researcher noticed that half of the farmers have maps of their farms and were able to take coordinates of the features within their farms. However, there were also half of the farmers who did not even have maps of their farms and were unable to take coordinates of the features within their farms. The researcher concluded that lack of exposure and training can impact the uptake and non-uptake of e-services marketing apps, maps, Google Earth Pro, and satellite images.

5.4. Recommendations

5.4.1 Recommendation 1. Adoption of an integrated system by agriculture officials and farmers.

GDARD officials are using too many systems such as Survey123 forms, farmer register, epic collector, Agriculture Decision Support System, digital pen solutions and other using manual forms. Using many systems leads to duplication of information and efforts since some systems are rolled out to provinces by DALRRD. The DALRRD's farmer register roll-out was a positive step, this system should be enhanced and be adopted as the only system to be used by DALRRD and all Agriculture provincial departments. There is now a national farmer database, although many farmers need to be added to it.

With the help of farmer register information, the departments will be able to plan their support for farmers and allocate resources accordingly. Another interesting fact is that farmer register data was collected electronically.

The integrated system should cater for GIS and RS interactive maps that farmers can zoom into their farms and assess farm activities using satellite images. Farmers can be able to among other things draw polygons for cultivated areas to estimate harvest and profits. This can help farmers plan how they will market their products, as they will know the quantity they will harvest. Farmers should be able to request services, provide feedback, access farming information, and market their products through an ICT-integrated application developed by GDARD or DALRRD. They can track the status of their request and access weather information without having to travel to the department to request services. Gauteng Broadband Network needs to be rolled out to farm areas. In some farms, network challenges will make accessing this integrated application difficult. Officials should have unlimited mobile data access during working hours to access this application. The delivery of services should not be hindered by data shortages.

5.4.2 Recommendation 2. Promoting the use of ICT, GIS, and 4IR technologies in agriculture.

The use of ICT, GIS, and 4IR technologies by GDARD and DALRRD officials is very low. For instance, GDARD does not use drone technology in agriculture, which is essential for monitoring farms and spraying crops. Agricultural officials cannot assist farmers with 4IR technologies if they themselves do not use them or have no knowledge about them. Both DALRRD and GDARD need to purchase 4IR technologies such as UAVs, sensors, robots, and software and systems for cloud computing (Microsoft Azure), the Internet of Things (IoT smart devices and IoT systems), artificial intelligence, and big data.

To capture high-resolution aerial images of fields, smallholder farmers and commercial farmers should use UAVs equipped with cameras and sensors. Data from these sensors can be used to assess crop health, detect pests and diseases, and improve precision agriculture.

Farmers should also use Internet of Things (IoT) devices such as soil moisture and weather sensors, RFID tags, and GPS collars that can monitor soil moisture, temperature, humidity, and livestock behaviour. As a result of this IoT data, farmers will be able to make timely decisions and optimize resource usage.

Commercial farmers should adopt Big Data analytics tools to process and analyse large volumes of agricultural data, such as historical weather patterns, crop yield data, and market trends. The information helps farmers make more informed decisions about planting, harvesting, and marketing their crops. With GIS technology, farmers can create detailed maps of their fields, showing soil types, moisture levels, and nutrient contents. Planting, irrigation, and fertilization can be guided by these maps, resulting in lower input costs and higher yields.

5.4.3 Recommendation 3. Smallholder farmer awareness programs.

There is a need for DALRRD and GDARD to develop tailored training programs that consider the levels of technological literacy of smallholder farmers. Provide hands-on training and user-friendly guides to ensure the effective adoption of technologies, such as smart devices, UAVs, satellites, and the Internet of Things (sensors, actuators, Agriculture applications such as mobile apps and web portals, RFID tags, GPS collars, and smart traps). The government should facilitate affordable access to the hardware and software required for 4IR, ICT, GIS, and RS. Consider partnering with technology providers, governments, or NGOs to provide farmers with subsidised or free equipment. Also, ensure that training materials are available in local languages. Smallholder farmers will be able to overcome language and literacy barriers because of this.

Promote data privacy and security awareness among farmers, emphasising the importance of safeguarding their data. To assist farmers with technology-related issues, DALRRD and GDARD can establish a reliable technical support system or helpdesk. Maintain farmer confidence by promptly addressing any technical challenges. Agriculture department officials can demonstrate how these technologies can benefit smallholder farmers. Officials can further highlight how 4IR, ICT, GIS, and RS can enhance decision-making and improve crop yields. A vital role can be played by VETS and Extension officers in training and supporting smallholder farmers.

5.4.4 Recommendation 4. Commercial farmer awareness programs.

Agriculture departments should offer advanced 4IR, ICT, GIS, and RS training programs for commercial farmers. Farmers should be encouraged to invest in state-of-the-art technology solutions for large farms, such as GIS mapping, precision agriculture tools, and high-resolution RS images.

To optimise yields, allocate resources, and optimise supply chains, the government should work with commercial farmers to develop customised technology solutions. The use of advanced data analytics and decision support systems should be encouraged to process vast quantities of data generated on commercial farms. To maximise productivity and profitability, these tools can help in making informed decisions. IoT, automation, and precision agriculture should be emphasised as key features of government programs to encourage sustainable farming practices.

It is important for agriculture departments to facilitate networking and collaboration among commercial farmers to share best practices and lessons learned in adopting 4IR, ICT, GIS, and RS technologies. This will lead to industry-wide improvements. Incentives should be provided to encourage commercial farmers to utilise IoT and ICT to optimise their supply chains, from production to distribution. The food supply chain can become more efficient and reliable as a result. Due to the increased use of digital technologies, it will be necessary to emphasise the importance of robust cybersecurity measures. Commercial farmers should invest in cybersecurity solutions to protect their data and operations. To ensure continued success and competitiveness, agriculture departments should assist commercial farmers in developing long-term sustainability plans that incorporate technology adoption.

5.4.5 Recommendation 5. The government should not neglect smallholder farms.

Agricultural departments as part of their extension duties could provide drone and other services to smallholder farmers. Thus, bridging the gap on affordability by smallholder farmers and commercial farmers. Agriculture departments should allocate more resources to support smallholder farmers so they can grow their businesses. These includes infrastructure development, access to credit, and technology transfers.

Agricultural extension services should provide smallholder farmers with training, knowledge, and technical support in 4IR, ICT, GIS, and RS. In addition, modern farming techniques, sustainable practices, and market access should be covered. Identify and facilitate market opportunities for smallholders, including cooperatives and value chains. Make seeds, fertilizers, and pesticides more affordable for smallholders by providing subsidies. Promote climate-smart agriculture, provide weather information, and support disaster preparedness among smallholders.

There is a need for research and development that caters to smallholder farmers' needs. Educate smallholder farmers about financial literacy, cooperative formation, and entrepreneurship to empower them to make informed business decisions. Monitoring and evaluating government programs aimed at smallholder farmers is essential for assessing their effectiveness. Implementing these recommendations can help alleviate the neglect of smallholder farms and promote a conducive environment for growth and productivity, thereby contributing to food security.

5.4.6 Recommendation 6. Awareness campaigns and training.

There is a need for agriculture departments to develop customised training programs for government veterinarians, extension officers, ICT, and GIS officials. Facilitate practical, hands-on workshops and field demonstrations to enable participants to gain practical experience using 4IR, ICT, GIS, and RS, so the officials can the share this knowledge with farmers. Agriculture officials need to be trained on 4IR technologies and practices including vertical farming, blockchain, artificial intelligence, UAVs, cloud computing, big data, sensors, and Internet of Things, as adoption by the farmers is low and not being utilised to its full potential. Agricultural officials cannot assist farmers with 4IR technologies if they themselves do not use them or are not familiar with them. In addition, there is also need for awareness of how automated UAVs can be useful in determining crop yield and crop health using NDVI images. The government should encourage ICT and GIS officials to develop user-friendly apps and tools tailored to the needs of farmers and extension services.

5.5. Conclusion of the chapter

This chapter presents a summary of the research findings and conclusions, along with appropriate recommendations. GDARD and DALRRD officials have adequate tools, including recent laptops, but face challenges with insufficient mobile data. They use GIS applications, GIS software, GPS instruments, and satellite images, and suggest robust tablets and an integrated system for efficiency. Research findings indicate that commercial farmers have high 4IR technology adoption due to affordability, while smallholder farmers' uptake is low due to financial and educational constraints. The study recommends adopting an integrated system by agriculture officials and farmers, promoting ICT, GIS, and 4IR technologies in agriculture, and implementing awareness programs for both smallholder and commercial farmers. It emphasizes that the government should not neglect smallholder farms and suggests conducting awareness campaigns and training programs. Additionally, future research should be conducted in other provinces to address the limitations of this study.

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APPENDICES

Appendix A: GDARD (Veterinarian, Extension, and advisory officials') questionnaire

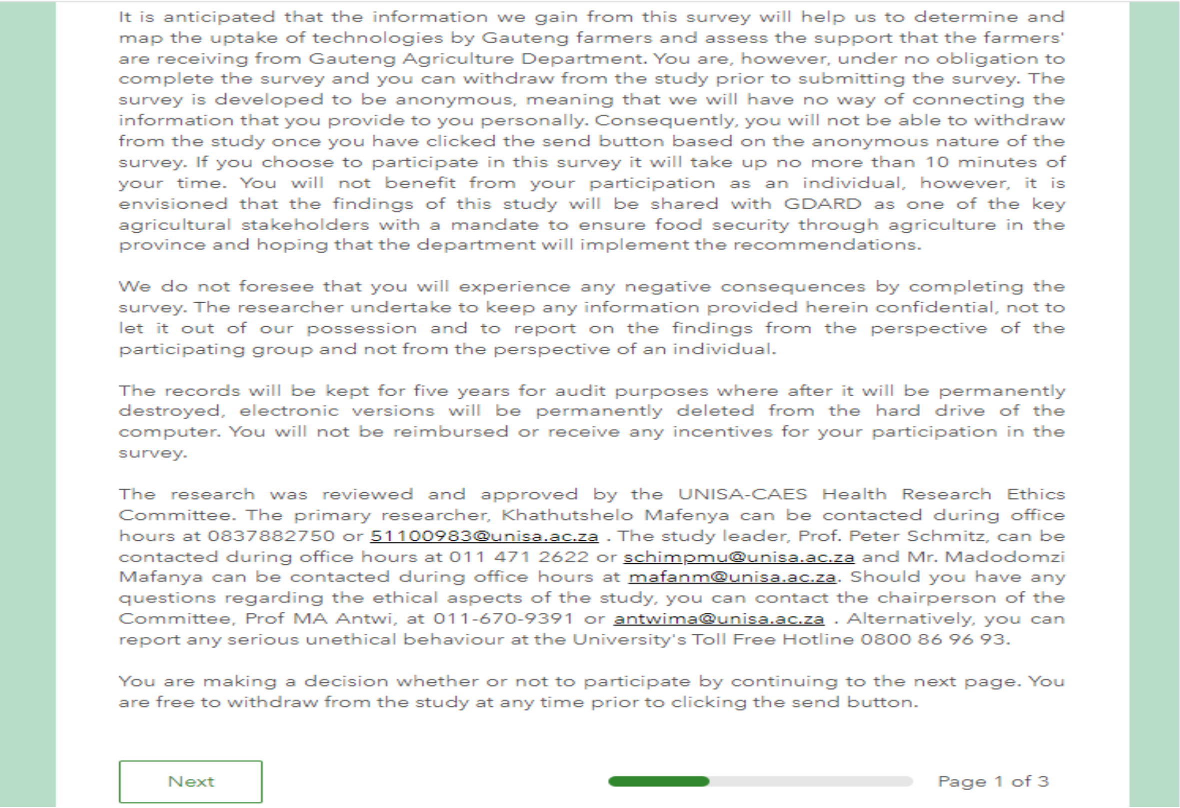
Informed Consent Sheet

Ethical clearance #:2021/CAES_HREC/160
Research permission #: GDARD permission letter

COVER LETTER TO AN ONLINE ANONYMOUS WEB-BASED SURVEY

You are invited to participate in a survey conducted by Mr. Khathutshelo Mafenya under the supervision of Prof. Peter Schmitz, an associate professor and Mr. Madodomzi Mafanya, lecturer in the Department of Geography towards a MA at the University of South Africa.

The survey you have received has been designed to determine the uptake of Information Communication Technology (ICT), Geographic Information System (GIS), Remote Sensing (RS) and Fourth Industrial Revolution (4IR) technologies in improving food security through agricultural sector in Gauteng, South Africa. You were selected to participate in this survey because of your knowledge in the Agricultural industry in the Gauteng Province. You will not be eligible to complete the survey if you are younger than 18 years and if your farm is outside Gauteng Province. By completing this survey, you agree that the information you provide may be used for research purposes, including dissemination through peer-reviewed publications and conference proceedings.



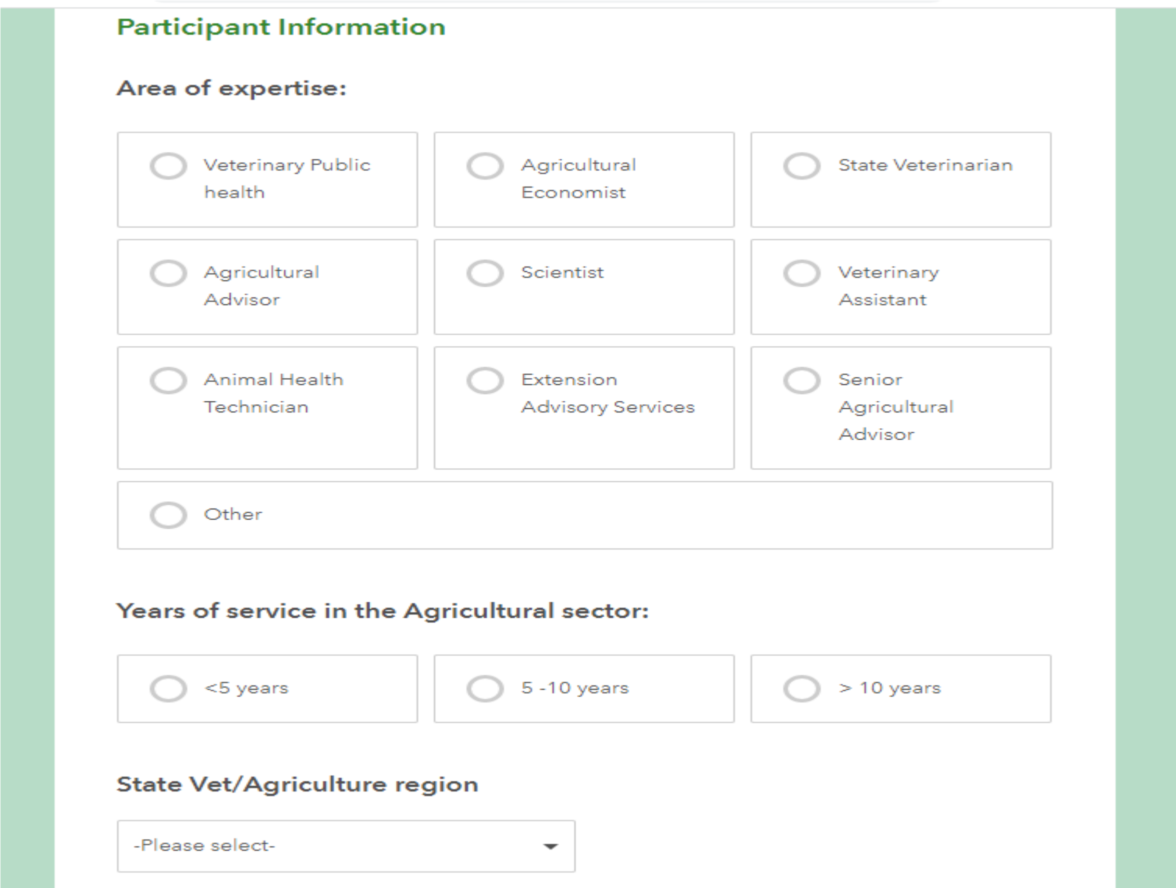
It is anticipated that the information we gain from this survey will help us to determine and map the uptake of technologies by Gauteng farmers and assess the support that the farmers' are receiving from Gauteng Agriculture Department. You are, however, under no obligation to complete the survey and you can withdraw from the study prior to submitting the survey. The survey is developed to be anonymous, meaning that we will have no way of connecting the information that you provide to you personally. Consequently, you will not be able to withdraw from the study once you have clicked the send button based on the anonymous nature of the survey. If you choose to participate in this survey it will take up no more than 10 minutes of your time. You will not benefit from your participation as an individual, however, it is envisioned that the findings of this study will be shared with GDARD as one of the key agricultural stakeholders with a mandate to ensure food security through agriculture in the province and hoping that the department will implement the recommendations.

We do not foresee that you will experience any negative consequences by completing the survey. The researcher undertake to keep any information provided herein confidential, not to let it out of our possession and to report on the findings from the perspective of the participating group and not from the perspective of an individual.

The records will be kept for five years for audit purposes where after it will be permanently destroyed, electronic versions will be permanently deleted from the hard drive of the computer. You will not be reimbursed or receive any incentives for your participation in the survey.

The research was reviewed and approved by the UNISA-CAES Health Research Ethics Committee. The primary researcher, Khathutshelo Mafenya can be contacted during office hours at 0837882750 or 51100983@unisa.ac.za . The study leader, Prof. Peter Schmitz, can be contacted during office hours at 011 471 2622 or schimpmu@unisa.ac.za and Mr. Madodomzi Mafanya can be contacted during office hours at mafanm@unisa.ac.za. Should you have any questions regarding the ethical aspects of the study, you can contact the chairperson of the Committee, Prof MA Antwi, at 011-670-9391 or antwima@unisa.ac.za . Alternatively, you can report any serious unethical behaviour at the University's Toll Free Hotline 0800 86 96 93.

You are making a decision whether or not to participate by continuing to the next page. You are free to withdraw from the study at any time prior to clicking the send button.



Participant Information

Area of expertise:

○ Veterinary Public health

○ Agricultural Economist

○ State Veterinarian

○ Agricultural Advisor

○ Scientist

○ Veterinary Assistant

○ Animal Health Technician

○ Extension Advisory Services

○ Senior Agricultural Advisor

○ Other

Years of service in the Agricultural sector:

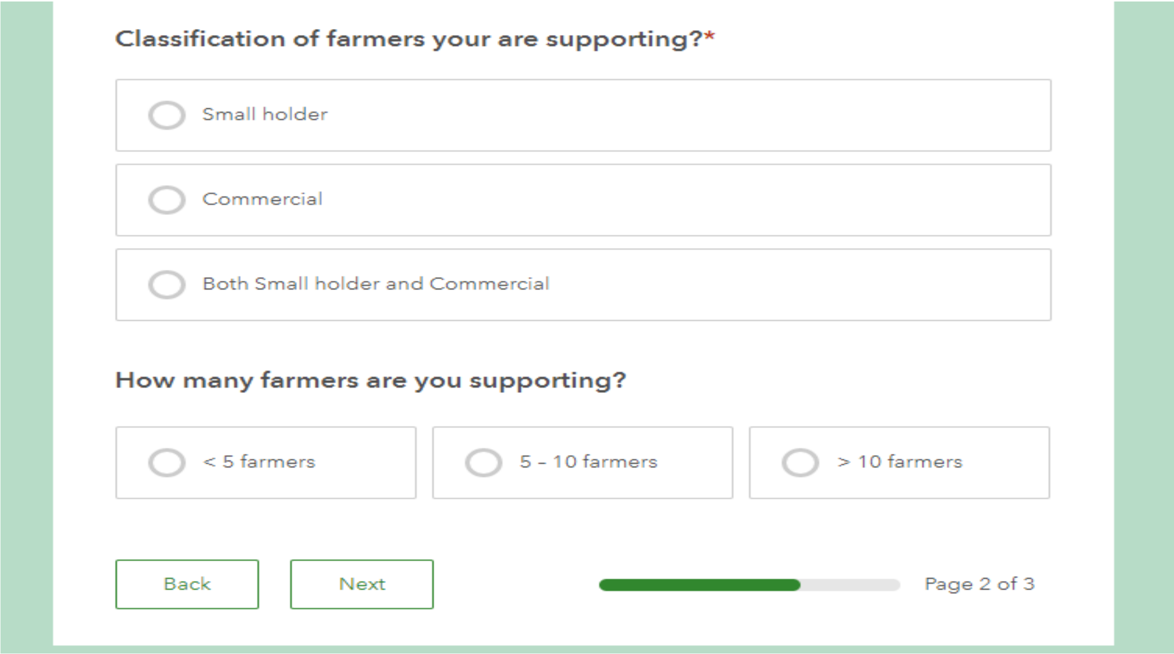
○ <5 years

○ 5 -10 years

○ > 10 years

State Vet/Agriculture region

-Please select-



Classification of farmers your are supporting?*

○ Small holder

○ Commercial

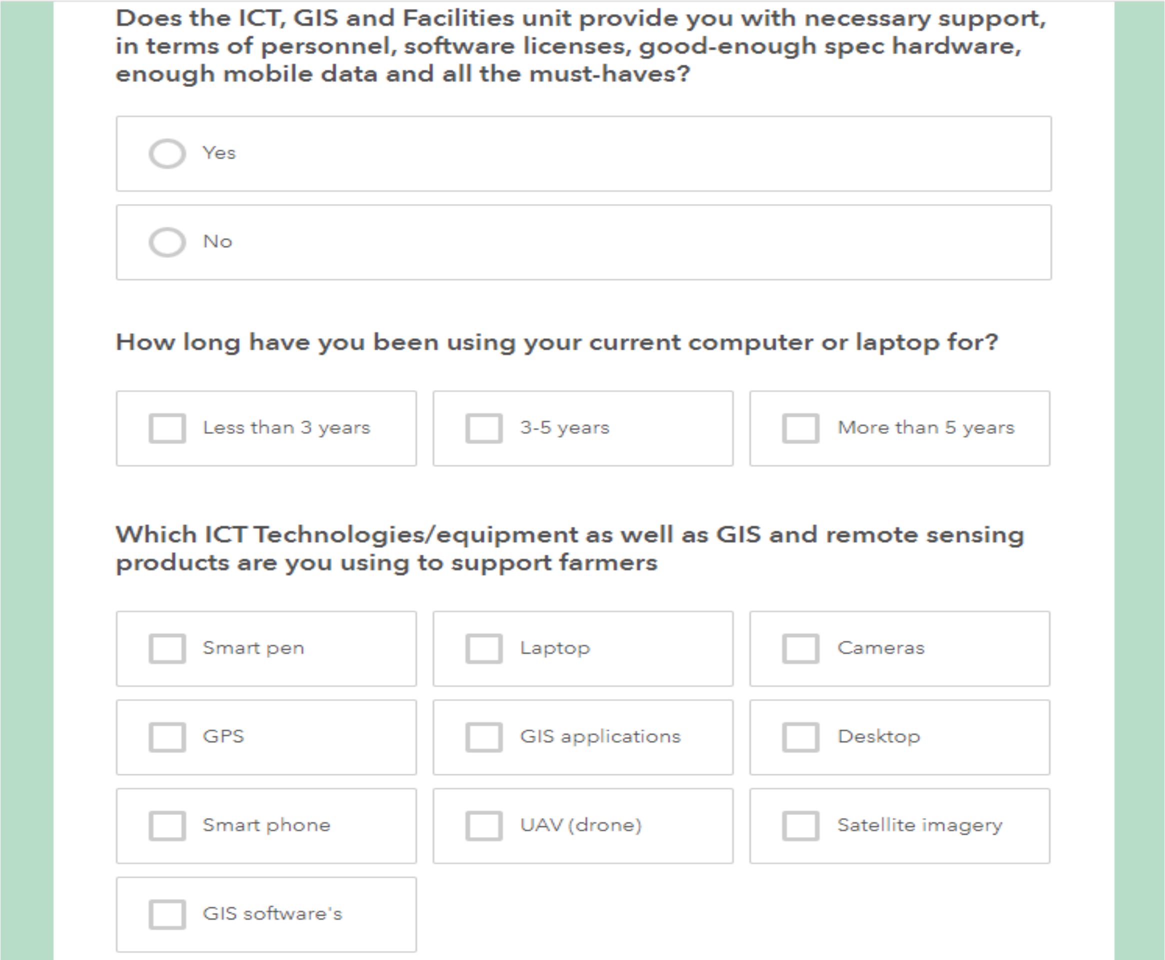
○ Both Small holder and Commercial

How many farmers are you supporting?

○ < 5 farmers

○ 5 - 10 farmers

○ > 10 farmers



Does the ICT, GIS and Facilities unit provide you with necessary support, in terms of personnel, software licenses, good-enough spec hardware, enough mobile data and all the must-haves?

○ Yes

○ No

How long have you been using your current computer or laptop for?

☐ Less than 3 years ☐ 3-5 years ☐ More than 5 years

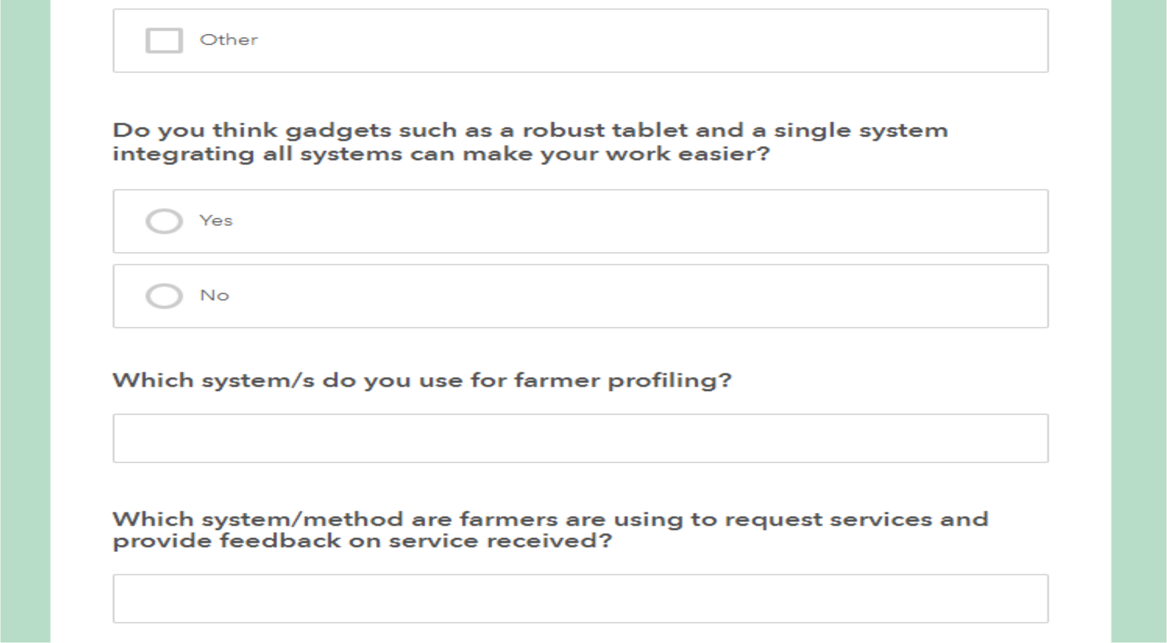
Which ICT Technologies/equipment as well as GIS and remote sensing products are you using to support farmers

☐ Smart pen ☐ Laptop ☐ Cameras

☐ GPS ☐ GIS applications ☐ Desktop

☐ Smart phone ☐ UAV (drone) ☐ Satellite imagery

☐ GIS software's



☐ Other

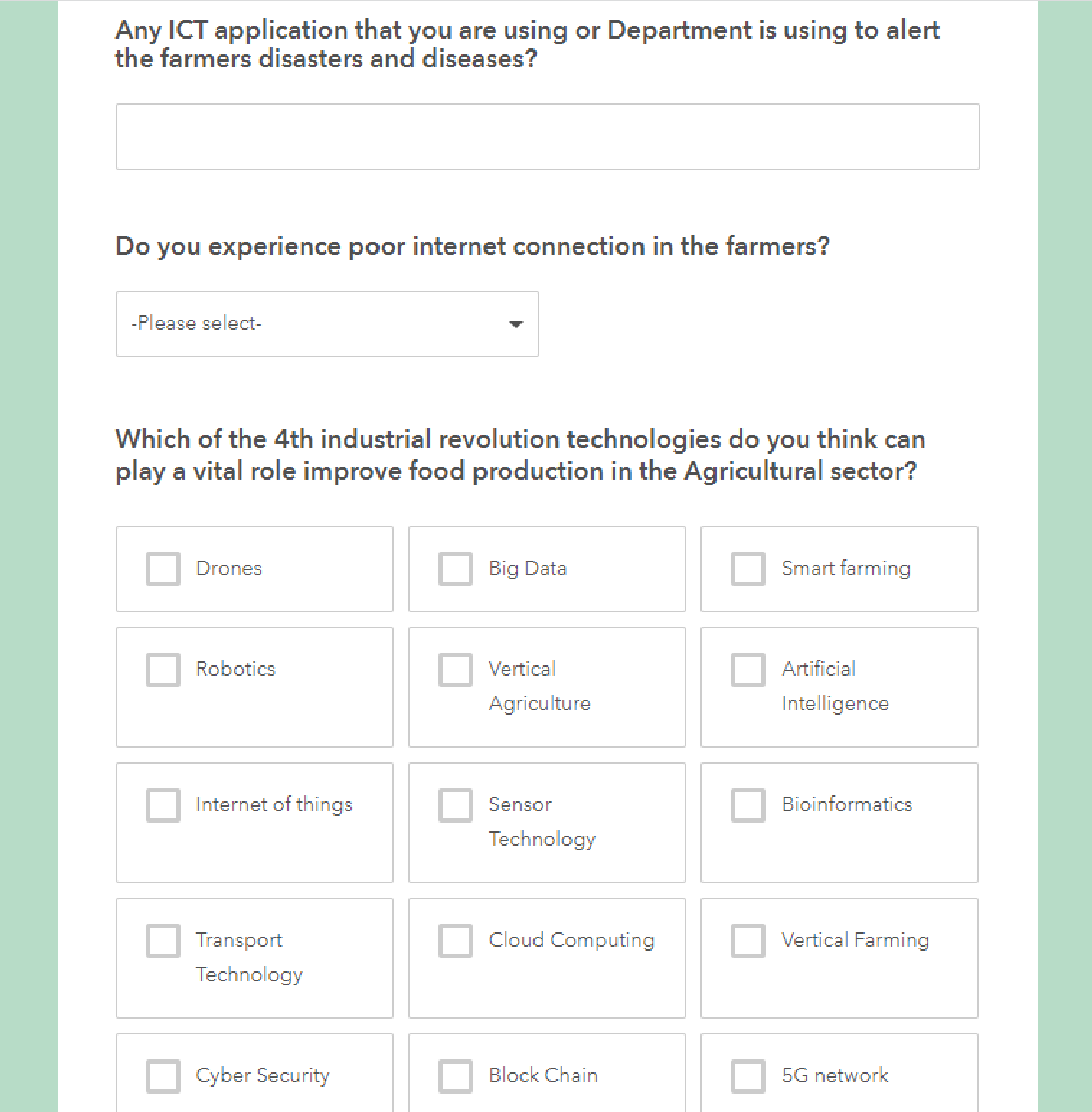
Do you think gadgets such as a robust tablet and a single system integrating all systems can make your work easier?

○ Yes

○ No

Which system/s do you use for farmer profiling?

Which system/method are farmers are using to request services and provide feedback on service received?



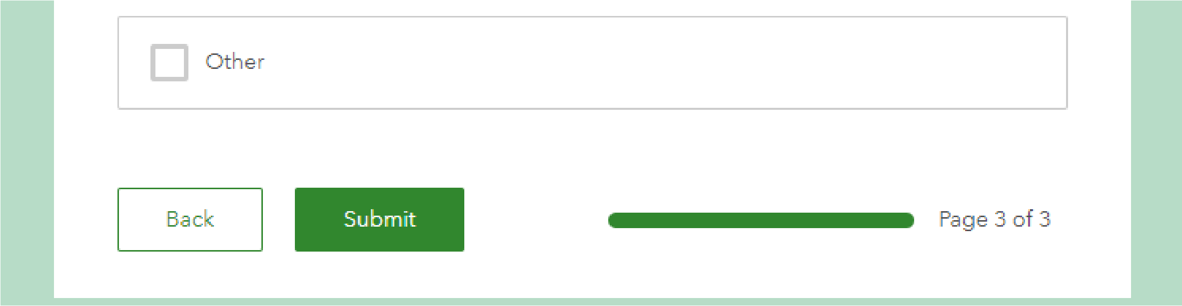
Any ICT application that you are using or Department is using to alert the farmers disasters and diseases?

Do you experience poor internet connection in the farmers?

-Please select-

Which of the 4th industrial revolution technologies do you think can play a vital role improve food production in the Agricultural sector?

☐ Drones
☐ Big Data
☐ Smart farming
☐ Robotics
☐ Vertical Agriculture
☐ Artificial Intelligence
☐ Internet of things
☐ Sensor Technology
☐ Bioinformatics
☐ Transport Technology
☐ Cloud Computing
☐ Vertical Farming
☐ Cyber Security
☐ Block Chain
☐ 5G network



☐ Other

Appendix B: DALRRD Interview Questions

Informed Consent Sheet

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Ethical clearance #:2021/CAES_HREC/160
Research permission #: 2/14/1/P

COVER LETTER TO AN ONLINE ANONYMOUS WEB-BASED SURVEY

You are invited to participate in a survey conducted by Mr. Khathutshelo Mafenya under the supervision of Prof. Peter Schmitz, an associate professor, and Mr. Madodomzi Mafanya, lecturer in the Department of Geography towards a MA at the University of South Africa.

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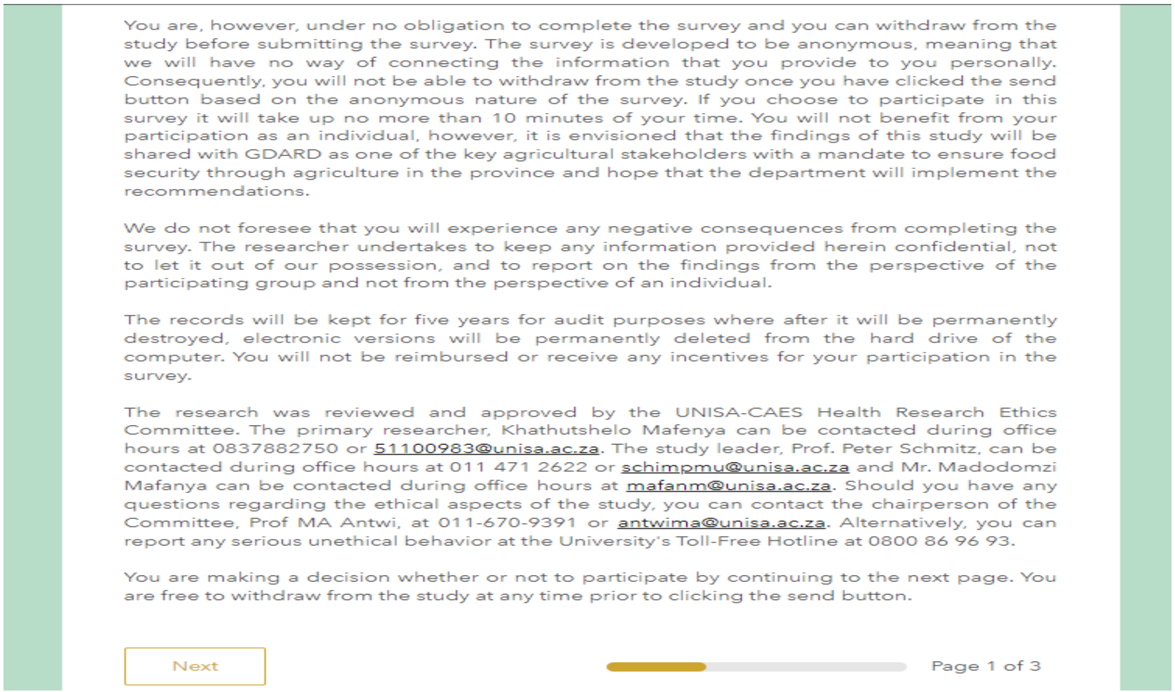
It is anticipated that the information we gain from this survey will help us to determine and map the uptake of technologies by Gauteng farmers, and assess the support that the farmers' are receiving from Gauteng Agriculture Department. It will further help us to assess the uptake of ICT and GIS by Agriculture personnel (people who work for the National department of agriculture and Gauteng including actual government departments, do they have a GIS section, how functional is it, personnel, software, hardware, are these departments and their people GIS enabled?)



You are, however, under no obligation to complete the survey and you can withdraw from the study before submitting the survey. The survey is developed to be anonymous, meaning that we will have no way of connecting the information that you provide to you personally. Consequently, you will not be able to withdraw from the study once you have clicked the send button based on the anonymous nature of the survey. If you choose to participate in this survey it will take up no more than 10 minutes of your time. You will not benefit from your participation as an individual, however, it is envisioned that the findings of this study will be shared with GDARD as one of the key agricultural stakeholders with a mandate to ensure food security through agriculture in the province and hope that the department will implement the recommendations.

We do not foresee that you will experience any negative consequences from completing the survey. The researcher undertakes to keep any information provided herein confidential, not to let it out of our possession, and to report on the findings from the perspective of the participating group and not from the perspective of an individual.

The records will be kept for five years for audit purposes where after it will be permanently destroyed, electronic versions will be permanently deleted from the hard drive of the computer. You will not be reimbursed or receive any incentives for your participation in the survey.

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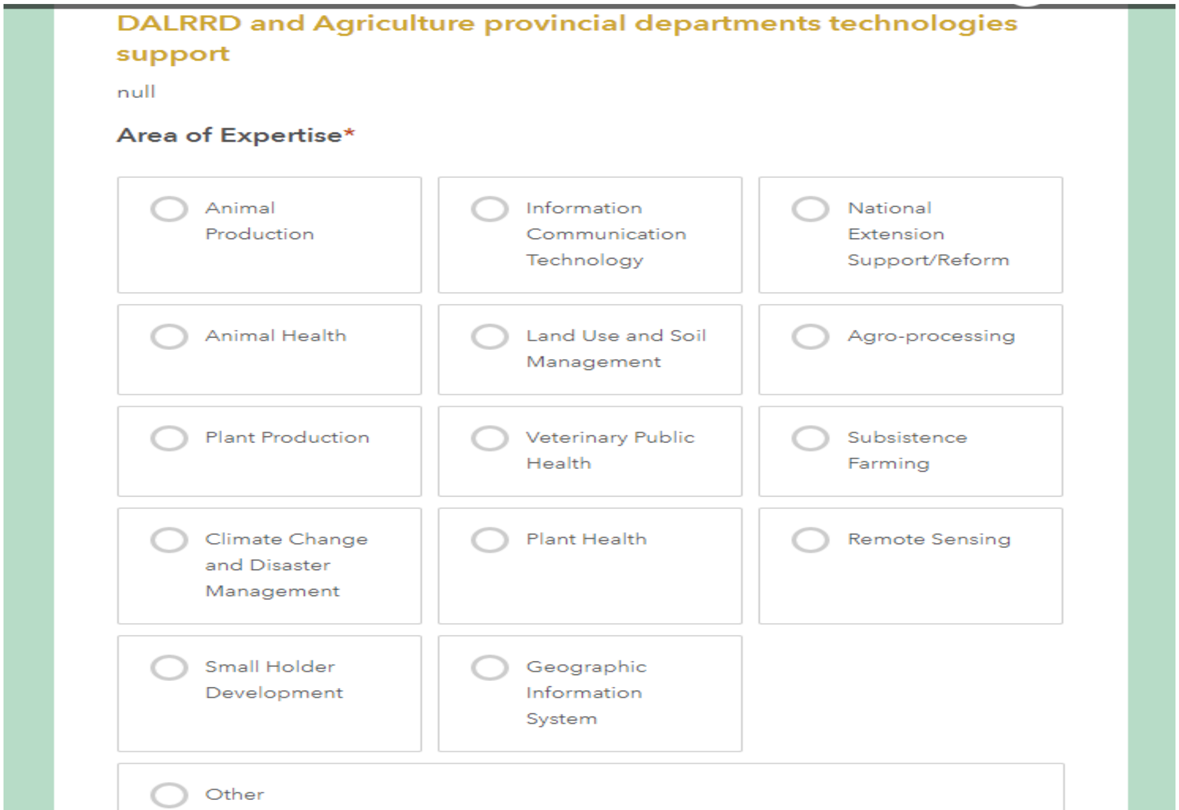
You are making a decision whether or not to participate by continuing to the next page. You are free to withdraw from the study at any time prior to clicking the send button.



DALRRD and Agriculture provincial departments technologies support

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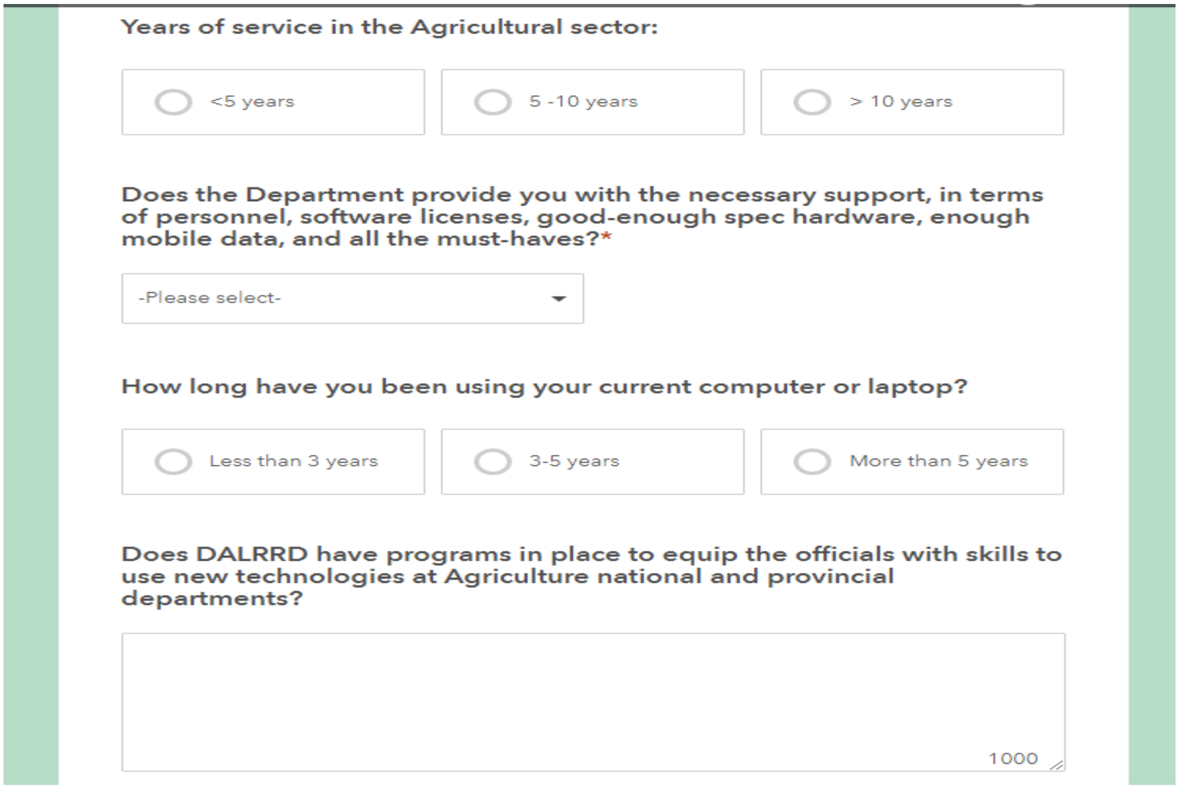
Area of Expertise*

- ○ Animal Production
- ○ Information Communication Technology
- ○ National Extension Support/Reform
- ○ Animal Health
- ○ Land Use and Soil Management
- ○ Agro-processing
- ○ Plant Production
- ○ Veterinary Public Health
- ○ Subsistence Farming
- ○ Climate Change and Disaster Management
- ○ Plant Health
- ○ Remote Sensing
- ○ Small Holder Development
- ○ Geographic Information System
- ○ Other



Years of service in the Agricultural sector:

○ <5 years ○ 5 -10 years ○ > 10 years

Does the Department provide you with the necessary support, in terms of personnel, software licenses, good-enough spec hardware, enough mobile data, and all the must-haves?*

-Please select-

How long have you been using your current computer or laptop?

○ Less than 3 years ○ 3-5 years ○ More than 5 years

Does DALRRD have programs in place to equip the officials with skills to use new technologies at Agriculture national and provincial departments?

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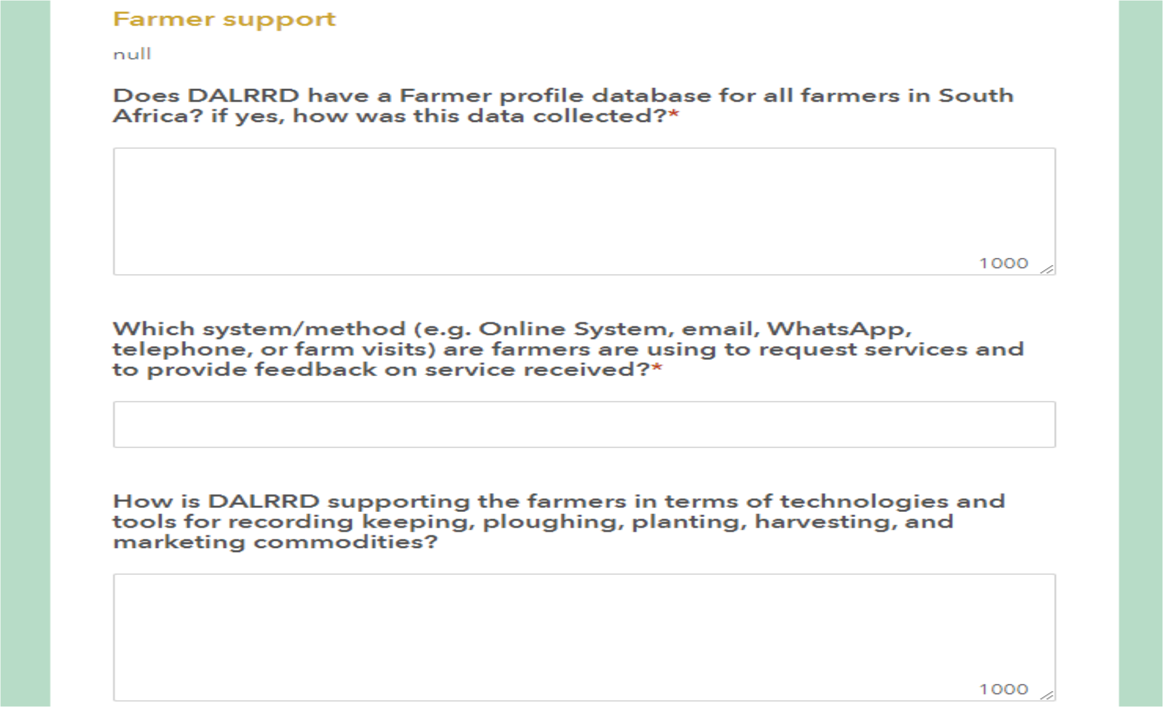

Farmer support

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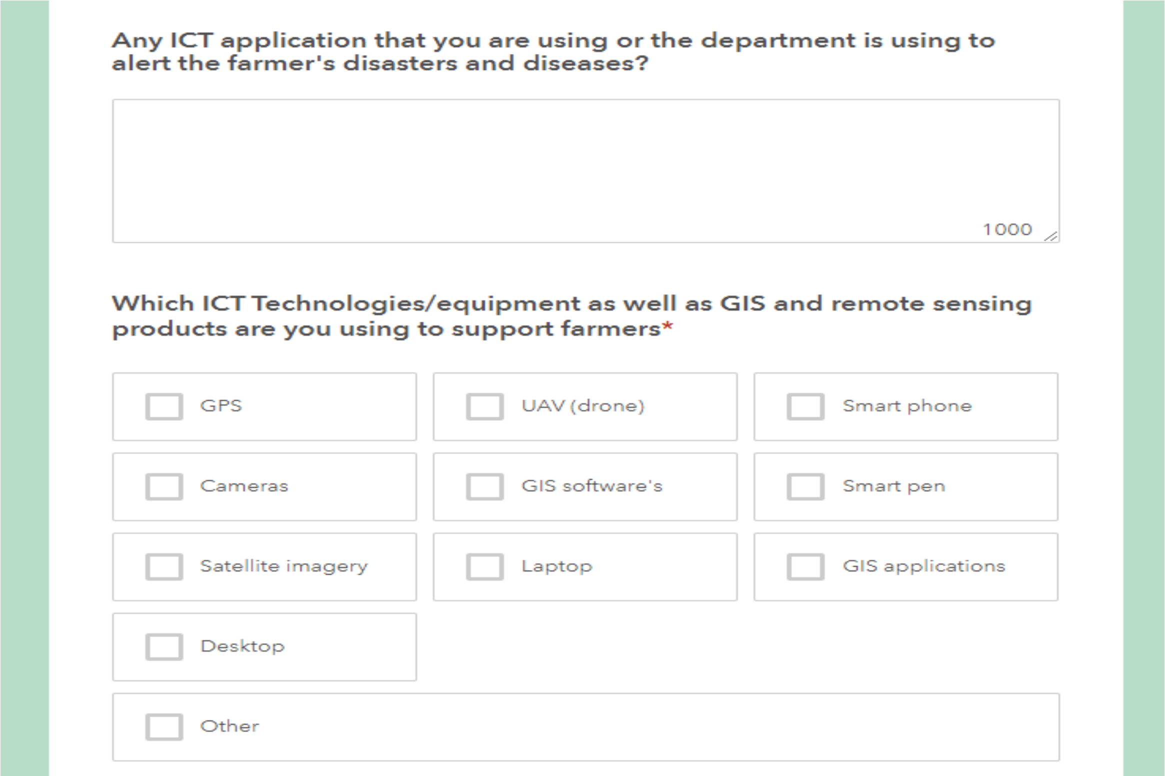
Does DALRRD have a Farmer profile database for all farmers in South Africa? if yes, how was this data collected?*

1000

Which system/method (e.g. Online System, email, WhatsApp, telephone, or farm visits) are farmers are using to request services and to provide feedback on service received?*

How is DALRRD supporting the farmers in terms of technologies and tools for recording keeping, ploughing, planting, harvesting, and marketing commodities?

1000

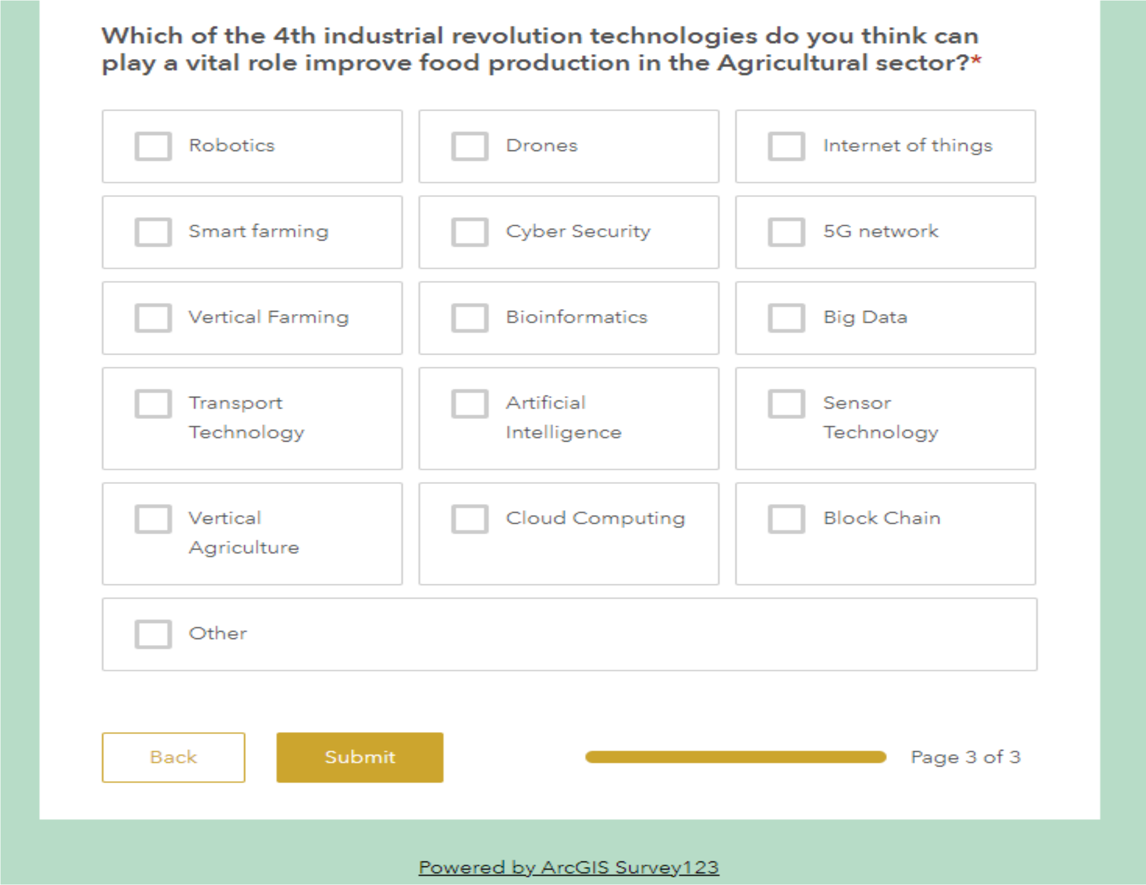


Any ICT application that you are using or the department is using to alert the farmer's disasters and diseases?

1000

Which ICT Technologies/equipment as well as GIS and remote sensing products are you using to support farmers*

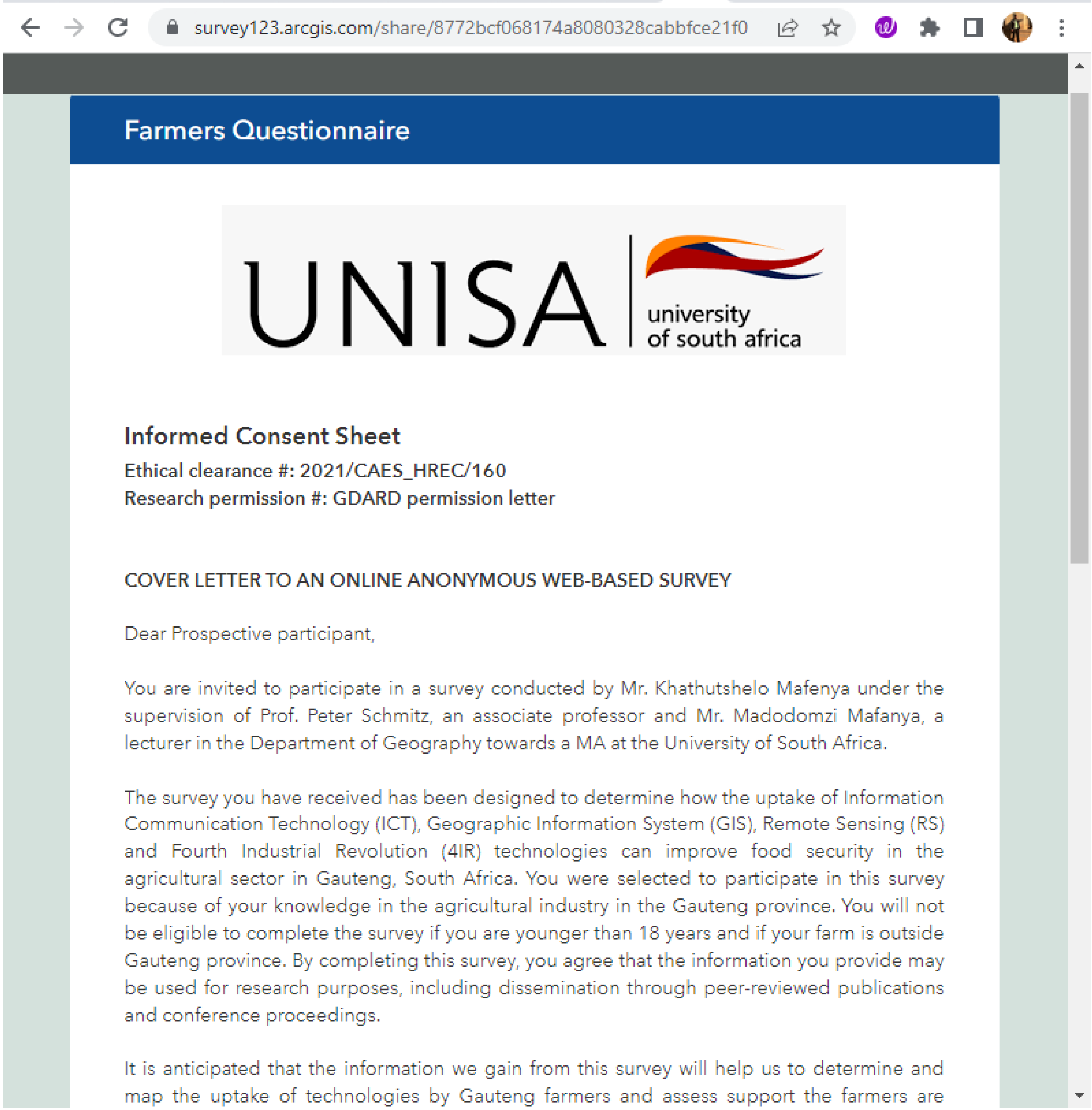
☐ GPS
☐ UAV (drone)
☐ Smart phone
☐ Cameras
☐ GIS software's
☐ Smart pen
☐ Satellite imagery
☐ Laptop
☐ GIS applications
☐ Desktop
☐ Other



Which of the 4th industrial revolution technologies do you think can play a vital role improve food production in the Agricultural sector?*

- ☐ Robotics
- ☐ Drones
- ☐ Internet of things
- ☐ Smart farming
- ☐ Cyber Security
- ☐ 5G network
- ☐ Vertical Farming
- ☐ Bioinformatics
- ☐ Big Data
- ☐ Transport Technology
- ☐ Artificial Intelligence
- ☐ Sensor Technology
- ☐ Vertical Agriculture
- ☐ Cloud Computing
- ☐ Block Chain
- ☐ Other

Appendix C: Farmers questionnaire



Farmers Questionnaire

Informed Consent Sheet

Ethical clearance #: 2021/CAES_HREC/160
Research permission #: GDARD permission letter

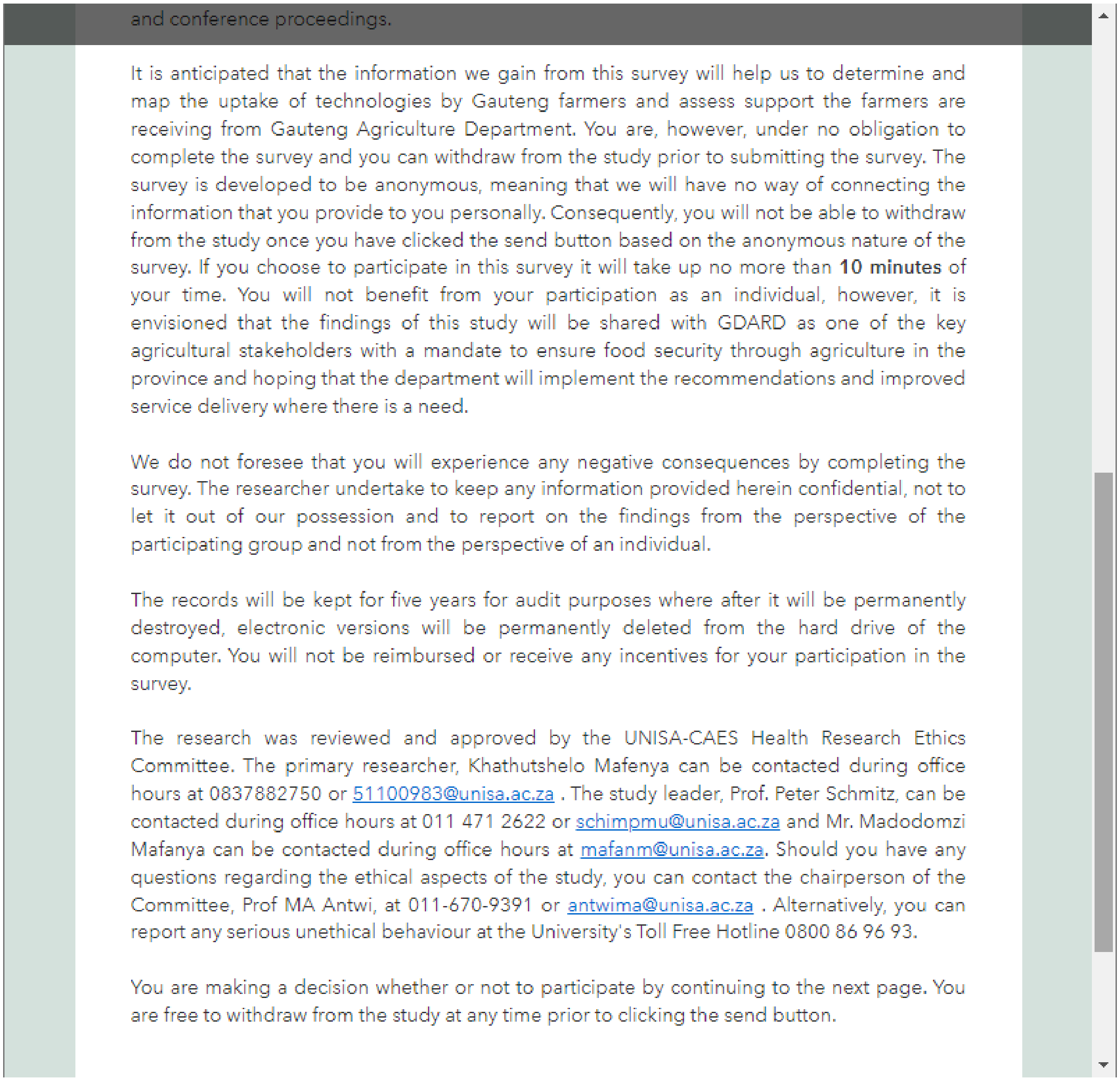
COVER LETTER TO AN ONLINE ANONYMOUS WEB-BASED SURVEY

Dear Prospective participant,

You are invited to participate in a survey conducted by Mr. Khathutshelo Mafenya under the supervision of Prof. Peter Schmitz, an associate professor and Mr. Madodomzi Mafanya, a lecturer in the Department of Geography towards a MA at the University of South Africa.

The survey you have received has been designed to determine how the uptake of Information Communication Technology (ICT), Geographic Information System (GIS), Remote Sensing (RS) and Fourth Industrial Revolution (4IR) technologies can improve food security in the agricultural sector in Gauteng, South Africa. You were selected to participate in this survey because of your knowledge in the agricultural industry in the Gauteng province. You will not be eligible to complete the survey if you are younger than 18 years and if your farm is outside Gauteng province. By completing this survey, you agree that the information you provide may be used for research purposes, including dissemination through peer-reviewed publications and conference proceedings.

It is anticipated that the information we gain from this survey will help us to determine and map the uptake of technologies by Gauteng farmers and assess support the farmers are



and conference proceedings.

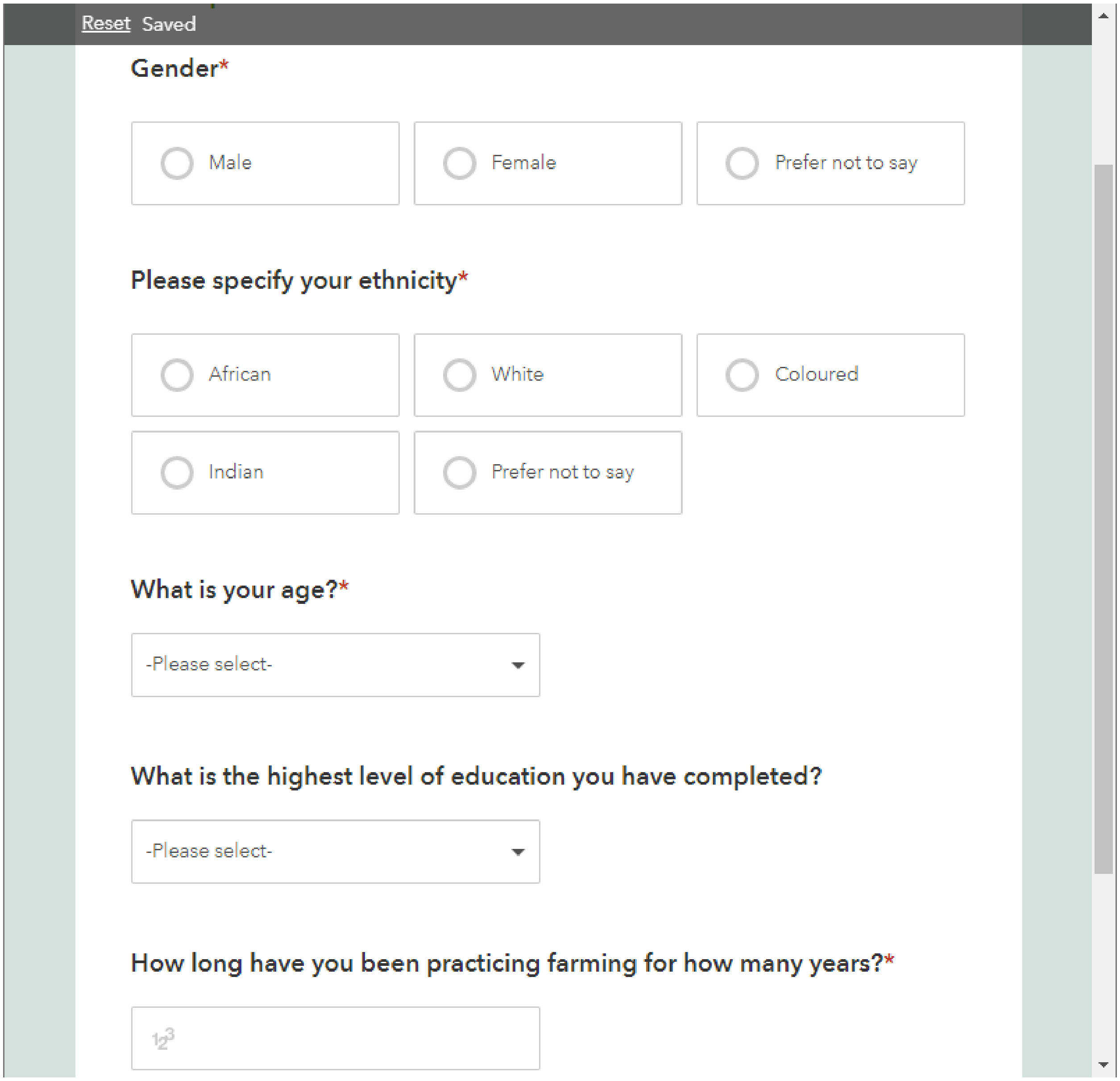
It is anticipated that the information we gain from this survey will help us to determine and map the uptake of technologies by Gauteng farmers and assess support the farmers are receiving from Gauteng Agriculture Department. You are, however, under no obligation to complete the survey and you can withdraw from the study prior to submitting the survey. The survey is developed to be anonymous, meaning that we will have no way of connecting the information that you provide to you personally. Consequently, you will not be able to withdraw from the study once you have clicked the send button based on the anonymous nature of the survey. If you choose to participate in this survey it will take up no more than **10 minutes** of your time. You will not benefit from your participation as an individual, however, it is envisioned that the findings of this study will be shared with GDARD as one of the key agricultural stakeholders with a mandate to ensure food security through agriculture in the province and hoping that the department will implement the recommendations and improved service delivery where there is a need.

We do not foresee that you will experience any negative consequences by completing the survey. The researcher undertake to keep any information provided herein confidential, not to let it out of our possession and to report on the findings from the perspective of the participating group and not from the perspective of an individual.

The records will be kept for five years for audit purposes where after it will be permanently destroyed, electronic versions will be permanently deleted from the hard drive of the computer. You will not be reimbursed or receive any incentives for your participation in the survey.

The research was reviewed and approved by the UNISA-CAES Health Research Ethics Committee. The primary researcher, Khathutshelo Mafenya can be contacted during office hours at 0837882750 or 51100983@unisa.ac.za . The study leader, Prof. Peter Schmitz, can be contacted during office hours at 011 471 2622 or schimpmu@unisa.ac.za and Mr. Madodomzi Mafanya can be contacted during office hours at mafanm@unisa.ac.za. Should you have any questions regarding the ethical aspects of the study, you can contact the chairperson of the Committee, Prof MA Antwi, at 011-670-9391 or antwima@unisa.ac.za . Alternatively, you can report any serious unethical behaviour at the University's Toll Free Hotline 0800 86 96 93.

You are making a decision whether or not to participate by continuing to the next page. You are free to withdraw from the study at any time prior to clicking the send button.



Gender*

○ Male ○ Female ○ Prefer not to say

Please specify your ethnicity*

○ African ○ White ○ Coloured

○ Indian ○ Prefer not to say

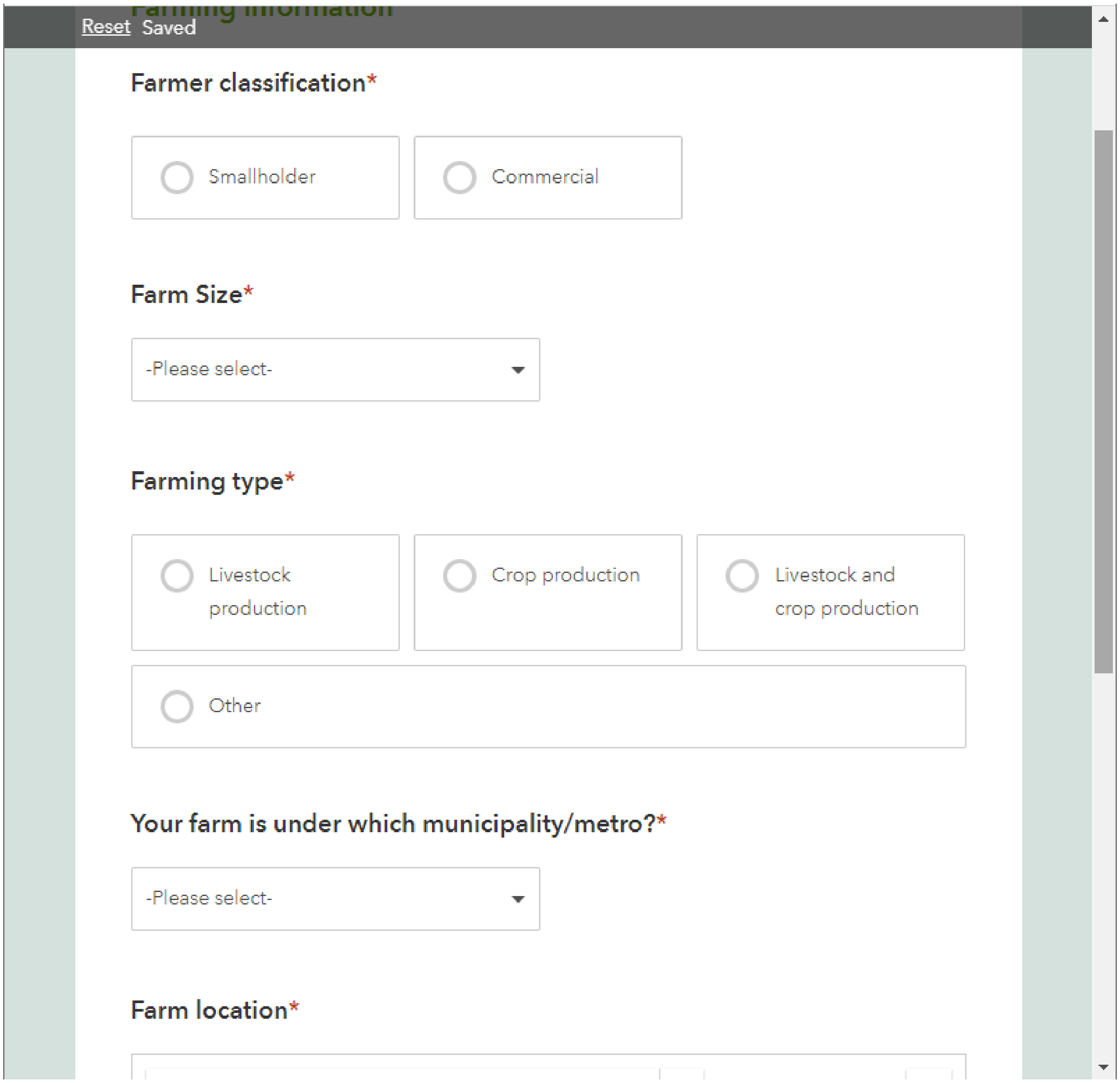
What is your age?*

-Please select- ▾

What is the highest level of education you have completed?

-Please select- ▾

How long have you been practicing farming for how many years?*



Farmer classification*

○ Smallholder

○ Commercial

Farm Size*

-Please select-

Farming type*

○ Livestock production

○ Crop production

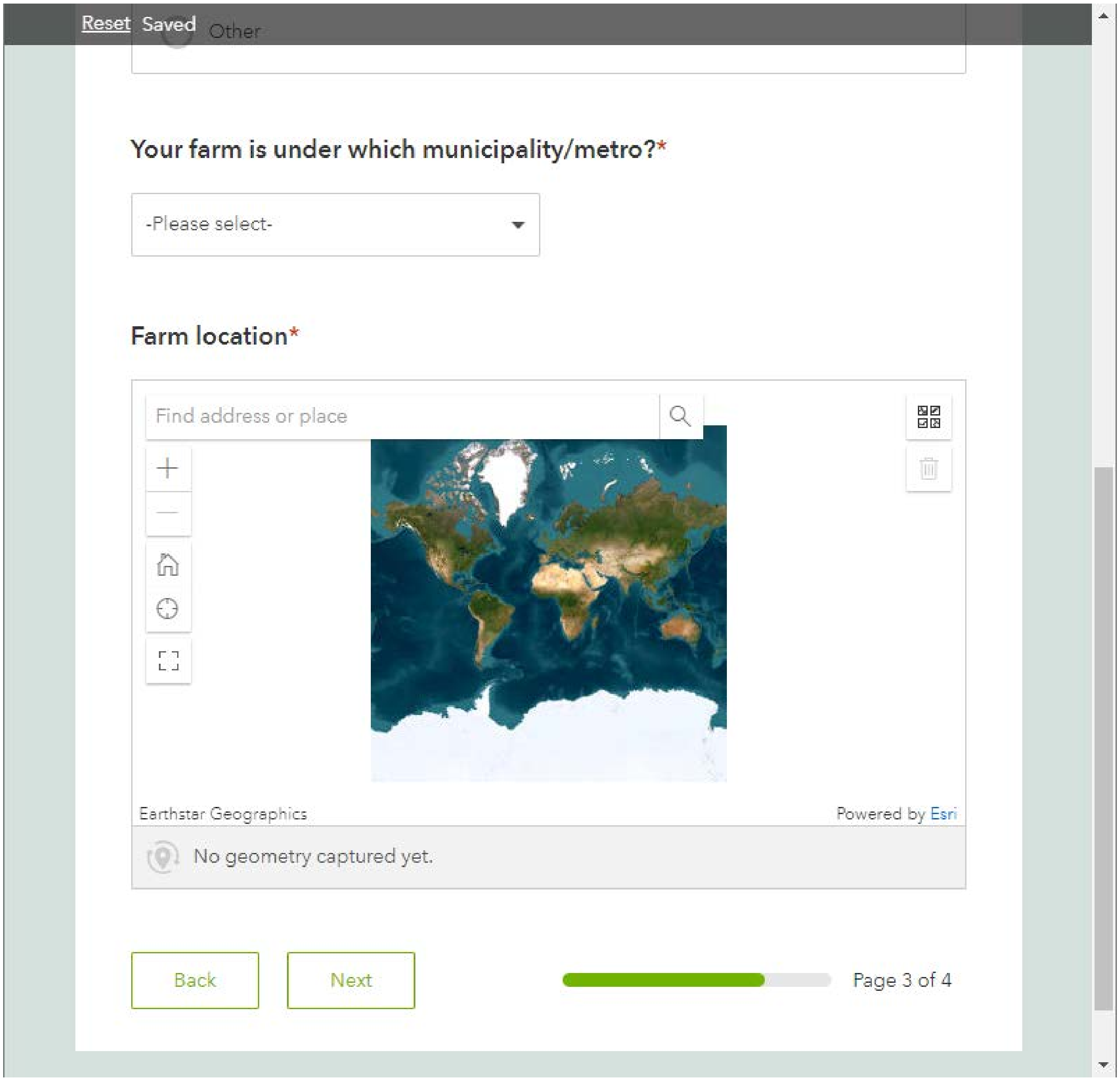
○ Livestock and crop production

○ Other

Your farm is under which municipality/metro?*

-Please select-

Farm location*

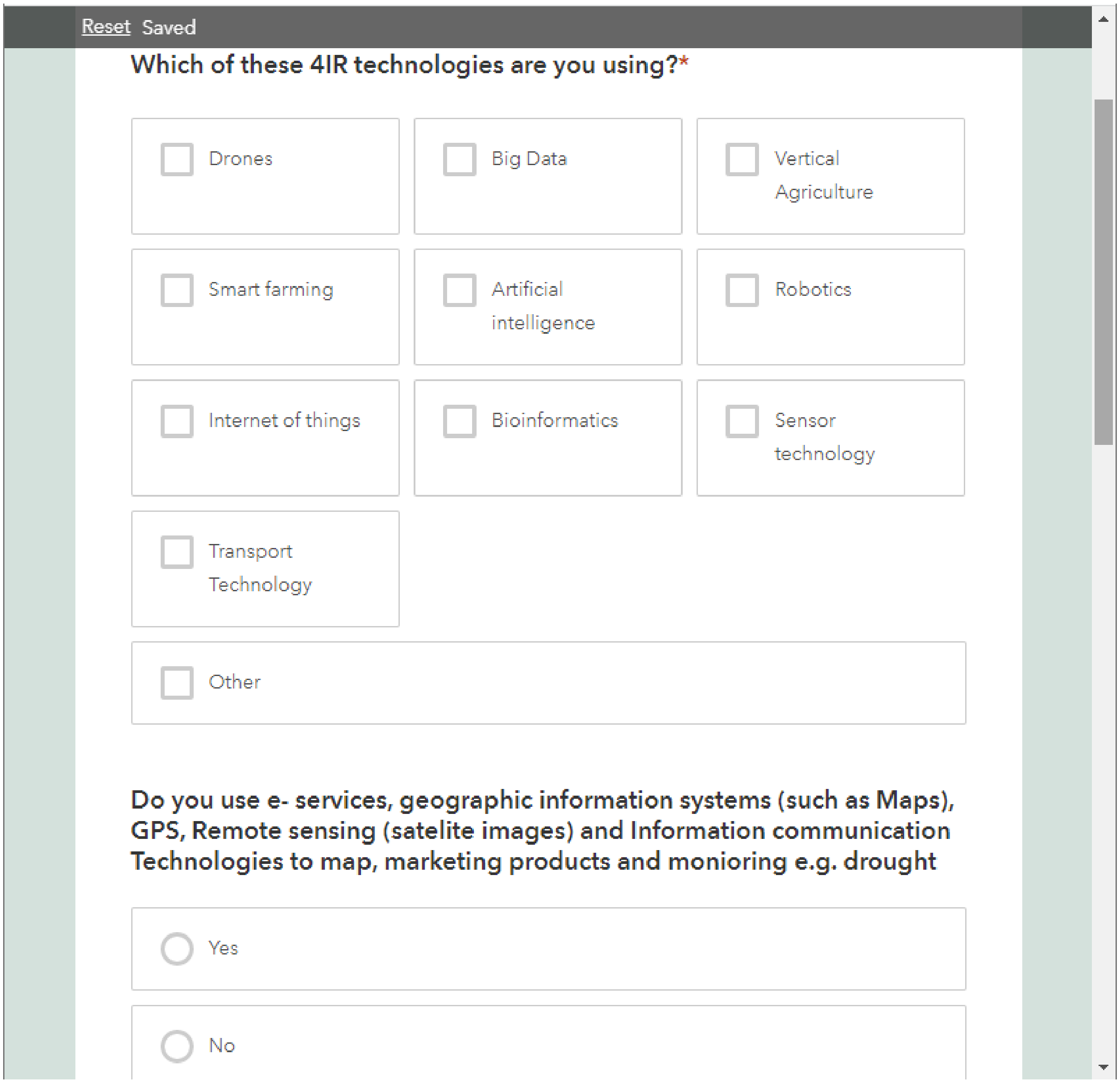


Your farm is under which municipality/metro?*

-Please select-

Farm location*

No geometry captured yet.

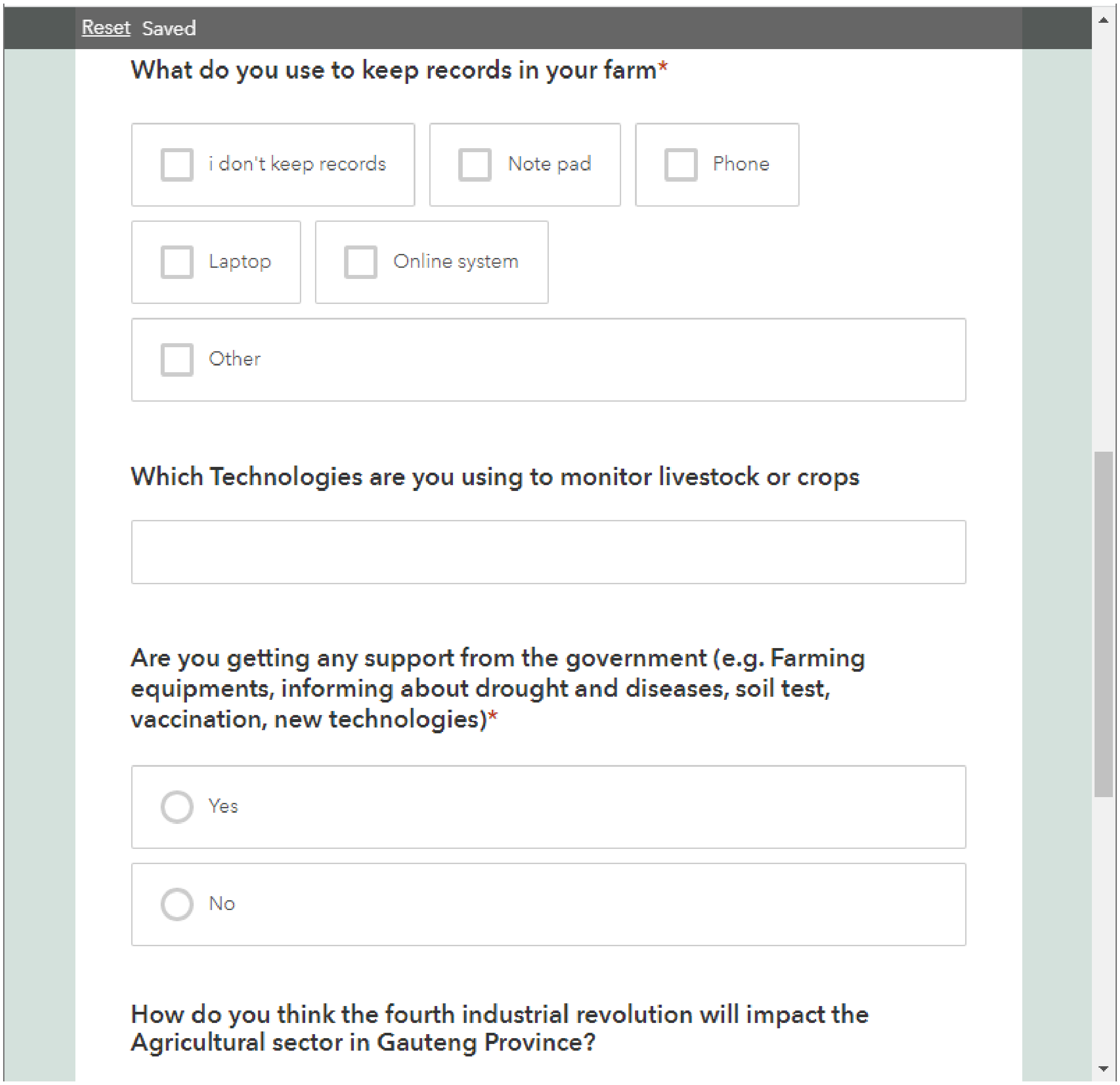


Which of these 4IR technologies are you using?*

☐ Drones
☐ Big Data
☐ Vertical Agriculture
☐ Smart farming
☐ Artificial intelligence
☐ Robotics
☐ Internet of things
☐ Bioinformatics
☐ Sensor technology
☐ Transport Technology
☐ Other

Do you use e- services, geographic information systems (such as Maps), GPS, Remote sensing (satelite images) and Information communication Technologies to map, marketing products and monioring e.g. drought

○ Yes
○ No



What do you use to keep records in your farm*

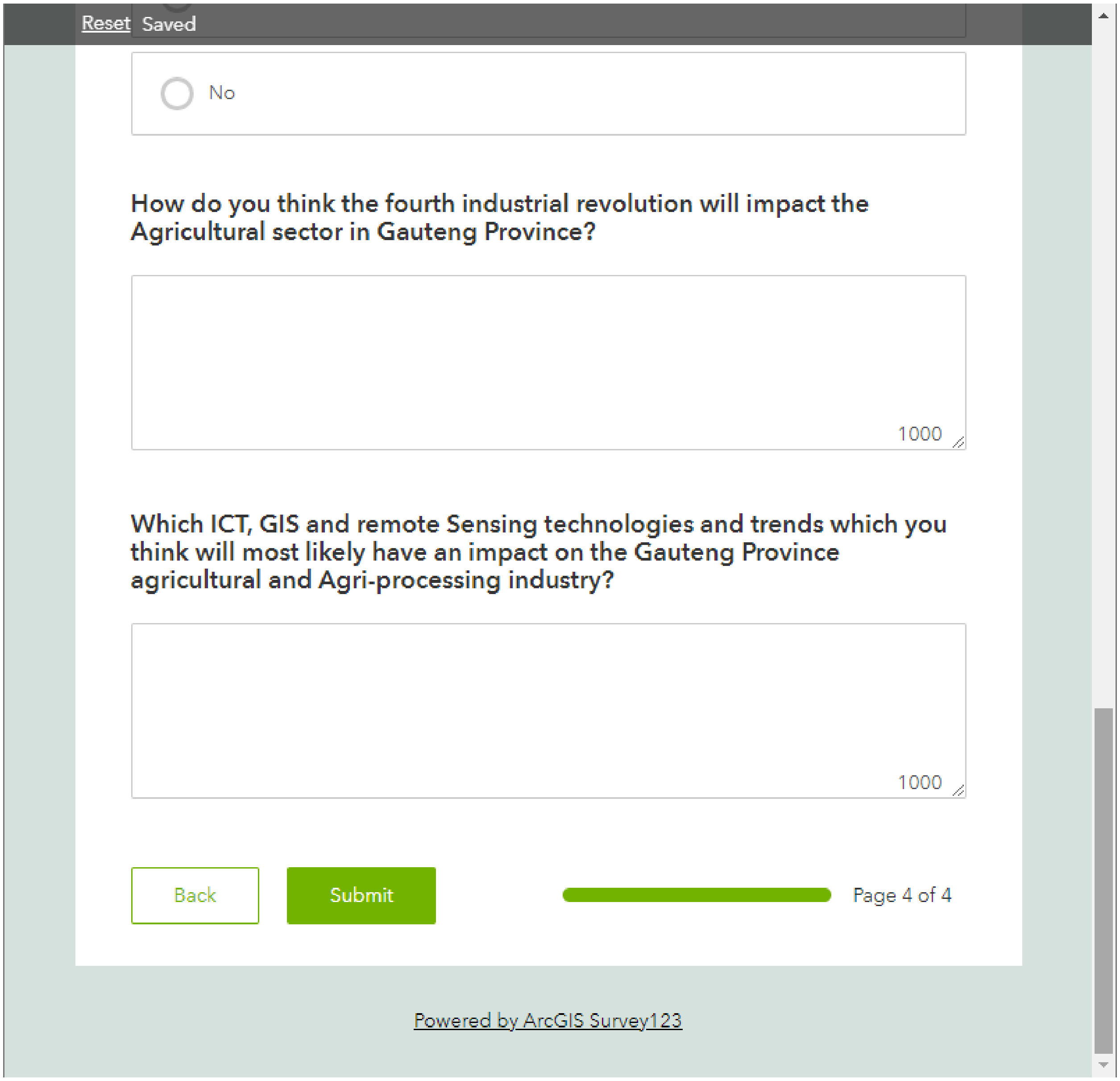
☐ i don't keep records
☐ Note pad
☐ Phone
☐ Laptop
☐ Online system
☐ Other

Which Technologies are you using to monitor livestock or crops

Are you getting any support from the government (e.g. Farming equipments, informing about drought and diseases, soil test, vaccination, new technologies)*

○ Yes
○ No

How do you think the fourth industrial revolution will impact the Agricultural sector in Gauteng Province?

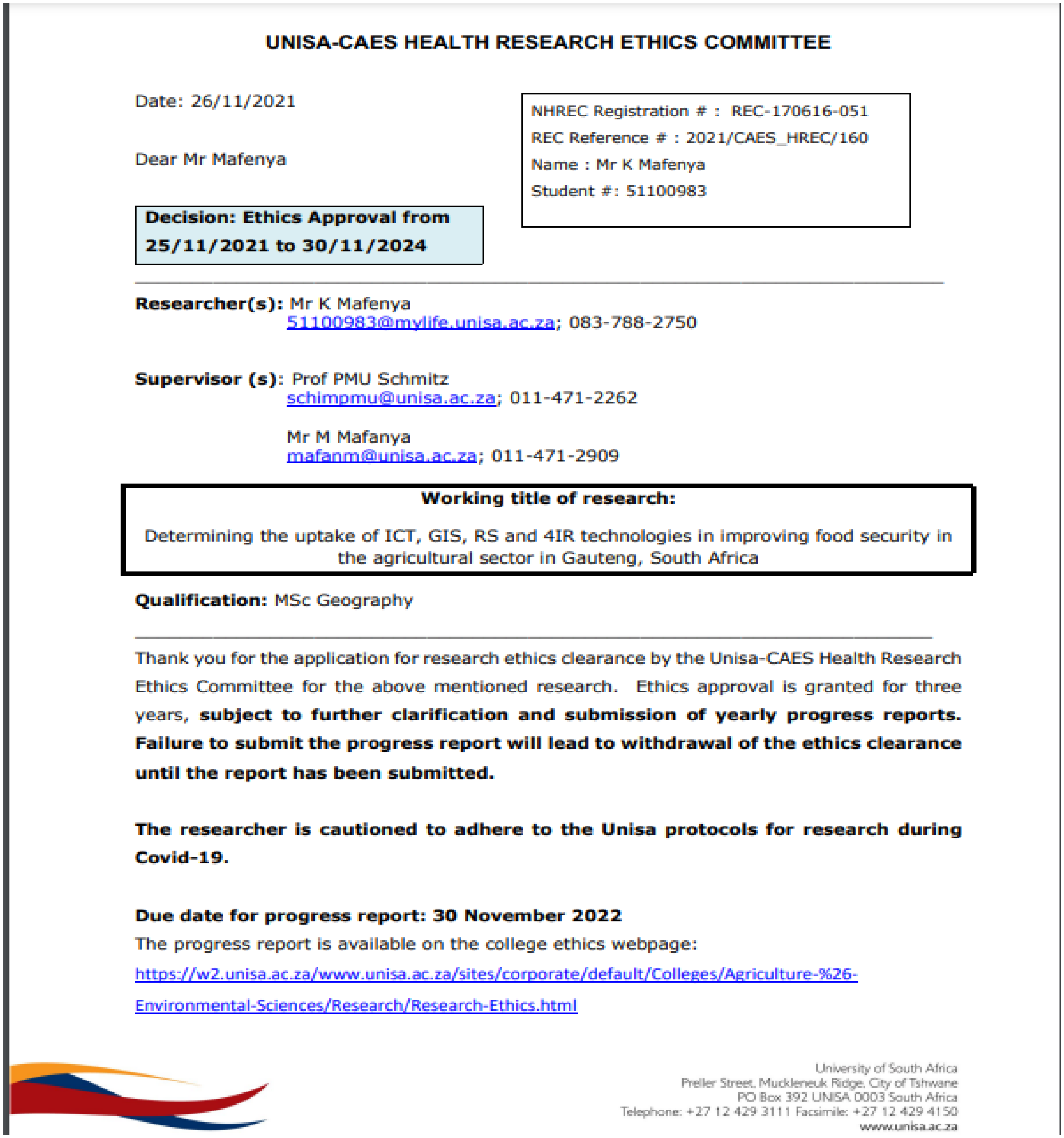


○ No

How do you think the fourth industrial revolution will impact the Agricultural sector in Gauteng Province?

Which ICT, GIS and remote Sensing technologies and trends which you think will most likely have an impact on the Gauteng Province agricultural and Agri-processing industry?

Appendix D: Unisa Ethics clearance letter



UNISA-CAES HEALTH RESEARCH ETHICS COMMITTEE

Date: 26/11/2021

NHREC Registration # : REC-170616-051
REC Reference # : 2021/CAES_HREC/160
Name : Mr K Mafenya
Student #: 51100983

Dear Mr Mafenya

Decision: Ethics Approval from 25/11/2021 to 30/11/2024

Researcher(s): Mr K Mafenya
51100983@mylife.unisa.ac.za; 083-788-2750

Supervisor (s): Prof PMU Schmitz
schimpmu@unisa.ac.za; 011-471-2262

Mr M Mafanya
mafanm@unisa.ac.za; 011-471-2909

Working title of research:

Determining the uptake of ICT, GIS, RS and 4IR technologies in improving food security in the agricultural sector in Gauteng, South Africa

Qualification: MSc Geography

Thank you for the application for research ethics clearance by the Unisa-CAES Health Research Ethics Committee for the above mentioned research. Ethics approval is granted for three years, **subject to further clarification and submission of yearly progress reports. Failure to submit the progress report will lead to withdrawal of the ethics clearance until the report has been submitted.**

The researcher is cautioned to adhere to the Unisa protocols for research during Covid-19.

Due date for progress report: 30 November 2022
The progress report is available on the college ethics webpage:
https://w2.unisa.ac.za/www.unisa.ac.za/sites/corporate/default/Colleges/Agriculture-%26-Environmental-Sciences/Research/Research-Ethics.html

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Appendix E: GDARD Permission letter

GAUTENG PROVINCE
AGRICULTURE AND RURAL DEVELOPMENT
REPUBLIC OF SOUTH AFRICA

Enquiries: Thandiwe Tsutsu
Office of the Head of Department: GDARD
Tel: +27 (0)11 240 2586
thandiwe.tsutsu@gauteng.gov.za

Mr Khathutshelo Mafenya
Assistant Director: Information Systems
Gauteng Department of Agriculture and Rural Development
56 Eloff Street
Johannesburg
2000

Dear Mr Mafenya

PERMISSION FOR MR KHATHUTSHELO MAFENYA TO CONDUCT RESEARCH FOR HIS MASTERS PROGRAMME.

The department has reviewed the request submitted by you to conduct research on "The significance of GIS, remote sensing and e-agriculture technologies in improving food security in the agricultural sector".

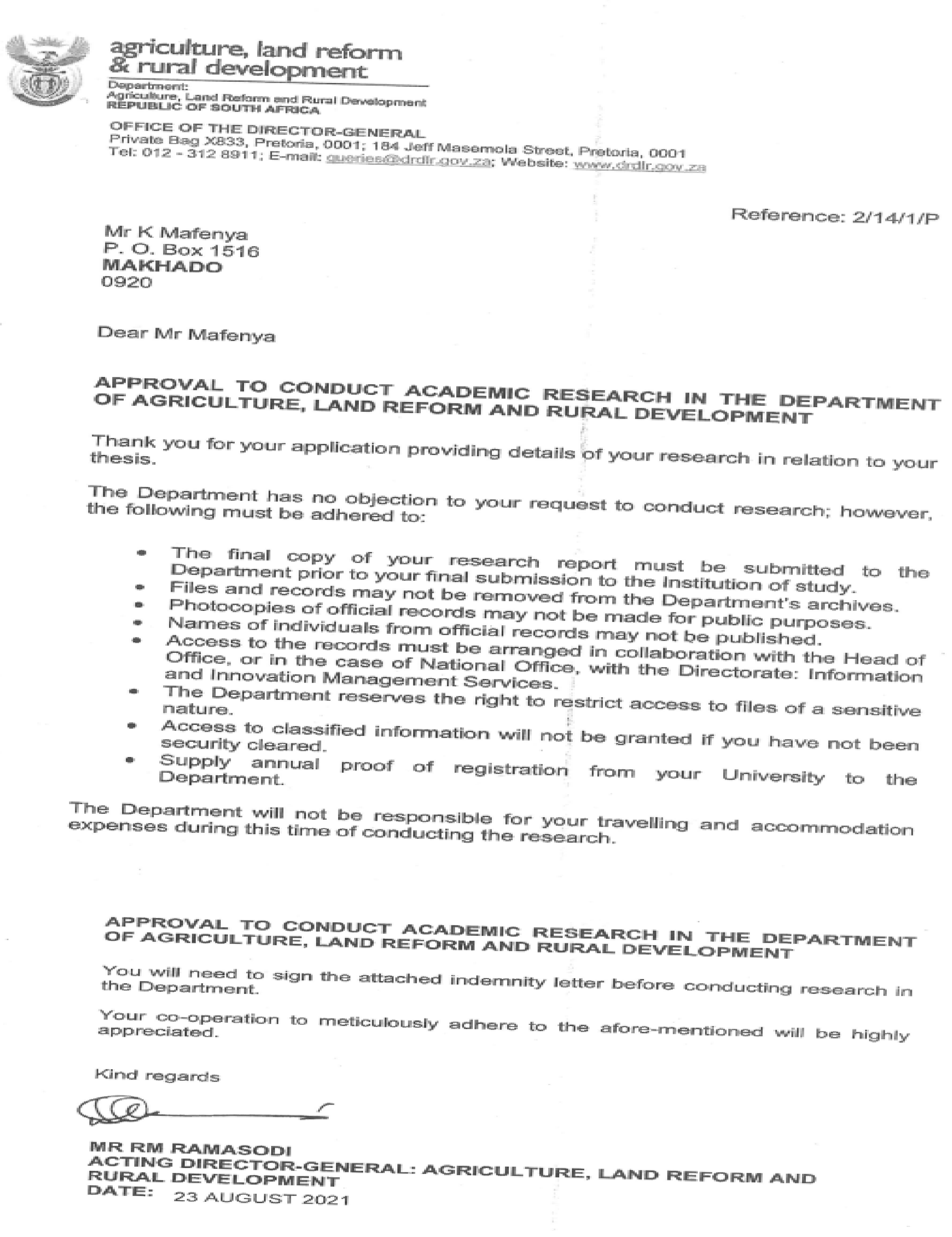
The importance of the study for the department has been considered. Therefore, the department grants permission to Mr K Mafenya to conduct research to evaluate the uptake of GIS, remote sensing and e-agriculture technologies by agricultural sector to improve food security in Gauteng.

For any further enquiries, please don't hesitate to contact Ms Thandiwe Tsutsu at 011 240 2586 or thandiwe.tsutsu@gauteng.gov.za.

Kind regards,

Ms Matilda Gasela
HEAD OF DEPARTMENT: AGRICULTURE AND RURAL DEVELOPMENT
Date: 13 APRIL 2021

Appendix F: DALRRD permission letter



agriculture, land reform
& rural development
Department:
Agriculture, Land Reform and Rural Development
REPUBLIC OF SOUTH AFRICA

OFFICE OF THE DIRECTOR-GENERAL
Private Bag X833, Pretoria, 0001; 184 Jeff Masemola Street, Pretoria, 0001
Tel: 012 - 312 8911; E-mail: queries@drdlr.gov.za; Website: www.drdlr.gov.za

Reference: 2/14/1/P

Mr K Mafenya
P. O. Box 1516
MAKHADO
0920

Dear Mr Mafenya

APPROVAL TO CONDUCT ACADEMIC RESEARCH IN THE DEPARTMENT OF AGRICULTURE, LAND REFORM AND RURAL DEVELOPMENT

Thank you for your application providing details of your research in relation to your thesis.

The Department has no objection to your request to conduct research; however, the following must be adhered to:

- The final copy of your research report must be submitted to the Department prior to your final submission to the Institution of study.
- Files and records may not be removed from the Department's archives.
- Photocopies of official records may not be made for public purposes.
- Names of individuals from official records may not be published.
- Access to the records must be arranged in collaboration with the Head of Office, or in the case of National Office, with the Directorate: Information and Innovation Management Services.
- The Department reserves the right to restrict access to files of a sensitive nature.
- Access to classified information will not be granted if you have not been security cleared.
- Supply annual proof of registration from your University to the Department.

The Department will not be responsible for your travelling and accommodation expenses during this time of conducting the research.

APPROVAL TO CONDUCT ACADEMIC RESEARCH IN THE DEPARTMENT OF AGRICULTURE, LAND REFORM AND RURAL DEVELOPMENT

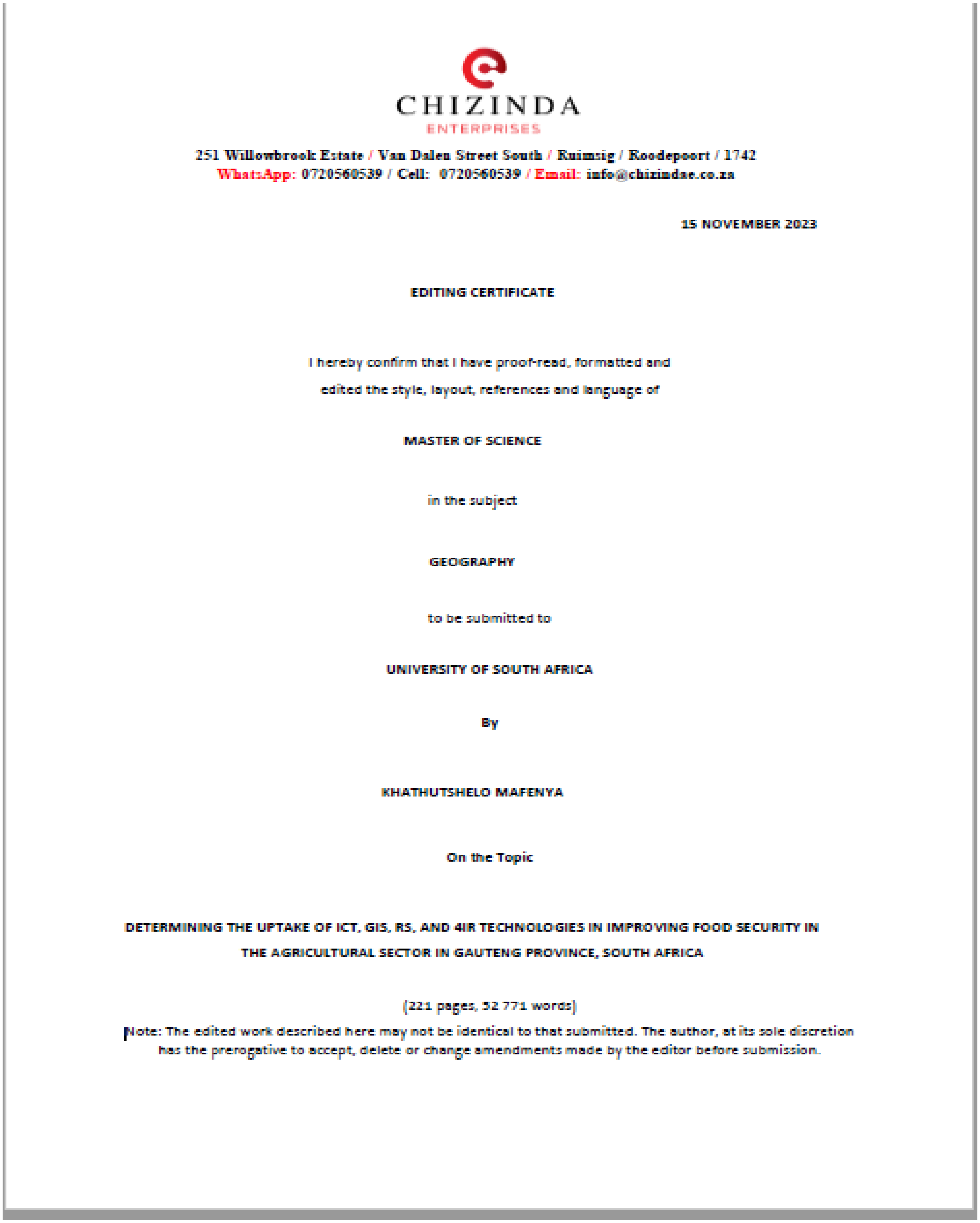
You will need to sign the attached indemnity letter before conducting research in the Department.

Your co-operation to meticulously adhere to the afore-mentioned will be highly appreciated.

Kind regards

MR RM RAMASODI
ACTING DIRECTOR-GENERAL: AGRICULTURE, LAND REFORM AND RURAL DEVELOPMENT
DATE: 23 AUGUST 2021

Appendix G: Editing certificate.



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15 NOVEMBER 2023

EDITING CERTIFICATE

I hereby confirm that I have proof-read, formatted and
edited the style, layout, references and language of

MASTER OF SCIENCE

in the subject

GEOGRAPHY

to be submitted to

UNIVERSITY OF SOUTH AFRICA

By

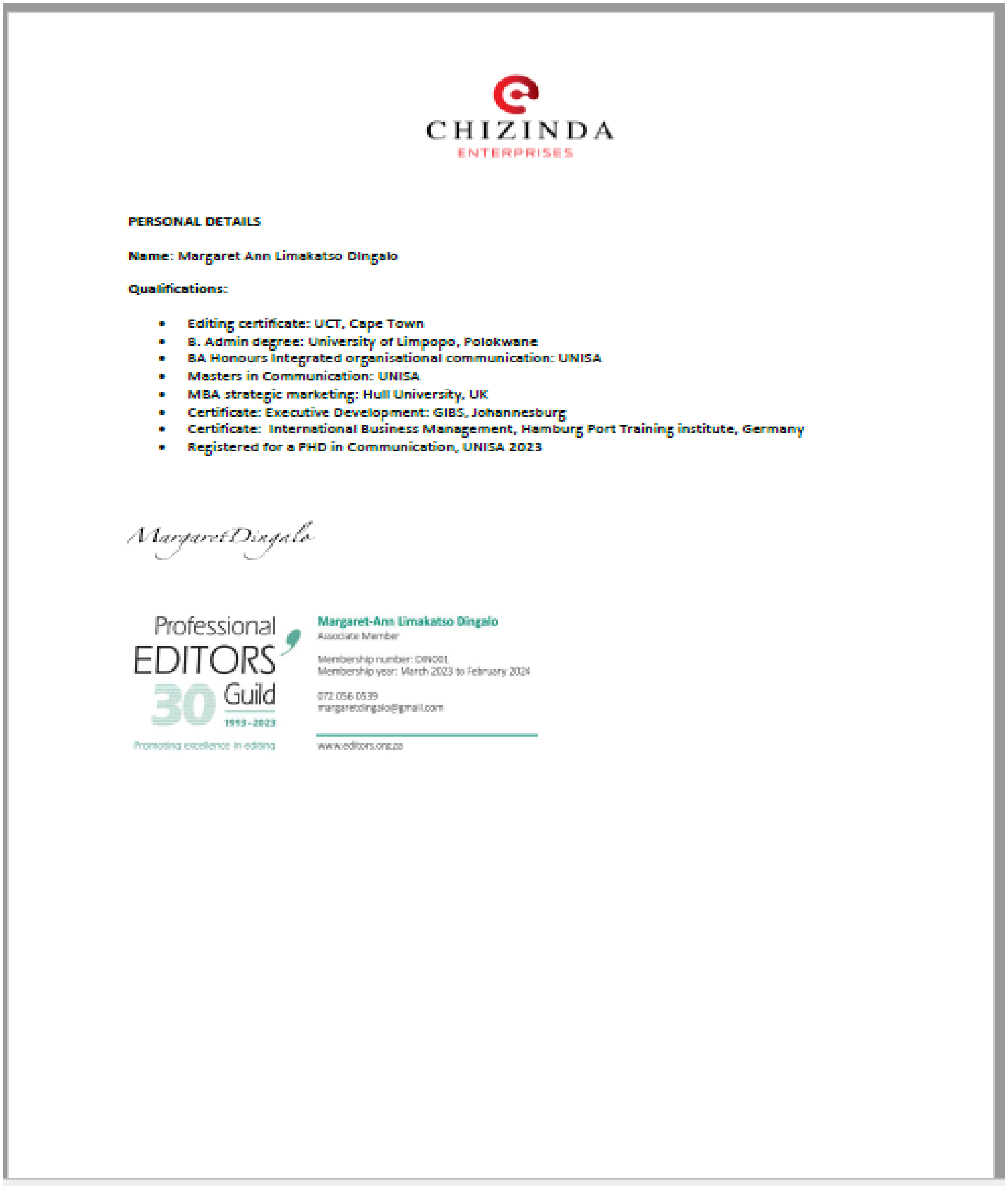
KHATHUTSHELO MAFENYA

On the Topic

DETERMINING THE UPTAKE OF ICT, GIS, RS, AND 4IR TECHNOLOGIES IN IMPROVING FOOD SECURITY IN THE AGRICULTURAL SECTOR IN GAUTENG PROVINCE, SOUTH AFRICA

(221 pages, 52 771 words)

Note: The edited work described here may not be identical to that submitted. The author, at its sole discretion has the prerogative to accept, delete or change amendments made by the editor before submission.



CHIZINDA
ENTERPRISES

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Qualifications:

- **Editing certificate: UCT, Cape Town**
- **B. Admin degree: University of Limpopo, Polokwane**
- **BA Honours integrated organisational communication: UNISA**
- **Masters in Communication: UNISA**
- **MBA strategic marketing: Hull University, UK**
- **Certificate: Executive Development: GIBS, Johannesburg**
- **Certificate: International Business Management, Hamburg Port Training institute, Germany**
- **Registered for a PHD in Communication, UNISA 2023**

Margaret Dingalo

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Associate Member

Membership number: DIN001
Membership year: March 2023 to February 2024

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