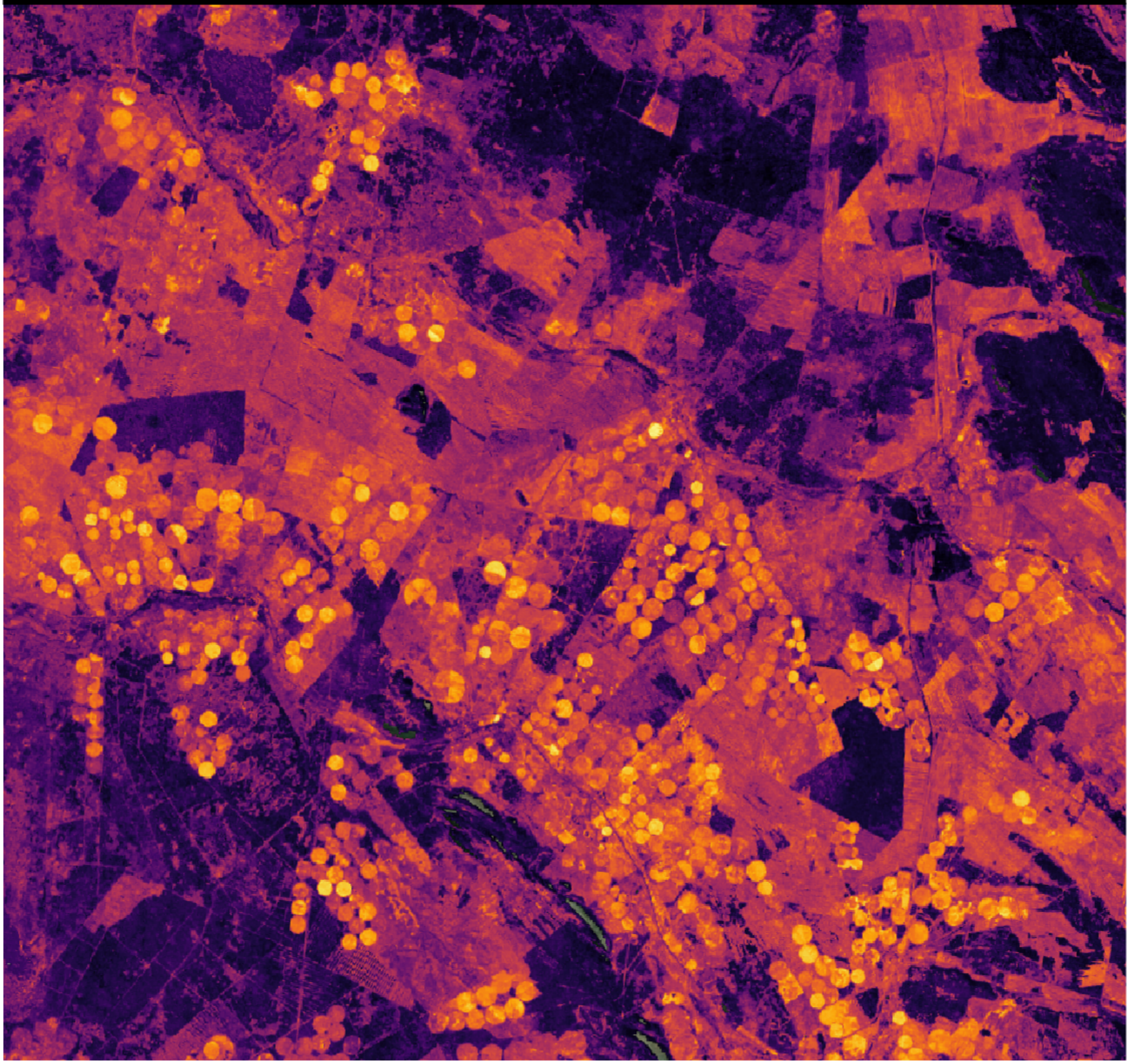
Digital Earth AFRICA

Information for Agriculture, Food and Water Security

A Roadmap to meet the needs of users in Africa with Earth Observation products and services.



Executive Summary

This Roadmap defines end user identified needs and gaps in improving agriculture and food security in Africa through Earth Observation (EO) technology, and outlines activities and partners that could be pursued to meet these needs. It is based on end user consultative workshops conducted in 2022 and 2023 during the implementation of the '*Information for Agriculture, Food and Water Security*' project funded by the Australian Centre for International Agricultural Research (ACIAR). Consultations were undertaken in six African countries: Botswana, Ethiopia, Kenya, Rwanda, South Africa, and Uganda. The consultations aimed to:

1. Identify capacity gaps (human and infrastructural) and the needs of the EO users.
2. Introduce stakeholders to Digital Earth Africa's products and services.
3. Undertake training of stakeholders on how to use the Digital Earth Africa platform and other products.
4. Identify potential stakeholders for collaboration and development of potential use cases.

The national workshops engaged approximately 377 participants (200 in national consultative workshops, and 177 in dissemination workshops) from nearly 150 different international, regional, national, and sub-national organisations representing academia, government, parastatal, non-government organisations, civil society, UN agencies, private sector and farmer organisations. The participatory stakeholder consultative workshops were facilitated by resource persons from Digital Earth Africa, supported by the project staff from partner organisations (the Association for Strengthening Agricultural Research in Eastern and Central Africa and the Centre for Coordination of Agricultural Research and Development for Southern Africa). Participants were asked to list their needs in relation to use of EO data, record the strengths, weaknesses, opportunities, and threats of the Digital Earth Africa platform, and list potential product development ideas. Users also received hands-on training on how to access and use Digital Earth Africa products and services.

The stakeholder consultations revealed the following key pathways to impact:

1. Connecting with smallholder farmers by recognising them as agents of food security and engaging with them through a broader network of stakeholders.
2. Enhancing the technical capacity of users through training and incorporating needs of end users as part of product co-design processes.
3. Developing and disseminating user friendly knowledge and research products for public consumption and usage to address real world problems.

Having identified pathways to impact, specific activities to progress these paths were listed. Technical and capacity development activities were listed against three 'tiers' representing the relative effort required for implementation. Tier 1 corresponds to the least additional requirement of resources, Tier 2 to country-specific adaptation of existing workflows and joint capacity building, and Tier 3 would require considerable additional resources, such as through multi-agency, multi-year projects. Potential partner and supporter organisations were also listed alongside each possible activity.

Technical opportunities identified were as follows:

- Tier 1
  - Spatial information on soil fertility and characteristics
- Tier 2
  - Crop-type mapping
  - Irrigated area mapping
  - Climate and crop production dashboards
- Tier 3
  - Early warning systems — pests and diseases
  - Early warning systems — crop production

Capacity development products and services opportunities were:

- Tier 1
  - Short training video series
  - Soil information training material
- Tier 2
  - Link with software developers and other service providers to enable app development and other interfaces
- Tier 3
  - Continental agriculture and food security specific capacity development initiative

This Roadmap documents evidence gathered via the in-person consultations on user-identified needs as well as gaps in information; and outlines pathways to meet them. It's expected that Digital Earth Africa should refer to this Roadmap in planning any activities relevant to agriculture and food security. The Roadmap can also be presented to potential partners and used to inform future investment choices. It's worthwhile noting that the consultation framework used in the development of this Roadmap can also be applied in other African nations. The planning aspects of the document can be treated as dynamic and subject to change provided that on-going dialogue is maintained between Digital Earth Africa and partners.

1. Introduction

1.1 Earth Observation for Agriculture, Food and Water Security in Africa

The African continent supports a proportionally large rural population engaged in subsistence and commercial agriculture supported by water resources of varying reliability (mainly rainfed). The Eastern and Southern Africa (ESA) region in Sub-Saharan Africa is particularly prone to recurrent droughts and is highly dependent on rainfed agriculture (OECD-FAO, 2016) making it more vulnerable to impacts of climate change. Climate relevant research and innovation is therefore critical in building resilient food systems to support the agricultural transformation agenda in the continent. Agricultural innovation and technical capacity building is a well-recognised development pathway for the African agricultural sector (Mwaniki, 2006). The Australian Centre for International Agricultural Research (ACIAR) supports this mission by investing in a wide range of agricultural research-for-development (AR4D) projects, often encompassing social and technical innovation in specific sectors, such as pastoralism and small scale irrigation.

Investments in agricultural and Natural Resources Management (NRM) innovations in Africa are often challenged by data scarcity and complex operating environments. An agronomic example is the preponderance of small, irregularly shaped crop fields with limited information on planted area, harvested area, yield, and input (such as pesticides and fertiliser) volumes. Earth observation (EO) and remote sensing can provide a cost-effective, scalable and reliable means of gathering information to fill some of these gaps. The World Economic Forum estimates that Digital Earth Africa has the potential to generate an impact of up to $1 billion/year through the provision of EO data products for African agriculture. However, specific user needs and capacity gaps need to be identified to ensure that Earth observation innovation and capacity are developed appropriately and disseminated effectively across the continent.

1.2 Digital Earth Africa

Digital Earth Africa (DE Africa) is an African public-good entity with EO capability whose primary objective is to use information from satellites to improve people's livelihoods. DE Africa provides open-access data as a public-good data infrastructure, along with supporting material, analysis environments, training programs, and user engagement initiatives across the entire African continent. This spectrum of activities aligns with DE Africa's commitment of continuously engaging with end users and co-designing relevant EO products and services. Training and capacity development are important components of product development since they improve user's understanding of the strengths and limitations of EO and enable more informed feedback to guide product and service development. Continuous capacity building and training of stakeholders is also critical in ensuring sustained uptake or use of the EO products and services.

Capacity building services are delivered by both DE Africa's operations team and implementing partner organisations while the co-designing of products and services is guided by the Product Development Task Team (PDTT). Further direction on operations is provided by the Governing Board and Technical Advisory Committee, with additional input from a diverse Stakeholder Community Group. Geoscience Australia and the South African National Space Agency (SANSA) act as host organisations for funders; with major funders including the Helmsley Charitable Trust and the Department of Foreign Affairs and Trade, Australia. This governance structure is described in Figure 1.

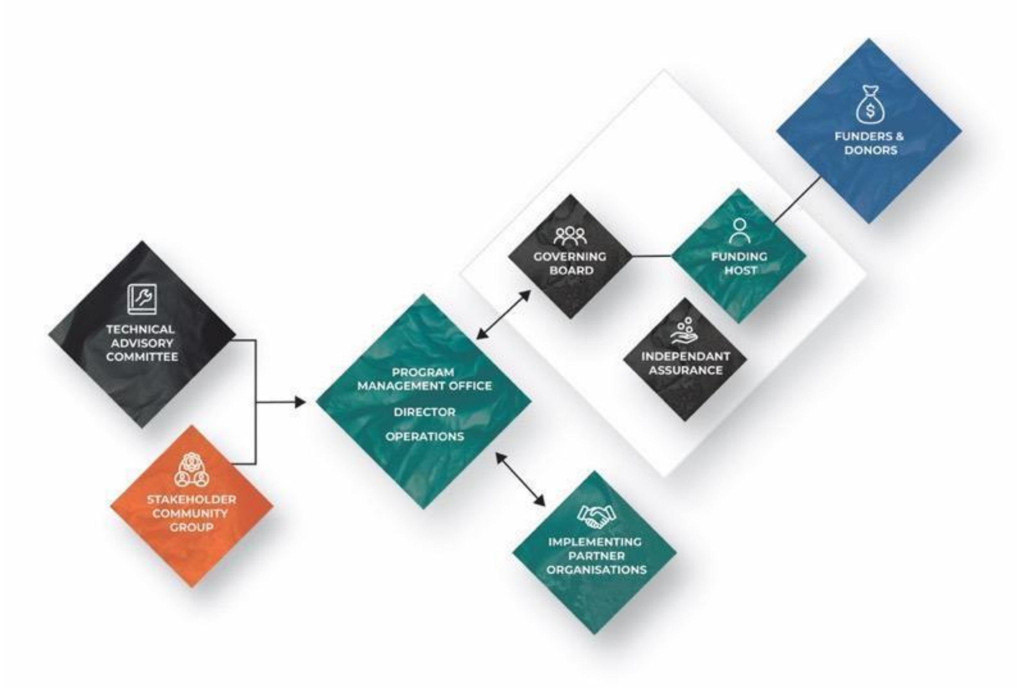


Figure 1: *Digital Earth Africa governing framework.*

DE Africa has established a wide network of implementing partners and users on the African continent. Key partners supporting this project included: The Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA) and The Centre for Coordination of Agricultural Research and Development for Southern Africa (CCARDESA). The two (2) Sub Regional Organizations (SROs) have established networks in the agricultural research and development communities across their member countries and were able to identify entry points in these networks for DE Africa.

1.3 Information for Agriculture, Food and Water Security Consultations

Funded by the Australian Centre for International Agriculture Research (ACIAR), the *Information for Agriculture, Food and Water Security* (IAFWS) project aimed to:

- Support consultations with African agricultural and water management agencies to understand the needs, opportunities and gaps for using EO-based services to sustainably increase agricultural productivity through improved water use, and;
- Develop a Roadmap for DE Africa to deliver services tailored to these needs to improve productivity and build resilience. This Roadmap identifies pathways to connect with smallholder farmers via intermediaries, such as national governments and

non-government agencies. These pathways are classified according to the complexity of technical developments needed and the depth of the discussions required to implement them with impact.

1.3.1 Project partners

This project was a collaborative effort between multiple stakeholders that included:

- Funding body:
  - Australian Centre for International Agricultural Research. Canberra and Nairobi offices.
- Contracted organisation:
  - Geoscience Australia — DE Branch.
- Lead organisations:
  - DE Africa Program Management Office (PMO)
  - South African National Space Agency — DE Africa host organisation
  - The Association for Strengthening Agricultural Research in Eastern and Central Africa, Uganda
  - The Centre for Coordination of Agricultural Research and Development for Southern Africa, Botswana.
- Supporting organisations and projects that had a presence on the advisory committee:
  - International Water Management Institute (IWMI), Ethiopia Office
  - The Food and Agriculture Organization of the United Nations (FAO)
  - ANU — Transforming Irrigation in southern Africa project.

1.3.2 Methodology

The project was implemented under six components with specific approaches:

1. Development of detailed project plan including a stakeholder mapping, project timeline and a communication plan.
2. Development of country-specific materials (presentations and demonstrations of Digital Earth Africa platforms (maps and sandbox) identified in the project plan to support stakeholder engagement: Materials focused mostly on water resources and crop or vegetation and were adjusted to fit within the local context.
3. Established information needs and priorities for agricultural and water management agencies during stakeholder consultation workshops in Uganda and Botswana in November 2022, Kenya and Rwanda in December 2022, Ethiopia in January 2023 and South Africa in February 2023. Through these initial workshops, the stakeholder list was updated, ongoing EO for food security initiatives were profiled, end user needs and expectations were documented, and potential areas of collaboration were identified.
4. Build technical capacity of end users in the use of the DE Africa platform based on the needs and priorities identified during initial consultation workshops. This was done through deep dive training sessions for participants from agricultural and water management agencies in Ethiopia in January 2023, in Uganda, South Africa and Kenya in February 2023 and in Rwanda and Botswana in March 2023. The hands-on training

ranged from simple explorations of crop and water dynamics via DE Africa Maps to advanced statistical analyses through the DE Africa Sandbox.

5. Development of a roadmap (this document) for meeting the EO data needs and addressing the challenges faced by users in the agricultural sector. Outputs from the initial consultative workshops and the deep dive training sessions were used to develop a policy brief with clear policy directions to support the institutionalisation of the use of EO data by both state and non-state actors in each country. The policy briefs were aimed to inspire consistent and timely integration of EO at each stage of the planning process for agricultural and food security projects. To ensure uptake of the recommendations from this (IAFWS) project, policy dialogues were organised in Rwanda and Uganda in May 2023; Botswana, Ethiopia and Kenya in June 2023.
6. Dissemination of the IAFWS project results. This was achieved through many avenues, including use of already popular and trusted platforms such as institutional websites, social media pages (mainly Twitter, Facebook, WhatsApp and LinkedIn). The messages were published in various forms including newspaper (physical and online) articles, blogs, TV interviews, Radio messages, event flyers, posters, banners and infographics. These messages help to increase awareness of use of EO data in the agricultural sector with the aim of improving food security and climate adaptation.

1.3.3 Criteria for selection of target countries

The six countries (Uganda, Kenya, Rwanda, Ethiopia, South Africa, and Botswana) of project implementation were selected based on the following assumptions:

1. Existence of a significant number of stakeholders using EO data, products and services.
2. High interest to deploy EO data and information for development actions.
3. Existence of large arid and semi-arid areas that could potentially benefit from deployment of EO data and tools for drought monitoring.
4. Presence of a reliable ICT infrastructure to potentially support enhanced utilisation of the EO products and services.
5. High potential for irrigation to increase crop production through irrigated agricultural land.
6. Presence of technical staff (DE Africa, ASARECA and CCARDESA).
7. Existence of partner organizations critical for realization of project objectives.

1.4 Review of existing literature

1.4.1 The status of Earth Observation in African agricultural and water resources research

It is widely recognised that there is unfulfilled potential to apply EO technology and techniques to agricultural and water management challenges across the African continent. However, despite an increasing abundance of EO data sources and access platforms, barriers to utilisation remain. These barriers can be broadly separated into inadequacies on the data supply side, and capacity gaps on the user side. Both these aspects of underutilisation have been explored in the academic literature on EO in Africa.

In a review of the AfriCultuReS[1] project, Pritchard *et al.* (2022) recognised the growing number of satellite-derived products and services being designed for decision makers in African agriculture. However, they identify that EO in African agriculture is characterised by underutilisation, unfulfilled potential, and unaddressed capacity gaps. They attribute some of these failings to duplication of existing products, sometimes parallel initiatives, and fragmentation in the EO community.

Speranza *et al.* (2022) identified that most EO users in Africa are either governmental organisations or researchers, with very few users beyond these sectors. Additionally, they report that dissemination of EO skills and knowledge have been primarily delivered by government officers and researchers and recommend the private sector be further engaged to deploy EO products and services. These findings from Speranza *et al.* (2022) illustrate that in some cases, but not all, there is a shift away from state support and movement towards the private sector as intermediaries in technology adoption.

Freely available EO data is a necessary starting point for applications in the agricultural sector, but it is not sufficient; a supporting environment including capacity building resources and end-user networks. Kganyago & Mhangara (2019) reviewed numerous data sources and access/analysis platforms available to African users and reported two global initiatives, Google Earth Engine (GEE) and the Sentinel Analysis Platform (SNAP). They use SANSA, DE Africa's host organisation, as an example of an organisation coordinating EO activities in South Africa. It is also important to note the existence of continent-wide initiatives such as DE Africa, and GMES & Africa since 2019. This characterisation of SANSA as an agency of knowledge dissemination is consistent with the observation made by Speranza *et al.* (2022), that extension and adoption has generally been driven by government departments.

The literature on the current status of EO for agriculture and natural resources management in Africa reveals a common emphasis on the need for capacity building in various forms, in addition to context-specific challenges with data supply and presentation (Kganyago & Mhangara, 2019; Pritchard *et al*., 2022; Speranza *et al*., 2022). This suggests that future investment should aim to optimise and improve existing data products and services to meet needs in the African context, but also to focus more deeply on capacity building through several entry points including, while also going beyond, the government and research sectors.

1.4.2 Capacity building initiatives in Africa

Capacity gaps have been widely cited as barriers to adoption and implementation of EO in Africa. However, recent literature has challenged the use of 'capacity development' as a 'buzzword' and argued that it lacks an accepted, clear definition (Pritchard *et al*. 2022). These authors also point to limited evidence for sustained and transformative impacts of capacity development (Pritchard *et al*. 2022). Pritchard *et al*. (2022) argue that capacity building initiatives have not effectively adopted systems-based approaches and ignored some relevant knowledge forms. This perhaps explains why EO knowledge remains concentrated within governments and the research sector (Speranza *et al*. 2022).

[1] *The AfriCultuReS project aimed to provide agricultural monitoring and early warning systems for Africa.*

DE Africa's experience is that numerous training courses are available from African providers for African users, including training courses provided by the Regional Centre for Mapping Resources and Development (RCMRD) in Kenya (Ottichilo, 2006), AFRIGIST in Nigeria, and AGRHYMET in Niger. There are also a growing number of GIS and remote sensing professionals being trained at African academic institutions. This is resulting in a greater emphasis being placed on using EO techniques for monitoring and analysis of agricultural lands and natural resources, and a greater range of users seeking training.

1.4.3 Identified opportunities

Reviewing the literature on capacity building initiatives for EO in Africa reveals a wide range of objectives and goals. For example, some organisations are aiming for widespread uptake of basic GIS applications, while other initiatives are pushing for more advanced implementations such as embedding EO in index-based insurance (see below), arguing for a trans-disciplinary and a multi-level approach to capacity building (Speranza *et al*. 2022).

Index-based insurance

Satellite data sets can be used to develop (weather and vegetation) index-based agricultural insurance products which serve as proxies to estimate the potential yield and total production from a given plot. Farmers whose yields go below the determined trigger level are then compensated for the lost yields which enables them to continue in production even after the occurrence of an extreme weather event.

Overall, there is a clearly agreed need for capacity building across Africa, and this will have to take a range of different forms; that is, capacity building is likely to encompass a wide range of activities and the lack of a narrow definition may not be problematic. It is useful, though, to consider several principles that arise in the literature, including:

1. Approaching capacity building activities as a **dialogue** and an exercise in co-production of knowledge so that capacity is built among all parties involved.
2. Recognising that there are simple and efficient modes of capacity building, such as short courses and online materials, but some esoteric objectives may require a more sophisticated trans-disciplinary approach.
3. Capacity gaps are unlikely to be the sole barrier to implementation of EO, and co-innovation may reveal necessary improvements on the data and products.

There is a clear demand for capacity building activities which can be met by DE Africa. The organisation has personnel dedicated to capacity development, and is also directly involved in product development, so can respond dynamically to user demands.

These aspects of DE Africa's capabilities can be leveraged by partnering with well-connected sub-regional organisations such as ASARECA and CCARDESA. The role of such agencies in implementing capacity building programs would be identifying 'fertile ground' for additional capacity in EO. For example, ASARECA and/or CCARDESA might recognise that a state agency could particularly benefit from EO. Their role would then be to identify the relevant individuals to engage in capacity building and to act as a conduit between these people and DE Africa, such as by coordinating EO training as part of a broader professional development program.

Furthermore, the consultations described in this Roadmap have identified specific capacity building opportunities which can be pursued taking into consideration the three conclusions drawn from the literature, above.

1.5 Roadmap design

The ultimate objective of this the Roadmap is to present a summary of potential activities in which DE Africa may invest, or prioritise resources and development effort, in the agriculture and water sectors. Components are direct outcomes from the initial consultations and deep dive workshops in six African countries. In keeping with the 'Agile' Program Management adopted for DE Africa, this Roadmap is a guide to addressing the identified priorities, which will be considered alongside input from DE Africa's Governing Board, the Technical Advisory Committee, the IAFWS Stakeholder Groups, and other key actors.

This Roadmap first reports on the initial stakeholder consultations, deep dive workshops and high-level policy dialogues that engaged participants across different agricultural and NRM sectors. The consultation and workshop structure is then recounted, and lessons learned for implementation in future consultation exercises are documented.

Key findings of all engagements are reported under three key thematic areas that include:

1. Packaging EO information for use by smallholder farmers.
2. Meeting the demand for training and capacity building.
3. The need for relevant, high-resolution and accessible EO data products and services.

2. Results from Needs Assessments

The IAFWS project employed three pronged and distinct engagement formats which included:

1. Initial stakeholder consultations.
2. Deep dive workshops.
3. High level policy dialogues in all the six countries of project implementation.

The consultations engaged around 200 people from approximately 150 different organisations. A total 68% of attendees were male, and 32% female. Detailed breakdowns of attendance across gender and sector are provided in Appendix 1.

2.1 Initial consultations

The initial consultations were one day events which aimed to bring together a diverse array of participants from agriculture and natural resource management sectors. Participation across these sectors listed by different stakeholders such as Universities, Farmers' Organisations, and the Private Sector are presented in Appendix 1.

Participants then formed focus groups (Photo 1) to discuss ways to connect DE Africa with smallholder farmers, and conduct a strengths, weaknesses, opportunities, and threats (SWOT) analysis of the program. These are summarised for each country in Appendix 1, and repeated themes across countries are shown in Table 1.

Photo 1: *Participants engaged in focus group discussions at the initial consultation in Botswana.*

To assess the internal (weaknesses and strengths) and external (opportunities and threats) factors likely to affect the development of the EO sector in the target countries, a SWOT analysis was conducted with the participants. The findings from the SWOT analysis are presented in Table 1 below.

Table 1: Summary of responses to the SWOT analysis conducted by participants at the six stakeholder consultation meetings.

SWOT Analysis	
Strengths ● Tailored to the African continent ● Open and free data	**Weaknesses** ● Limited awareness; not well known ● Resolution (spatial and temporal) is perceived as low for some applications
Opportunities ● Conduct further capacity building and user engagement activities ● Develop products and services with more relevance to smallholder farmers	**Threats** ● Financial sustainability ● Competition from similar service providers

The opportunities identified in the initial consultations form the basis for the next steps and priority work areas outlined in this Roadmap. Table 2 below provides more details of the opportunities identified.

Table 2: Expanded list of opportunities identified in the initial consultation workshops (organised by themes).

Identified Opportunity	**Further Detail**
Connecting better to and more widely with end-users to achieve impact	● Connect further with decision makers. ● Research project collaboration and engagement ● App developers can leverage the platform ● Link outputs to apps and other media ● App development and linking to other initiatives, e.g. the Agrima App in Botswana.
Capacity building	● Conduct more training, especially online ● Expand capacity building activities ● Build capacity and improve access through training.
Communicating the presence and relevance of DE Africa to users	● Use case development ● Develop story maps ● Create more awareness about the program ● Generate more use cases e.g. wildlife monitoring, natural disaster monitoring.
Technical enhancement	● Perceived inaccuracy of some products ● Incorporate higher spatial resolution products.

To map out strategies and pathways for impacting livelihoods of smallholder farmers through use and uptake of EO data and information, workshop participants were asked to list strategies for linking with smallholder farmers. Results from this exercise (by country) are also presented in Appendix 1, based on common themes such as:

- Develop accessible user interfaces that farmers can engage with.
- Engage with farmers through networks, especially via extension officers and agencies.
- Identify and work with 'champion' farmers.

2.2 Deep dives

The deep dive consultations focused on delivery of capacity building for participants (Photo 2). Participants created accounts on the DE Africa Sandbox and were taken through 'hands-on' exercises in loading, inspecting, plotting, and analysing EO data on the platform. Once participants had become familiar with the platform through the training activities, they were then asked to suggest product development opportunities for DE Africa.

Following the initial consultation workshops, which sought broad feedback on the opportunities for DE Africa to meet the needs of the agriculture and natural resource management sectors, the deep dive workshops had a deeper focus on technical training and data products. This meant that the product development proposals made by participants after they had completed training had a more technical, data product focus. However, the suggestions made must be considered in light of the broader opportunities identified in the initial consultation regarding interfaces, accessibility, and capacity building.

Photo 2: *Some of the participants of the deep dive workshop in Addis Ababa, Ethiopia*

During the consultations, participants made various proposals on product development. Table 3 lists the product ideas and suggestions that arose in the consultation process (Appendix 1). Most importantly, these suggestions come from stakeholders who are directly involved in the agriculture and food security sector. The recommendations represent their thoughts on how EO might best meet information needs and gaps in the target countries.

Table 3: Summary of technical product development proposals made during consultations in six African countries.

Soil	Crops	Climate, Weather & Water
• Land suitability • Fertility • Land use and development planning	• Yield forecast • Crop-type mapping • Pests and diseases • Irrigated area mapping • Market information • Weed detection	• Rainfall • Temperature • Forecasts and outlooks • Early Warning Systems, including floods

2.3 Policy dialogues

Policy dialogues were conducted in all the six project countries in May and June 2023 and were facilitated by ASARECA and DE Africa staff. The overall objective of the policy dialogues was to disseminate the results of the IAFWS project to stakeholders, especially high-level policy makers in Government Ministries, Departments and Agencies. The policy dialogues also provided a platform to deliberate on the potential role of the policy makers in fostering the development of the EO sector, especially regarding the uptake of EO products and services and improving the policy and regulatory environment. The dialogues also identified strategies needed to institutionalise the use of EO data, products, and services in national planning processes to create sustainable impacts on the livelihoods of smallholder farmers and pastoral communities. Specific objectives included:

1. To disseminate the achievements of the IAFWS project and emphasise the role of EO data in supporting food security and enhancing climate adaptation.
2. To understand the process of institutionalising the utilisation of EO data, products, and services in national planning processes of various Government Ministries, Departments and Agencies.
3. To establish and discuss collaboration frameworks with ASARECA, CCARDESA and DE Africa for capacity strengthening of stakeholders in the use of the DE Africa platform.

The policy dialogues were attended by 177 participants, see Photo 3 (29 in Botswana, 34 in Ethiopia, 55 in Kenya, 36 in Rwanda, 25 in South Africa and 50 in Uganda). Participants came from international, regional and national organisations including National Agricultural Research Institutes, National Space Agencies, Department of Meteorology, Department of Climate Change, Ministry of Agriculture, Ministry of water, natural resources, and environment, Forest Research Institutes, National Bureau of Statistics, Universities, the private sector, NGOs, CGIAR centers, and UN organisations.

Photo 3: *Some of the participants of the policy dialogue in Nairobi, Kenya.*

Key findings that emerged from the policy dialogues include:

1. Existence of several institutions that are already using EO data, products and services for ecological modelling and forecasting pest outbreaks.
2. Urgent need to partner with telecom companies to be able to reach millions of smallholder farmers and get feedback from them.
3. Need to partner with a network of extension service providers or digital connectors to increase uptake of EO services since some smallholder farmers who need EO information are illiterate or don't have access to smartphones.
4. Need to translate EO products into simple language that can be easily understood by smallholder farmers and policy makers at all levels. This will ensure wide uptake especially among farmer organisations and other community development organisations that directly work with farmers.
5. Most of the agricultural data at National Agricultural Research Institutes (NARIs), MoA, Meteorology departments and Universities are not accessible to the Private sector or any other development partners.
6. Use cases are needed to demonstrate to farmers how EO data can support decision-making and increase farm productivity or resilience.
7. ASARECA and CCARDESA need to support their stakeholders in terms of digitising agricultural data collection and cloud storage. This may involve committing to make agricultural data FAIR (Findable, Accessible, Interoperable, and Reusable) and constitute stakeholders within the EO data value chain into a platform to avoid duplication.
8. ASARECA needs to support its member NARIs in drafting a data governance framework and establishing one-stop hubs for all agricultural research data within a country.
9. ASARECA and CCARDESA need to consider partnering and linking their Knowledge Management (KM) hubs with non-agricultural institutions such as National Space Agencies, UN agencies and Government MDAs that already have Geodata portals, data cubes, EO Knowledge hubs and access to high-resolution satellite imagery.
10. ASARECA and Kenya National Bureau of statistics need to jointly develop standardised data (administrative and survey) collection and publication/sharing

protocols and increase data literacy among both state and non-state actors at county level.

11. ASARECA and CCARDESA need to support their member countries in undertaking policy analysis and formulation for the EO sector based on the data/evidence generated during the policy dialogues.

3. Key Objectives

Considering the broad themes that emerged, results from the initial consultations and deep dive workshops reveal that DE Africa should pursue the following key objectives:

1. Connecting with smallholder farmers.
2. Strengthen and expand user engagement and capacity development.
3. Developing accessible information products.

3.1 Connecting with smallholder farmers

Smallholder farmers are often the agents of change in food security and rural development endeavours across Africa. Workshop participants and farmers' organisations revealed a deep commitment to ensure smallholder farmers reap the benefits of EO.

Smallholder farmers are defined as an individual or household involved in agricultural activities on a relatively small plot of land. They are "small-scale farmers, pastoralists, forest keepers, fishers who manage areas varying from less than one hectare to 10 hectares" (Food and Agriculture Organisation*,* 2012). The specific land size that defines a smallholder farmer may vary across regions and countries, but generally, it refers to farmers who cultivate small plots of land for subsistence or to generate income for their families.

Smallholder farmers often rely on traditional farming methods and have limited access to modern agricultural technologies, resources, and infrastructure. They usually employ family labour or engage with a small number of hired workers to carry out farming activities.

In each of the IAFWS consultations, participants noted the importance of leveraging existing networks to form sustainable links with smallholder farmers. In each of the six countries, connecting through extension agencies and extension officers was listed as a key strategy. Extension services play a fundamental role in the agriculture sector in many African countries, and in some cases have strong agency over farmer actions, such as the choice of which crops to grow and when to plant them. Engaging with extension services in such contexts is non-negotiable. Smallholder farmers therefore fit within a network, within which DE Africa must play a role.

The consultations also revealed that some applications for smallholder farmers might be made through dialogue between DE Africa, ASARECA, CCARDESA and smallholder farmers, while other initiatives and applications may require dialogue with more parties. For example, an interpretable software application showing soil moisture status or NDVI progress for a selected field could be implemented between DE Africa, ASARECA, extension agencies, the private sector and smallholder farmers. Conversely, implementation of Earth Observation analysis as part of a national crop insurance scheme would require more comprehensive dialogue involving a wider range of stakeholders including the private sector and government ministries. This Roadmap seeks to classify pathways to connect with smallholder farmers based on the complexity of applications and of the discussions required to implement them.

Figure 2 shows a conceptual framework of pathways to impact smallholder farming systems, with the centrality of smallholder farmers as agents of food security illustrated in their position at the centre of the diagram. Three avenues of activity are nominated based on results of the consultations:

1. Data visualisation and interpretable dashboards which present data in an informative way, such as soil moisture status or NDVI curves.
2. Decision support and data processing which present outputs from data analysis and processing which goes beyond visualisation, such as derivation of crop-type maps or yield forecasts.
3. Decision processes and policy implementation which present decision-ready information for a decision or policy, such as the risk of crop failure for insurance schemes.

Examples of activities are given under each classification. Round arrows represent the circular, ongoing, dialogue that is necessary to the co-design and maintenance of all products and services at DE Africa.

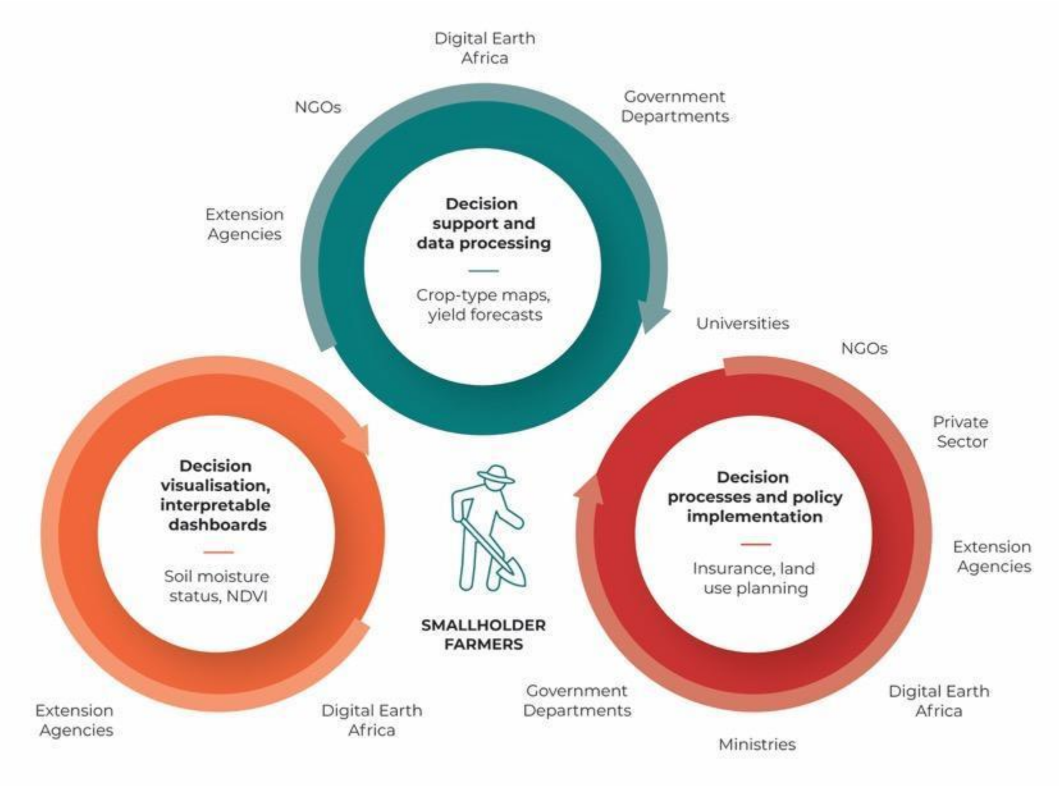


Figure 2: *Conceptual diagram illustrating pathways to impacting smallholder farmers via simple data visualisation, decision support and data processing, and decision processes and policy implementation. Circular arrows represent an ongoing co-design dialogue with the stakeholders listed.*

Figure 2 illustrates the centrality of smallholder farmers, though this project has prompted consideration of whether smallholder farmers are best approached as ‘users’, or as ‘beneficiaries’, or some balance of each. Participants in the consultation noted several hurdles to smallholder farmers engaging with DE Africa as ‘users’. For example, internet connectivity is limited at many smallholder farming locations and capacity gaps exist not just in EO, but across a broad spectrum of digital literacy. However, smallholder farmers may be regarded as the ultimate ‘beneficiaries’ of DE Africa activities without being directly involved in using data. In practice, different pathways to impact are likely to involve smallholder farmers as either or both of ‘users’ and ‘beneficiaries’, depending on objectives.

To become users of data, consultations revealed the need for more accessible interfaces to DE Africa data. Such interfaces should negate the need to write any programming code; rather, they should enable ‘point and click’ interactivity and quick access to insights. They should also present data in a way which is informative to smallholder farmers. The specifics of this should be determined through the co-design process involving smallholder farmers themselves, and extension agents, represented in the bottom-left part of Figure 2.

Co-design processes and dealings with smallholder farmers should also recognise that rural sectors in African nations may be undergoing transformation, and farmers may therefore be seeking opportunities outside farming. Fan & Brzeska (2016) argue that agricultural development paradigms should acknowledge that smallholder farmers may seek other opportunities in agricultural value chains or beyond agriculture. DE Africa should aim to support the “development and coexistence of different farming models” and agricultural service provision in such circumstances (Fan & Brzeska 2016). This means that DE Africa should remain flexible, dynamic, responsive to user needs, and be willing to support a range of agricultural development pathways, rather than supporting a particular model.

3.2 Capacity development and user engagement

Inadequate awareness of DE Africa, and capacity gaps in accessing and using the data, were consistently identified as program weaknesses at the consultation workshops. This reveals unmet demand for further user engagement and capacity building activities. The consultations also provoked thought and discussion on how users are identified and classified, and different forms of training for different users.

Prospective users can be identified, and can identify themselves, through a range of communication avenues. The lack of awareness of DE Africa identified in consultations raises a causality dilemma; there needs to be a balance between ready-made use cases and products which attract users to DE Africa, and DE Africa contacting prospective users to seek guidance on appropriate products and use cases. In the agriculture and food security domain, it is likely that prospective users have clear wants and needs (as articulated during the consultations) related to their domain expertise, but do not have the requisite expertise in Earth observation to request products and services with desired specifications. This is why entry-point products and services, and training in how to use them, are critical aspects of the co-design dialogue with users.

It was evident from the deep dive consultations that participants were able to give much more informed and valuable advice about the strengths, limitations, and opportunities for EO data once they had completed basic training in the DE Africa Sandbox. This reveals the importance of training as a key aspect of co-design dialogue. In an effective dialogue, both the users and the providers become more informed during the course of product development. Initial training, and later more specialised training, is a key element of this.

DE Africa currently offers a range of training and engagement activities including:

- Weekly live sessions that alternate between English and French, which have proven to be a popular means of engaging users in product releases and conducting training;
- Online courses and modules such as 'Introduction to the Sandbox' which is a fully online, self-paced course; and
- An online help desk and guides which users can access.

Participants at many consultations offered novel ideas for alternative training formats beyond those currently offered, including 5–10 minute online videos demonstrating basic data access and analysis which would be shorter and broader in content than both the live sessions and the online courses. They would be pitched at end-users who are interested in improving their knowledge of the platform asynchronously. The workshops themselves demonstrated the value of in-person interaction, training, and dialogue where there is an identified objective. In-person training is the most expensive and potentially least efficiency form of training in terms of reaching broad audiences across the continent. However, the dialogue and interaction it enables cannot be replicated in online forums. Targeted in-person engagement is critical among key stakeholders during more complex co-design processes, such as those represented in the bottom right of Figure 2. Overall, the mode of training and user engagement will depend on the characteristics and needs of the user, and overall objectives.

Immediate opportunities in capacity development that were suggested during consultations were:

- Short training video series
- Expand IAFWS to more countries
- Design soil information training material
- Continent-wide in-person training program targeted at specific user groups in the agricultural and NRM research and development communities such as:
    - Extension agencies
    - Departments of Agriculture
    - Farmers' Organisations (incl. farmers themselves)
- Training programs and capacity building services specific to developers and the private sector such as:
    - Leveraging the DE Africa platform in service provision
    - Incorporating EO data into software application development

3.3 Accessible information products and services

The consultations and deep dive workshops revealed numerous information services and products DE Africa could pursue to meet the needs of smallholder farmers. However, it is noted that these product ideas are logical entry-points, and further consultation would be required to identify decision points and provide information in the required format and time to inform the decision.

A major part of further consultation is ensuring that services and products will be accessible to desired users. To achieve this, two elements of their design need to be considered:

1. The network via which the product or service is to be adopted, such as through state (extension agencies, Ministries of Agriculture) or non-state (NGOs, private agronomists) actors.
2. The interface used to access the product or service, such as an interactive Dashboard, a static map, or an analysis environment.

Networks can be developed by seeking advice from a range of relevant actors in the first instance, which will vary by country and region. For example, private sector actors formed a large portion of participants in South Africa and Kenya and consultation feedback from South Africa especially noted the importance of the private sector (Appendix 1). Contrastingly, state actors, such as the Rwanda Agriculture and Animal Resources Development Board (RAB), were widely referred to in Rwanda. Broad initial engagement will identify a select set of actors able to play a bridging role between DE Africa and smallholder farmers.

Decisions on interfaces must be made in consultation with bridging intermediaries and users. Their capacity in EO analytics, the level of time invested in receiving information from the interface, and the volume/detail of information required to inform a decision must be considered during consultation. For example, a static crop-type map may be sufficient in some instances, while a dynamic interface showing the latest agroclimatic measures for a farm area selected by a user may be necessary in other circumstances.

The ideas identified in consultations vary in complexity and technical feasibility for implementation. In some cases, access and interpretation of DE Africa's products and services within the program's existing consultation and capacity building services may be sufficient. In other cases, a more comprehensive co-design process may be required and technical expertise beyond DE Africa may be sought. This means that information products can be sorted and prioritised both on the level of demand and the complexity of implementation.

4. Opportunities

4.1 Tiered approach

In this roadmap, each proposed pathway has been assigned a *'Tier'* rating. The rating reflects the technical, resourcing, and logistical resources required to meet the user-identified information need, with Tier 1 requiring the least additional resources and Tier 3 the most (Table 4). Additional resources would be sought from partners for delivery of activities listed under all three Tiers. More details on potential partnerships are provided in Figure 4, which illustrates the sequential steps of circular dialogue when delivering a stated need.

Table 4: Tier ratings according to complexity, time, partnership (further defined in Figure 4), and resource requirements.

Tier Rating	Technical Complexity	Time	Partnership	Resources
Tier 1	Low	12 months	Dialogue with relevant user groups	Medium
Tier 2	Medium	12–24 months	Some formal partnership with regional agricultural organisations or similar	High
Tier 3	High	3 years +	Multi-agency, such as DE Africa and a CGIAR centre, in conjunction with regional agricultural research organisations.	High

Generally, activities classified as Tier 1 indicate that implementation is easily deliverable with some additional user consultation, technical effort, and training material development, beyond that already planned by DE Africa. Tier 1 activities could be started and completed within a 12-month period. Examples include additional training activities such as out-scaling to new countries. Tier 1 products and services should be prioritised according to perceived user demand and availability of willing partners. Additional resourcing would be required to implement Tier 1 proposals.

Tier 2 pursuits are those that can be leveraged from existing DE Africa products and services but require additional technical development and user engagement to implement. The expertise could be mostly sourced from within DE Africa's existing personnel and that of implementing partners and collaborators, such as ASARECA. Tier 2 projects could generally be implemented in around twelve months, such as development and dissemination of new training material. The IAFWS project is itself a good example of a Tier 2 initiative.

Initiatives classified as Tier 3 are ambitious projects which would require a multi-agency, multi-year approach with considerable additional resourcing. They would also involve greater scale than Tier 1 and 2 products and services; for example, they may be completely new continental scale applications requiring engagement in numerous African nations.

4.2 Tiered opportunities

Tables 5 and 6 categorise the identified opportunities against each Tier. Table 5 lists technical products and services while Table 6 deals with capacity building opportunities. The opportunities included in these Tables are those that were repeatedly identified in consultations and workshops. The Tables are not exhaustive; there may be separate opportunities or some that are tangential to those listed that could be pursued and the list of potential partners and supporters may be expanded. The Tables should be treated as dynamic and subject to change.

Table 5: Technical products and services that may meet needs and gaps in Earth Observation for agriculture and food security organised by tier which represents resourcing and effort required for implementation.

Tier	Products and Services	Description	Budging Strategy	Potential Partners	Status	Priority Countries
Tier 1	Soil fertility & characteristics	Mapping soil fertility and other soil variables such as pH with a view to map agricultural land capability.	Co-design with extension agencies and farmers organisations.	iSDA soil	**Active:** the Fertility Capability Classification is available in the DE Africa Sandbox and training material is being developed	Botswana, Ethiopia, Kenya, Rwanda, Uganda, South Africa
Tier 2	Crop-type mapping	Crop-type mapping is often a prerequisite to more detailed analyses such as yield forecasting.	Engage with farmers organisations, agriculture departments, and extension agencies to determine crops of interest and co-design a data collection workflow.	CGIAR centres, Agriculture & Food Security agencies, ESA WorldCereal	**Active:** this activity has been completed by Digital Earth Africa in some countries and regions. However, no new activities are planned	Botswana, Ethiopia, Uganda

Tier 2	Irrigated area mapping	A map which differentiates between irrigated and rainfed cropland would be useful for numerous applications, such as water resources monitoring.	Engage with extension agencies to better understand the characteristics of irrigation in different regions, liaise with agriculture ministries to determine information. needs and policy implications.	CGIAR centres, ESA WorldCereal, National Governments e.g. Ministries of Agriculture & Irrigation Departments	**Inactive:** this has been ideated but not formally planned.	Botswana, South Africa, Ethiopia
Tier 2	Climate & crop production dashboard	This product addresses feedback raised regarding the need for a simpler interface for some users	Work with CGIAR centres and extension agencies to understand the information required by smallholder farmers, how it should be presented, and at what times it is needed.	CGIAR centres, Agriculture & Food Security agencies, extension agencies.	**Active:** formal planning is underway.	Rwanda, Botswana, South Africa, Kenya
Tier 3	Early warning systems — pests & diseases	Monitoring and forecasting of pest and disease pressure could enable farmers and service providers (e.g. pest management officers and agronomists) to better prepare.	Identify farmer decision points on pest management based on consultation with extension agencies and CGIAR centres.	CGIAR centres, global forecasting and early warning initiatives e.g. USGS FEWSNET	Inactive: ideated but not yet planned.	Ethiopia, Kenya, South Africa, Uganda
Tier 3	Early Warning Systems - Crop Production	Yield forecasting and crop early warning systems are frequently requested due to their	Identify farmer decision points on crop management (e.g. input applications) based on consultation with	CGIAR centres, ESA WorldCereal, global forecasting and early warning initiatives e.g.	Active: some initial (though largely informal) planning has been occurring.	Ethiopia, Kenya South Africa, Uganda

		potential to improve food security. However, they are technically challenging to implement effectively.	extension agencies and CGIAR centres.	USGS FEWSNET		

Table 6: Capacity development products and services that may meet needs and gaps in Earth Observation for agriculture and food security organised by tier which represents resourcing and effort required for implementation.

Tier	Products and Services	Description	Connecting to smallholder farmers	Potential Partners	Status	Priority Countries
Tier 1	Short Training Video Series	Short training videos that could be used as self-paced training material were identified as an opportunity.	Work with agriculture departments to understand topics of interest, relevant languages, and best forms of delivery.	DE Africa implementing partners	Active: formally planned and budgeted.	Continent wide (with consideration for language requirements)
Tier 1	Soil Information Training Material	The demand for soils information identified in the workshops would logically be accompanied by training material.	Form a working group of users who expressed interest in using soils information to guide co-design of training material.	iSDA soil	Active: A live session has been delivered and annotated notebooks have been added to the platform.	Continent wide (with consideration for language requirements)
Tier 2	DE Africa for Developers	Opportunities were identified to leverage EO data in private service provision and connecting to app developers.	Engage interested parties, such as software and app developers, from the private sector and seek strategic engagement with	Private sector	Inactive: ideated but not yet formally planned.	TBC

			extension agencies to ensure end-user needs are being considered.			
Tier 3	Continental Agriculture & Food Security Capacity Building Initiative	A continental capacity building initiative involving both in-person training and online material would assist in overcoming lack of awareness and capacity gaps related to agriculture, food security, and NRM. This would be additional to continental capacity building work delivered under DE Africa Phase III.	Co-design training material with extension agencies that have established networks in smallholder farmer communities. Seek to engage 'champion farmers' prior and during training to facilitate peer-learning.	DE Africa implementing partners, ASARECA, CCARDESA, the African Capacity Building Foundation	Inactive: ideated but not yet formally planned.	Continent wide

The Tiered products and services in Tables 5 and 6 itemise and categorise opportunities, though they can still be considered as sitting within thematic areas (Table 3) and as part of the food security and agricultural development network (Figure 2). Figure 3 illustrates this idea by showing smallholder farmers dealing with decision points related to soils, crops, and climate, weather, and water. The decision points are where smallholder farmers connect with DE Africa and a broader community of extension service providers, NGOs, agricultural departments and ministries, and other actors. Information and data feeds into this community through DE Africa, where a circular dialogue leads to development of products and services that meet information needs at the decision point. Examples of decision points and related products & services (to be further scoped and developed in circular dialogue) are given in tables adjacent to each thematic dialogue.

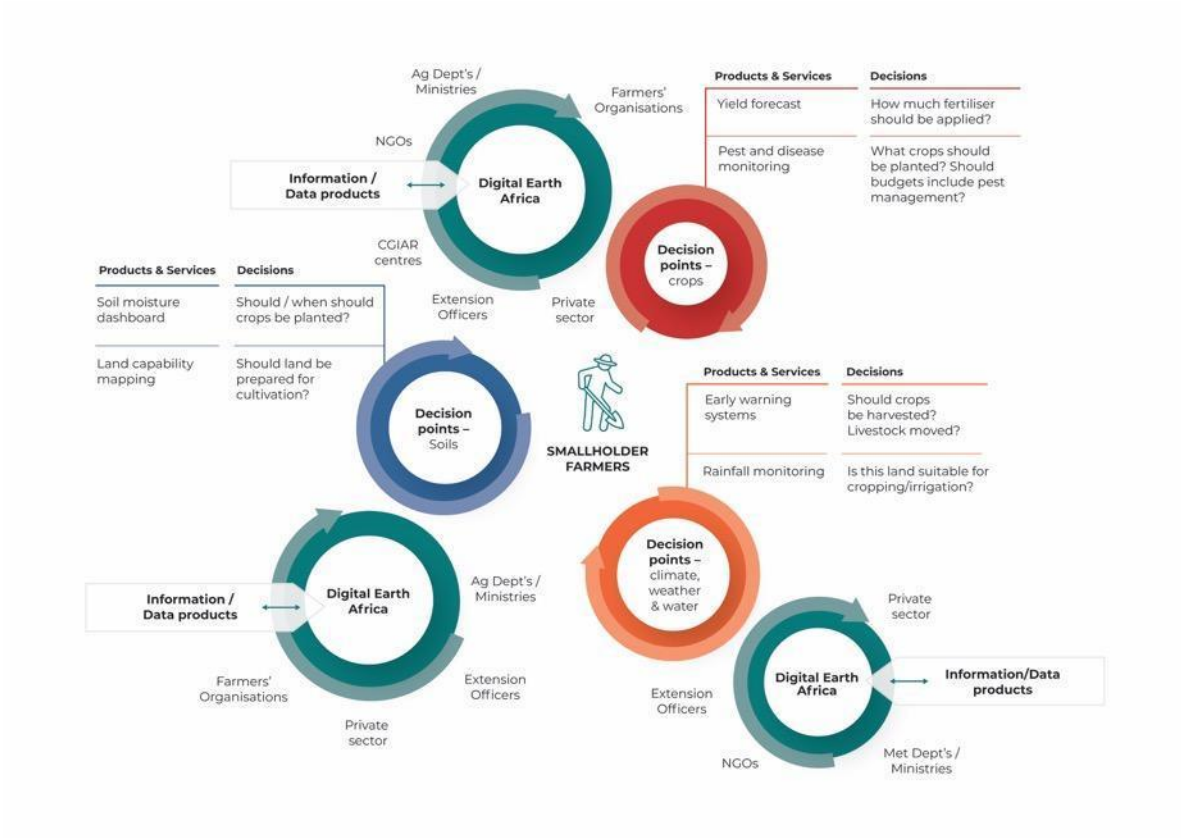


Figure 3: *Conceptual illustration of how smallholder farmers can engage with Digital Earth Africa through decision points in various thematic aspects of agriculture.*

5. Next steps

The results of the consultations and workshops reveal unmet demand for numerous engagement and capacity building activities. Reactions to the DE Africa program were overwhelmingly positive, though lack of awareness and perceived risks associated with competitors were commonly nominated by workshop participants. This reveals that DE Africa needs a clear communication strategy that reaches the agriculture and NRM sector. The strategy needs to articulate that DE Africa is:

- Providing a routine, reliable and operational EO service with open and free data
- Specifically designed for the African continent
- Committed to diversity, inclusion, and engagement at continental, national, regional and local scales
- A leading source of capacity development in the EO field.

These elements separate DE Africa from organisations perceived to be conducting similar operations and raise awareness of DE Africa's capabilities.

This Roadmap documents key opportunities arising from consultation and discussion, with careful consideration of how smallholder farmers can be the ultimate beneficiaries of activities. The document can be referred to by DE Africa and potential partners and supporters as pathways to impacting food security are pursued.

There are numerous opportunities to meet the needs and gaps identified to pursue projects whilst maintaining dialogue between DE Africa, ASARECA & CCARDESA, and the other stakeholders identified during consultations. Maintenance of dialogue will be critical to effective co-design. Potential partners and supporters should also be approached to understand their willingness and capacity to be involved. DE Africa will also maintain contact with ACIAR, as funders of this scoping work, to identify any potential activities DE Africa can contribute to.

The pathway to achieving some of the opportunities identified in this Roadmap can be conceptualised as a series of sequential dialogues. Figure 4 illustrates this by showing a sequence of steps that can be followed when pursuing an identified opportunity, such as those described in Tables 5 and 6. This diagram can be used as a planning tool and a checklist to ensure necessary consultation and dialogue occurs in product development, and that opportunities for user engagement and feedback are not missed.

The dialogue processes described in Figure 4 begin with identifying relevant user groups. A 'decision point' or information need is then identified before an initial use case is implemented. Feedback on the product or service is then sought as part of a training process. The product or service is then revised based on feedback and scaled beyond the use case. Finally, the product or service is presented to the broader community with feedback sought and revisions made as necessary.

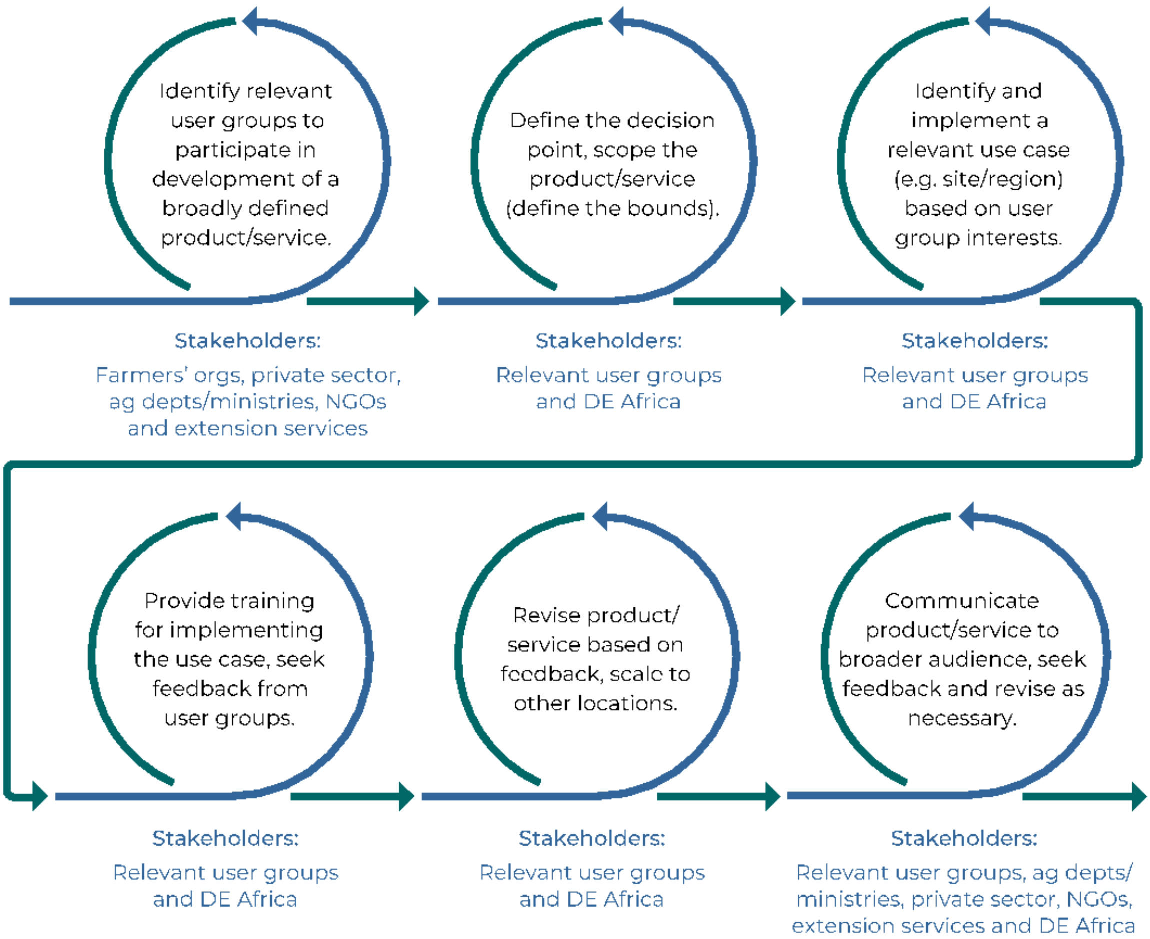


Figure 4: *Sequential steps of circular dialogue which Digital Earth Africa will undertake when pursuing opportunities to provide information for agriculture, food, and water security.*

This Roadmap is subject to change as priorities shift in response to user requirements, advances in technology, and relationships with data providers that support the African Earth Observation community. The priorities and needs are clarified and defined by DE Africa's Governing Board, the Product Development Task Team, the Technical Advisory Committee and DE Africa's stakeholders and key users. We recommend that the Roadmap be routinely reviewed and updated.

Acknowledgements

The IAFWS project was funded by the Australian Centre for International Agricultural Research (ACIAR) under project code WAC/2021/164. It was implemented by Digital Earth Africa via Geoscience Australia and the Digital Earth Africa Program Management Office at the South African National Space Agency, in collaboration with the Association with Strengthening Agricultural Research in Eastern and Central Africa and the Centre for Coordination of Agricultural Research and Development for Southern Africa.

Digital Earth Africa is supported by the Helmsley Charitable Trust and the Australian Government — Department of Foreign Affairs and Trade with additional support from numerous key partners.

This project benefitted from consultation partners, in an advisory capacity, representing the International Water Management Institute (IWMI), the Group on Earth Observations, the Food and Agriculture Organisation, and the Australian National University.

6. References

Fan, S., & Brzeska, J. (2016). Sustainable food security and nutrition: Demystifying conventional beliefs. *Global Food Security*, *11*, 11–16. https://doi.org/10.1016/j.gfs.2016.03.005

Food and Agriculture Organisation. (2012). *SMALLHOLDERS AND FAMILY FARMERS*. Food and Agriculture Organization. Retrieved June 9, 2023, from https://www.fao.org/fileadmin/templates/nr/sustainability_pathways/docs/Factsheet_SMALLHOLDERS.pdf

Kganyago, M., & Mhangara, P. (2019). The Role of African Emerging Space Agencies in Earth Observation Capacity Building for Facilitating the Implementation and Monitoring of the African Development Agenda: The Case of African Earth Observation Program. *International Journal of Geo-Information*, *8*(7). https://doi.org/10.3390/ijgi8070292

Mwaniki, A. (2006). Achieving food security in Africa: Challenges and issues. *UN Office of the Special Advisor on Africa (OSAA)*.

Ottichilo, W. K. (2006). REGIONAL CENTRE FOR MAPPING OF RESOURCES FOR DEVELOPMENT (RCMRD): GEO-INFORMATION CAPACITY BUILDING ACTIVITIES IN AFRICA. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Science*, *36*(6), 295–299.

Pritchard, R., Alexandridis, T., Amponash, M., Ben Khatra, N., Brockington, D., Chiconela, T., Ortuno Castillo, J., Garba, I., Gomez-Gimenez, M., Haile, M., Kagoyire, C., Kganyago, M., Kleine, D., Korme, T., Manni, A. A., Mashiyi, N., Massninga, J., Mensah, F., Mugabowindekwe, M., … Zoungrana, E. (2022). Developing capacity for impactful use of Earth Observation data: Lessons from the AfriCultuReS project. *Environmental Development*, *42*. https://doi.org/10.1016/j.envdev.2021.100695

Speranza, C. I., Akinyemi, F. O., Baratoux, D., Benveniste, J., Ceperley, N., Driouech, F., & Helmschrot, J. (2022). Enhancing the Uptake of Earth Observation Products and Services in Africa Through a Multi-level Transdisciplinary Approach. *Surveys in Geophysics*, *44*, 7-41. https://doi.org/10.1007/s10712-022-09724-1

Appendix 1: Country Reports

A1.1 Botswana

A1.1.1 Initial consultation

The initial consultation in Gaborone, Botswana took place on 6–7 November 2022 with approximately 27 participants across the two days. A wide range of stakeholders were present from Botswana and several surrounding countries (Figure A1). The farming community was represented by the farmers' organizations, though government officials, the university sector, and non-governmental organisations/ not-for-profit organizations comprised a large proportion of participants (Figure A2). The majority of participants were male (Figure A3).

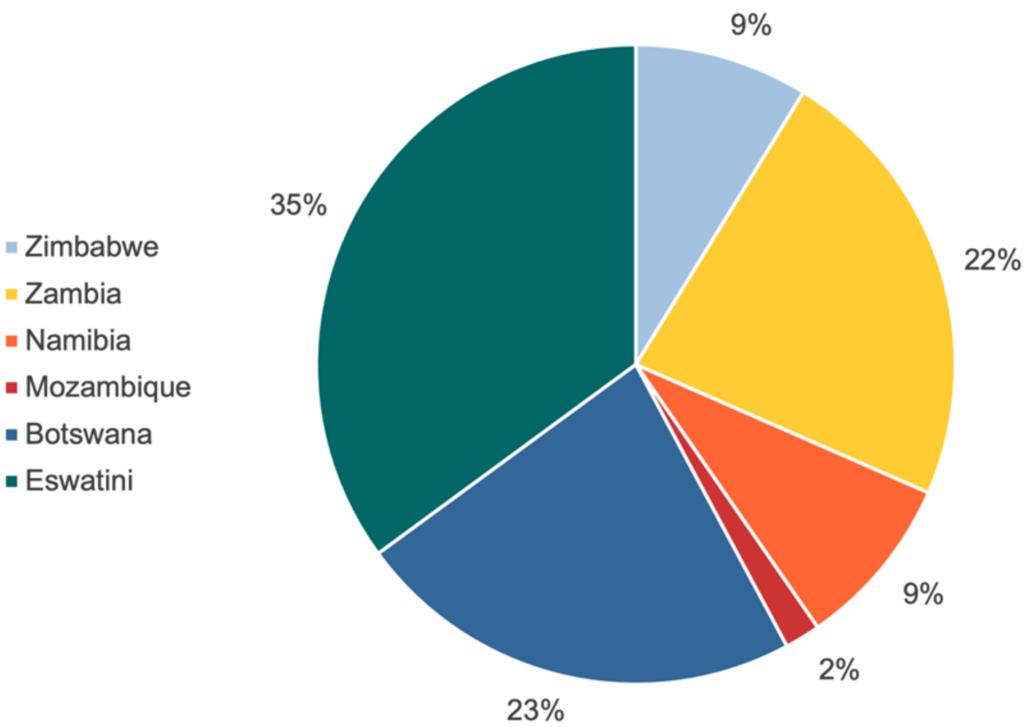


Figure A1: *Distribution of participant country of origin at the Botswana initial consultation.*

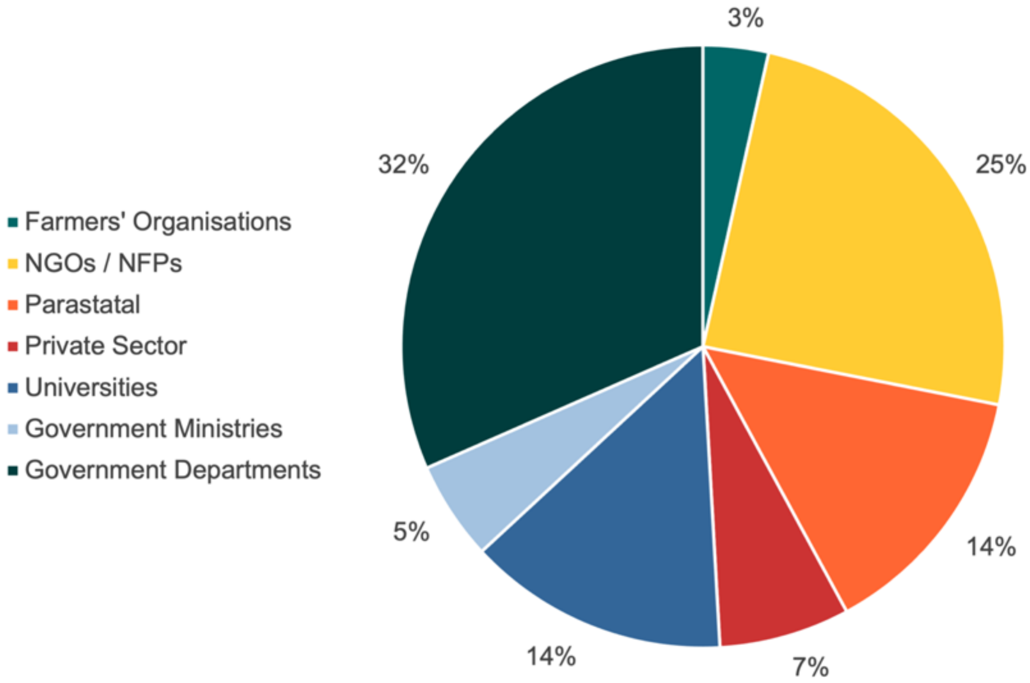


Figure A2: *Distribution of sectors represented at the Botswana initial consultation.*

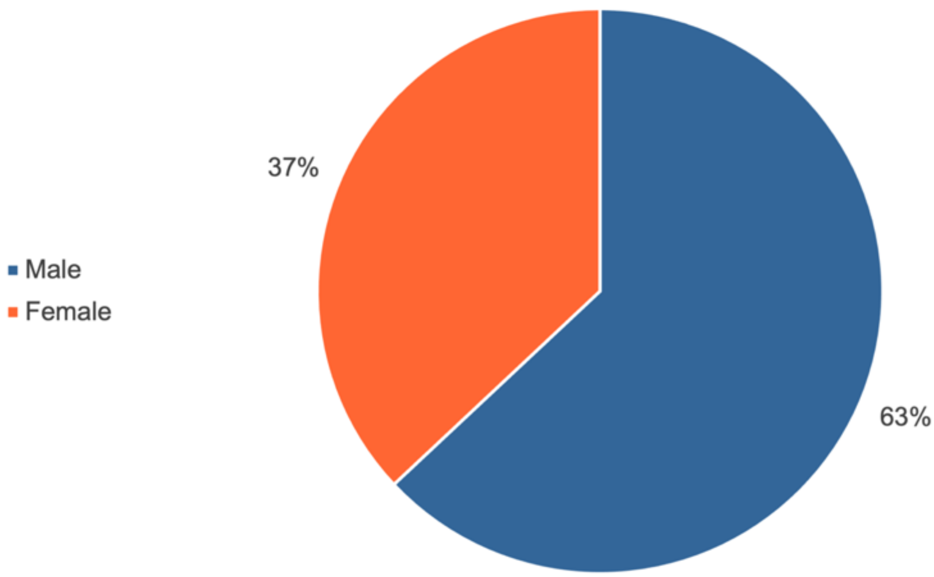


Figure A3: *Distribution of genders represented at the Botswana initial consultation.*

Day one of the initial consultation was filled with presentations from officials and representatives from CCARDESA and DE Africa, who gave overviews of EO data and the

DE Africa platform. This prompted valuable discussion on existing data products and services and their capacity to support food security initiatives.

On day two, participants were asked to provide feedback on DE Africa, and identify opportunities for Earth Observation to meet the needs of smallholder farmers. These discussions were held in smaller focus groups. Feedback was also sought on policy implications and potential partnerships. Participants listed the following strategies to better link to smallholder farmers:

- Form linkages initially with extension officers and build EO capacity among extension officers.
- Conduct workshops and meetings (kgotla, public forums) that can be led by extension officers.
- Provide user-friendly applications e.g. climate services dashboard that can be easily interpreted and provided in local languages.

The overall strengths, weaknesses, opportunities and threats of DE Africa identified by participants in focus groups can be summarized in Table A1 below.

Table A1: Responses to the strengths, weaknesses, opportunities, and threats analysis conducted by participants at the Botswana consultation.

SWOT Analysis	**Nil**
Strengths • Free & accessible • Tailor made for the African context • Contemporary and attractive to young farmers.	**Weaknesses** • Not broadly known; limited awareness • Requires internet • Some computer programming is required to gain the complete benefit of the data • The spatial resolution of the data is perceived to be too low.
Opportunities • App development by public and private actors and linking to other initiatives e.g. the Agrima App published by the Ministry of Agriculture in Botswana • Generate more use cases e.g. wildlife monitoring, natural disaster monitoring.	**Threats** • Sustainability beyond funding • Accuracy of products • Competing platforms and cloud services • New satellite missions

A1.1.2 Deep dive consultation

The deep dive consultation was held on 2–3 March 2023 and approximately 25 delegates participated (see image below). The distribution of sectors in attendance was similar to the initial consultation, though a greater representation from the private sector was noted (Figure A4). The majority of participants were male (Figure A5).

Caption: *Group photo of participants at the Botswana deep dive consultation.*

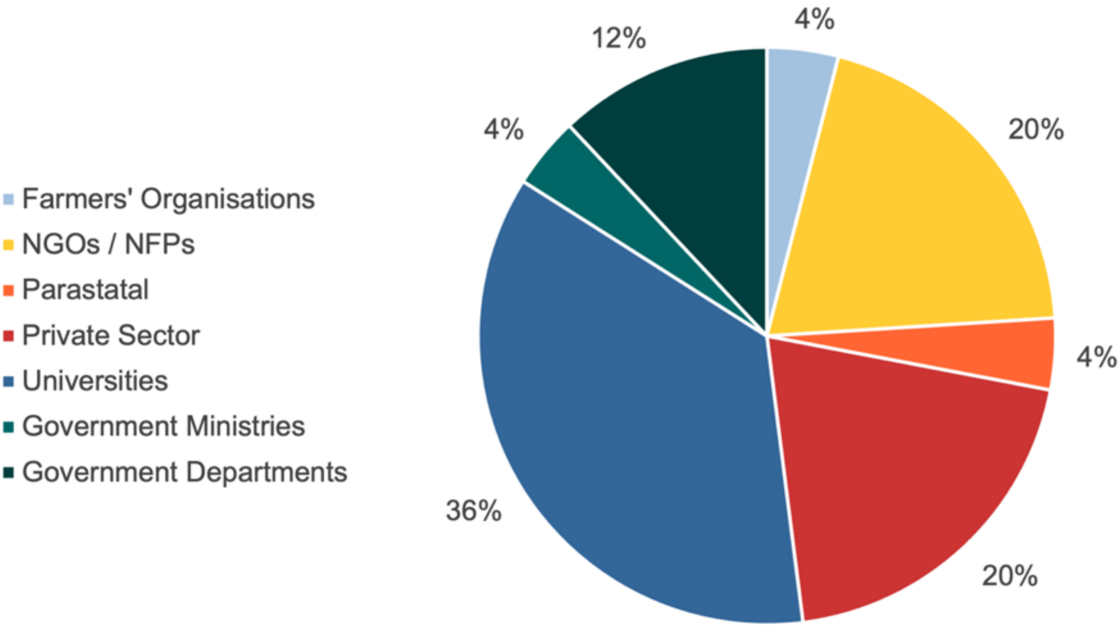


Figure A4: *Distribution of sectors represented at the Botswana deep dive consultation.*

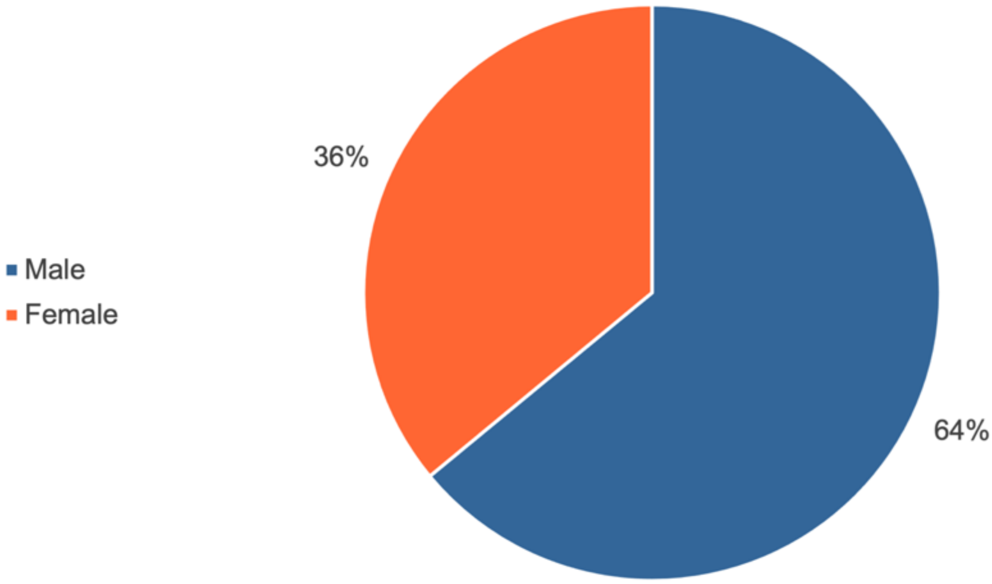


Figure A5: *Distribution of genders represented at the Botswana deep dive consultation*

The deep dive consultation involved a more detailed overview of the Digital Earth Africa platform and hands-on training in how to use the platform to investigate crop health, phenology, vegetation anomalies and water extent. This gave participants a greater appreciation of the strengths and limitations of the platform and enabled them to give informed requests for technical product development. Requested products included:

- Soil type mapping
- Land suitability mapping
- Pest prevalence and expansion monitoring
- Crop yield estimation
- Crop type mapping
- Mapping cropped and potential croplands

A1.2 Ethiopia

A1.2.1 Initial consultation

The Ethiopia initial consultation and deep dive workshop were conducted on consecutive days from January 17–19 2023, attracting approximately 33 participants over the course of the consultations. Universities were well-represented, as were personnel from Government Departments, which mainly comprised institutes such as the Ethiopian Institute of Agricultural Research and the Ethiopian Meteorological Institute (Figure A6). Less than 10% of participants were female (Figure A7).

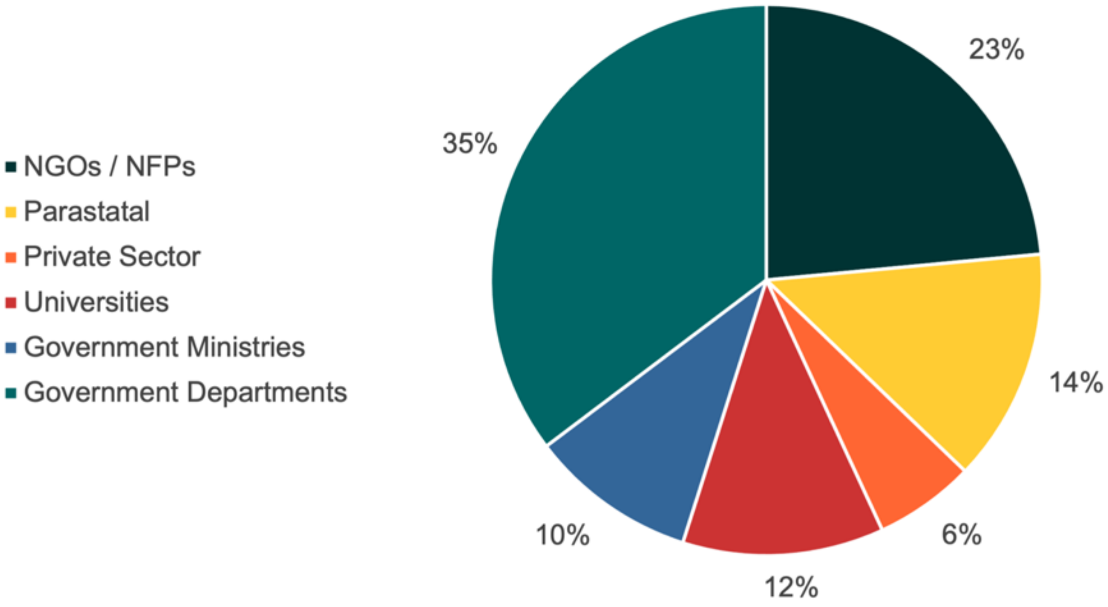


Figure A6: *Distribution of sectors represented at the Ethiopia initial consultation.*

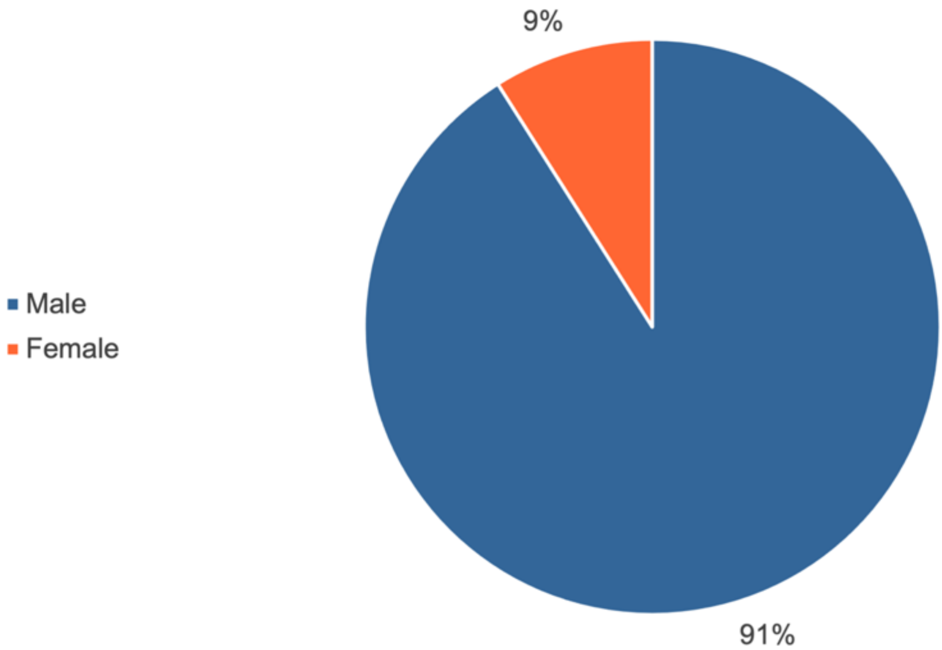


Figure A7: *Distribution of genders represented at the Ethiopia initial consultation.*

Participants listed the following strategies to better link to smallholder farmers:

- Build capacity and networks among extension officers.
- Provide information that is crop specific and/or regionally specific.
- Adopt local language where possible.
- Integrate with devices farmers are already using e.g. through apps.
- Engage with existing capacity building exercises e.g. farmer training centres.

Responses to the strengths, weaknesses, opportunities and threats exercise (performed by several groups) are summarised in Table A2.

Table A2: Responses to the strengths, weaknesses, opportunities, and threats analysis conducted by participants at the Ethiopia consultation.

SWOT Analysis	Nil
Strengths • Analysis-ready data and cloud-based service • Specific to the African continent • Links to the Africa geoportal.	**Weaknesses** • Lack of awareness about the program • Capacity and skills gaps related to data science and processing among potential users • Access requires internet connectivity • Lack of a clear business model.
Opportunities • Build capacity and improve access through training • Create more awareness about the program • Link outputs to apps and other media.	**Threats** • Sustainability of funding beyond current rounds of funding • Data sources may not be secure and reliable.

Products and use cases suggested included:

- Land degradation monitoring
- Crop yield estimates
- Crop disease monitoring
- Crop type mapping (wheat, barley, mapping clustered wheat clustered areas)
- Soil health monitoring
- Integrating imagery from drones/UAVs, validation of remotely sensed products
- Land suitability assessment for irrigation and other agricultural uses
- Biomass and carbon accounting
- Estimation of evaporation/evapotranspiration
- Water resources monitoring and early warning systems for floods
- Assessment of rangelands and forage production
- Soil health mapping (soil salinity)
- Land degradation assessment and effect on ecosystem services, land degradation and restoration
- Water quality and forest degradation monitoring and mapping

A1.3 Kenya

A1.3.1 Initial consultation

The initial consultation in Nairobi, Kenya, was held on 8 December 2022 attracting around 21 participants, and the following deep dive workshop was held on 27–28 February 2023 with 25 participants. Government departments and institutions, such as the Kenya Agricultural and Livestock Research Organisation, were well represented (Figure A8). Kenya also hosts numerous international research institutions and other NGOs, such as the International Livestock Research Institute and World Agroforestry, which were also represented. The farming community was represented by the Women Farmers' Association of Kenya. Over 40% of attendees were Female (Figure A9).

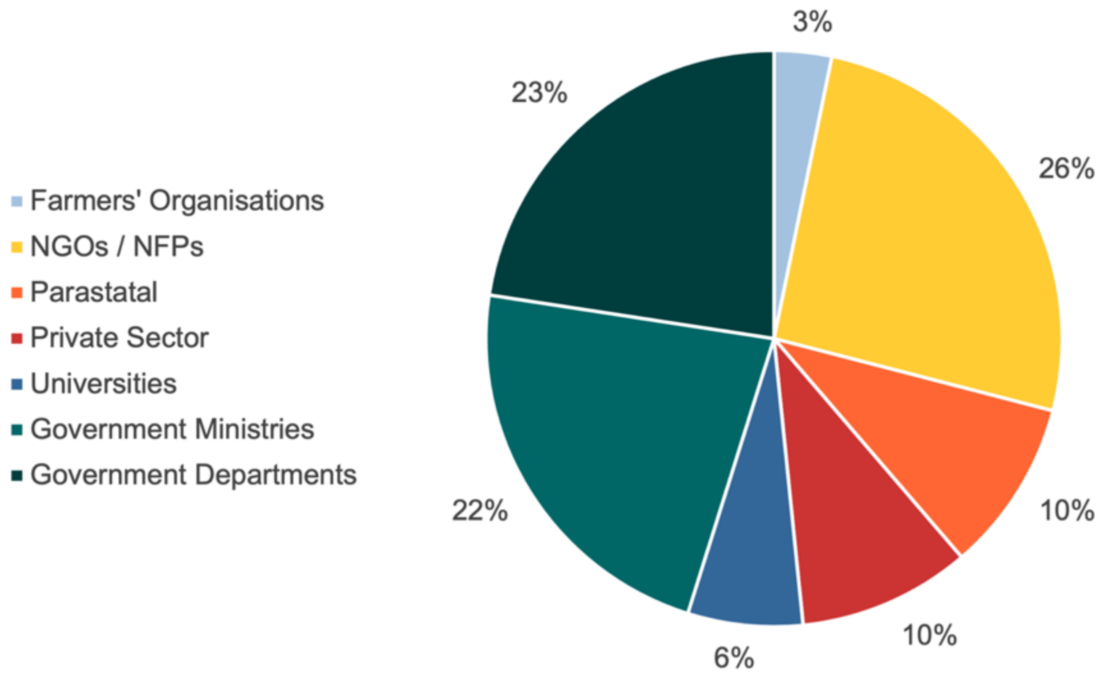


Figure A8: *Distribution of sectors represented at the Kenya initial consultation.*

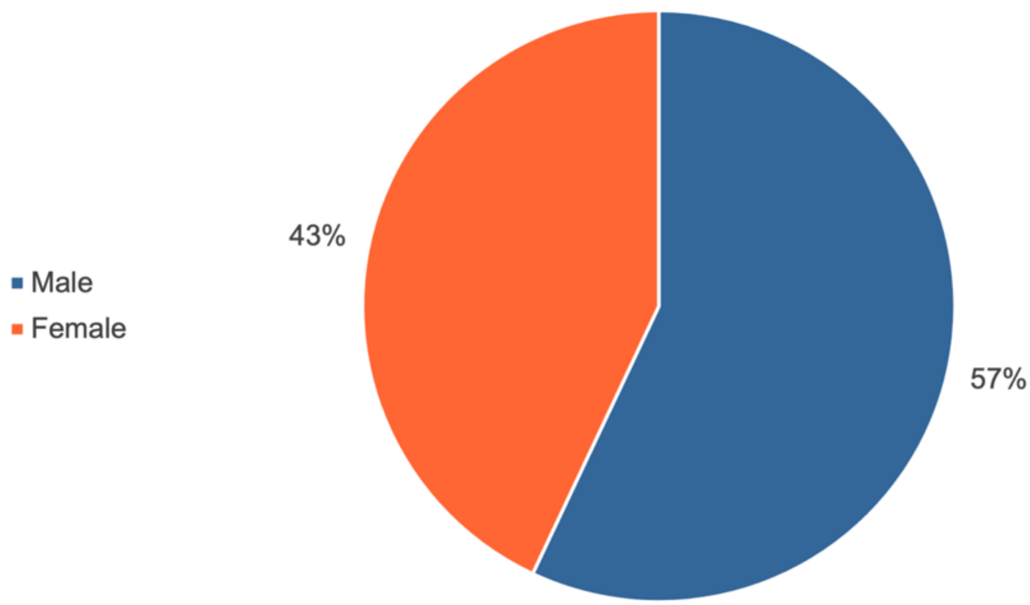


Figure A9: *Distribution of genders represented at the Kenya initial consultation.*

Caption: *Participants at the Kenya initial consultation.*

Groups nominated the following strategies to link EO and DE Africa with smallholder farmers:

- Use extension officers as a linkage and leverage existing networks at agriculture departments;
- Use village chiefs (Chief Barazas) as entry points;
- Create 'champions' who can lead adoption among farmers.

Responses to the strengths, weaknesses, opportunities and threats exercise (performed by several groups) are summarised in Table A3.

Table A3: Responses to the strengths, weaknesses, opportunities, and threats analysis conducted by participants at the Kenya consultation.

SWOT Analysis	Nil
Strengths • Timely provision of data • Specific to the African continent • Links to the Africa geoportal.	**Weaknesses** • Spatial resolution could be inadequate for some applications • Lack of capacity among users.
Opportunities • Develop StoryMaps which communicate narratives with geographic information, drawing on Esri's Africa Geoportal which is partnered with DE Africa • Incorporate higher spatial resolution products.	**Threats** • Sustainability of funding beyond current rounds of funding • There is strong competition in the Earth Observation sector.

Product and service ideas:

- Link with private sector to provide advisory on soil, and potentially support insurance;
- Early warning systems, including for pests and diseases;

- Identification of different cropping patterns and systems e.g. mixed cropping, Phenology mapping for phases and types (food crops, cash crops);
- Water resources planning and monitoring of irrigation;
- Need for an agricultural information hub;
- Food security monitoring for long and short rains, rainfall trends;
- Rangeland monitoring;
- Flood risk mapping;
- Mapping of landslide hotspots;
- Crop yield estimation (especially sugarcane).

A1.4 Rwanda

A1.4.1 Initial consultation

The Rwanda initial consultation was held on 6 December 2022 with 22 participants, and the deep dive was held on 2–3 March 2023 with 28 participants. Like Kenya, government departments, such as agriculture departments, and international NGOs were prominent at these workshops (Figure A10 and the image below). The Rwanda Agriculture and Animal Resources Development Board (RAB) a strong presence and therefore featured strongly in both the initial consultation and the deep dive. The majority of participants were Male (Figure A11).

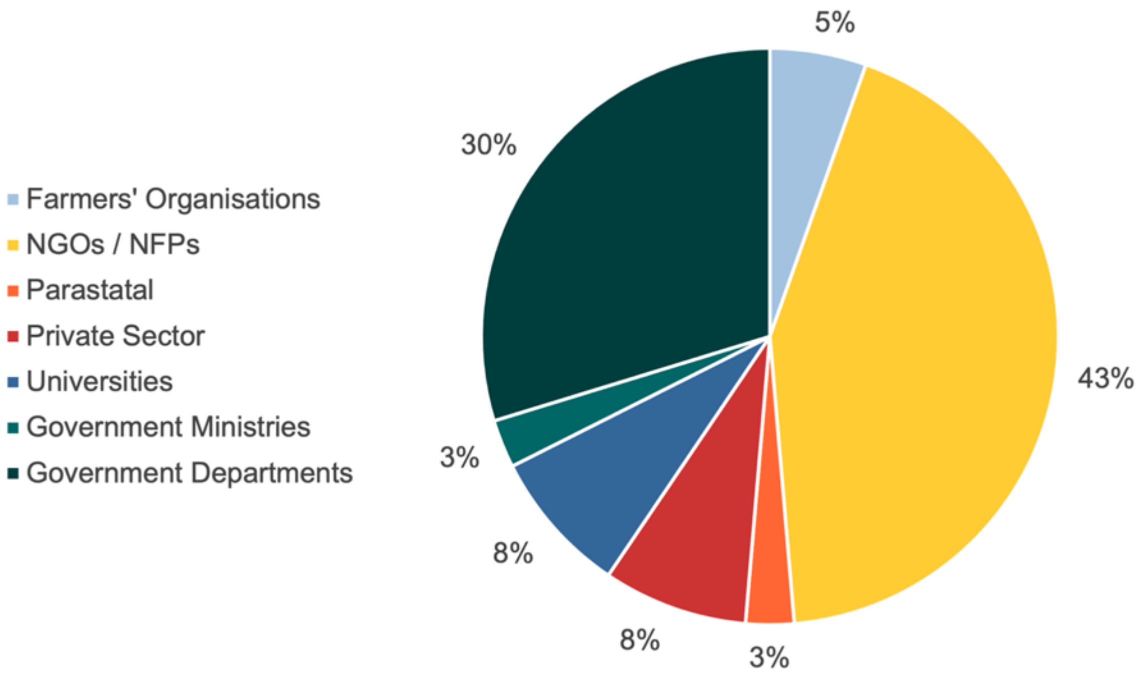


Figure A10: *Distribution of sectors represented at the Rwanda initial consultation.*

Caption: *Participants at the Rwanda initial consultation.*

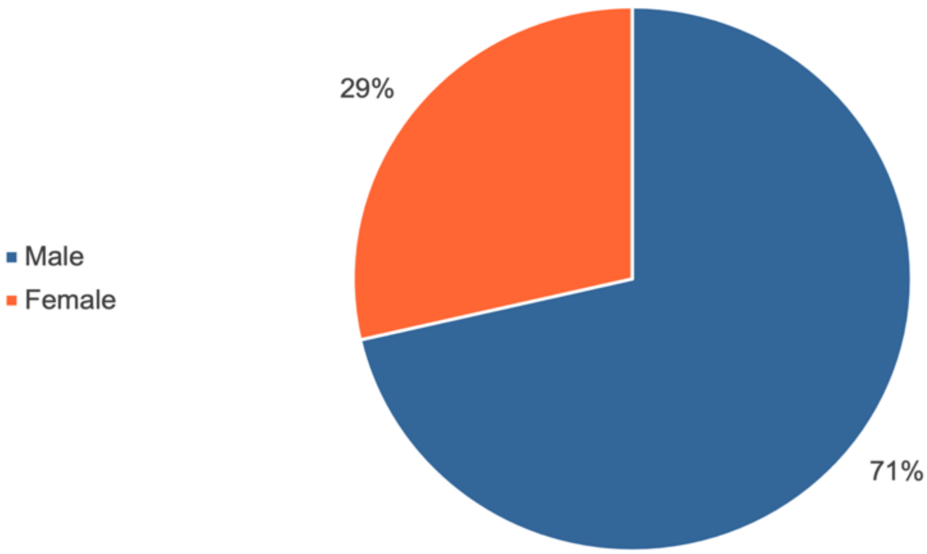


Figure A11: *Gender distribution of participants at the Rwanda deep dive consultation.*

Noting the strong presence of RAB at the discussions, participants noted the following strategies to connect to smallholder farmers:

- Work with extension services through the RAB and local governments;
- Work through farmers' associations/cooperatives;
- Look at engaging 'champion' farmers;
- Enhance awareness of Earth Observation and DE Africa through media.

Four small focus groups conducted discussions and nominated strengths, weaknesses, opportunities and threats for DE Africa's products and services (Table A4).

Table A4: Responses to the strengths, weaknesses, opportunities, and threats analysis conducted by participants at the Rwanda consultation.

SWOT Categories	Nil
Strengths - Specific to the African continent - Skilled staff - Open source and free.	**Weaknesses** - Not tailored to smallholder farmers - Doesn't link with existing climate and weather services - Resolution is insufficient for some applications e.g. tree mapping - Low awareness.
Opportunities - Conduct more training, especially online - Connect further with decision makers - Perceived inaccuracy of some products.	**Threats** - Lack of financial capacity and/or certainty, unclear financial sustainability - Reliance on primary data providers - Many similar service providers - Limited capacity of end-users.

Recommendations for product and service development included:

- Pest and disease monitoring and management
- Soil management and mapping information
- Training programs, including online live sessions and pre-recorded modules
- In-person capacity building activities, especially for extension personnel
- Agricultural spatial planning and production
- Precision agriculture/climate smart agriculture monitoring
- Biodiversity conservation
- Availing tools and data for decision support in spatial planning

A.1.5 South Africa

A1.5.1 Initial consultation

The South Africa initial consultation and deep dive workshop were held consecutively from the 14–16 February 2023 with 26 participants. There were several dignitaries representing Australia, South Africa, and the African continent on the first day of proceedings. Small groups performed the usual strengths, weaknesses, opportunities and threats analysis and interested participants continued onto the deep dive workshops for the following two days.

The consultations attracted delegates from numerous institutions including the University of Johannesburg, University of Witwatersrand, and NGOs such as the FAO and IWMI. Some private sector actors also participated (Figure A12 and image below). Over 30% of the participants were Female (Figure A13).

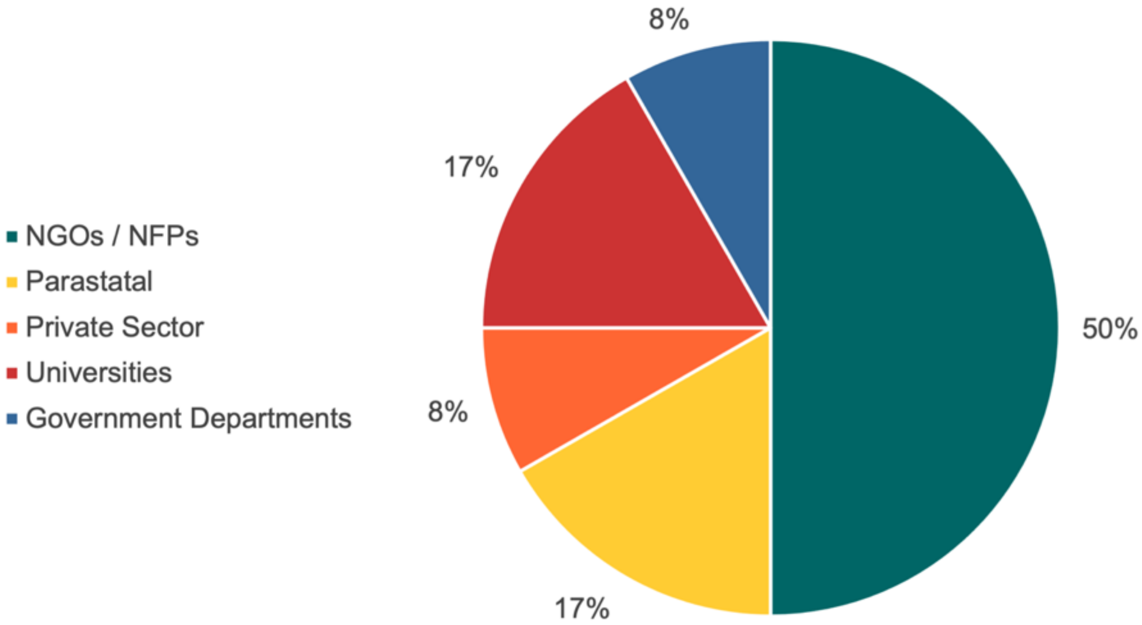


Figure A12: *Distribution of sectors represented at the South Africa initial consultation.*

Caption: *Participants at the South Africa initial consultation.*

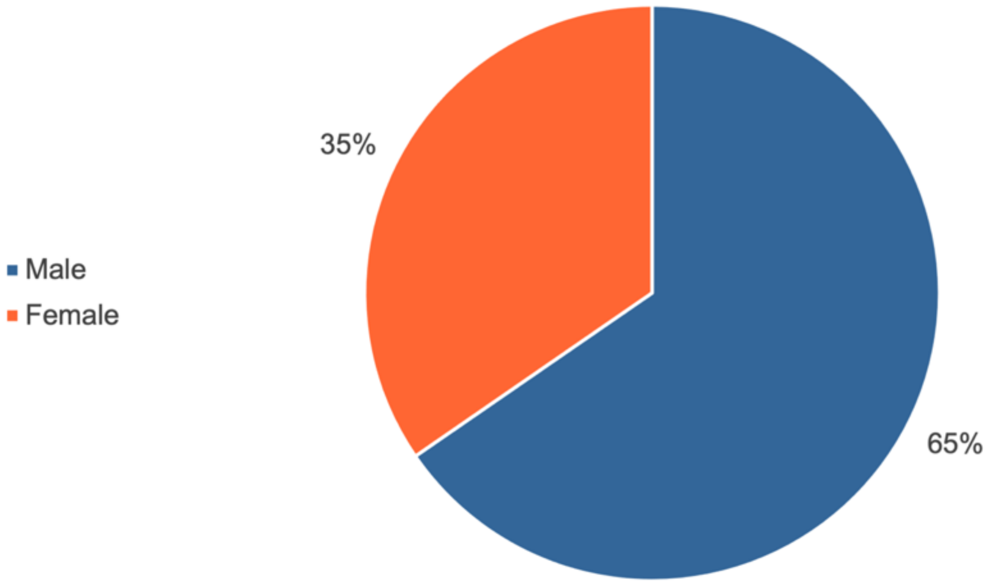


Figure A13: *Distribution of gender represented at the South Africa initial consultation.*

Participants in the South Africa consultations nominated the following strategies to connect with smallholder farmers:

- Utilise existing networks and structures such as farmers' associations and the private sector;
- Develop new user interfaces for better information accessibility.

Responses to the strengths, weaknesses, opportunities, and threats analysis were similar to other countries (Table A5).

Table A5: Responses to the strengths, weaknesses, opportunities, and threats analysis conducted by participants at the South Africa consultation.

SWOT Analysis	Nil
Strengths • Free and open analysis ready data • Strong user community	**Weaknesses** • Not visible in many sectors • Narrow group of users who have the capacity to leverage the data.
Opportunities • Use case development • Research project collaboration and engagement	**Threats** • Competition from other data providers.

Ideas and suggestions for product development included:

- Mapping of smallholder farming activity;
- Early warning systems, including for floods;

- Wetland monitoring and protection;
- Spatial planning for development, including urban agriculture;
- Soil information and soil moisture;
- Crop growth monitoring and weed detection;
- Flood risk mapping;
- Disaster management;
- Agricultural value chains and agricultural information systems.

A1.6 Uganda

A1.6.1 Initial consultation

The initial consultation in Kampala, Uganda, took place on 30 November 2022 with around 31 participants and the deep dive consultation took place on 23 February 2023 with approximately 30 participants. A broad range of NGOs and NFPs engaged in the discussions, including representatives from organisations such as the FAO, CIFOR, and LANDnet Uganda. There were also representatives from the Uganda National Meteorological Authority and the National Agricultural Research Organisation, classified as government departments. Four universities were also represented (Figure A14). Notably, 48% of participants were Female (Figure A15 and image below). Overall, the meetings in Uganda comprised a diverse range of stakeholder voices.

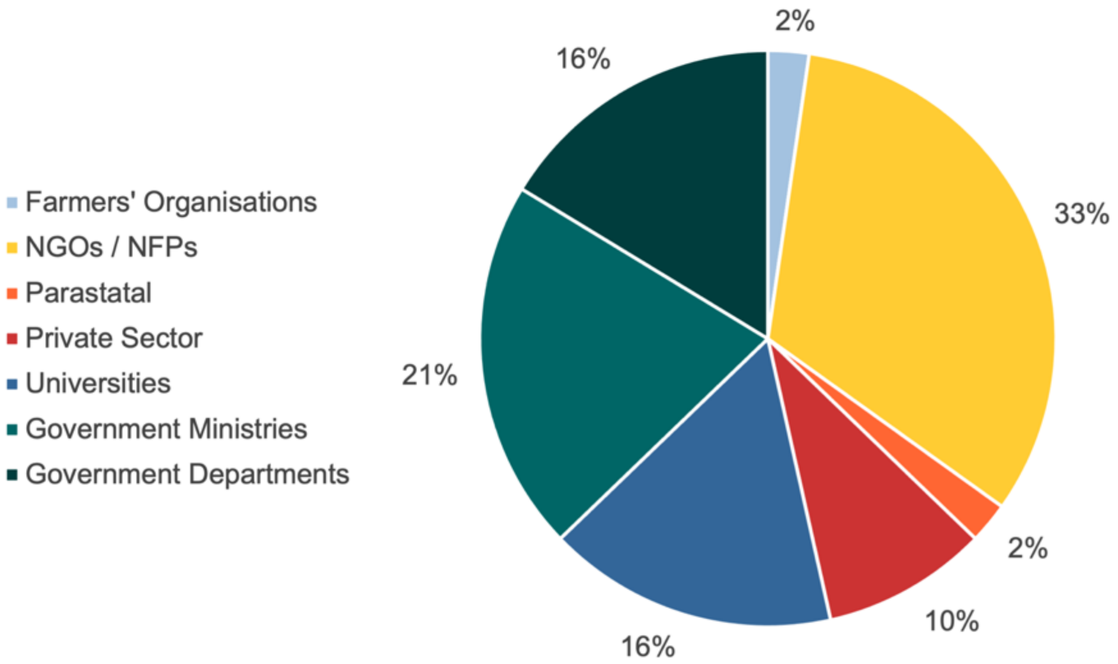


Figure A14: *Distribution of sectors represented at the Uganda initial consultation.*

Caption: *Participants at the initial consultation in Uganda.*

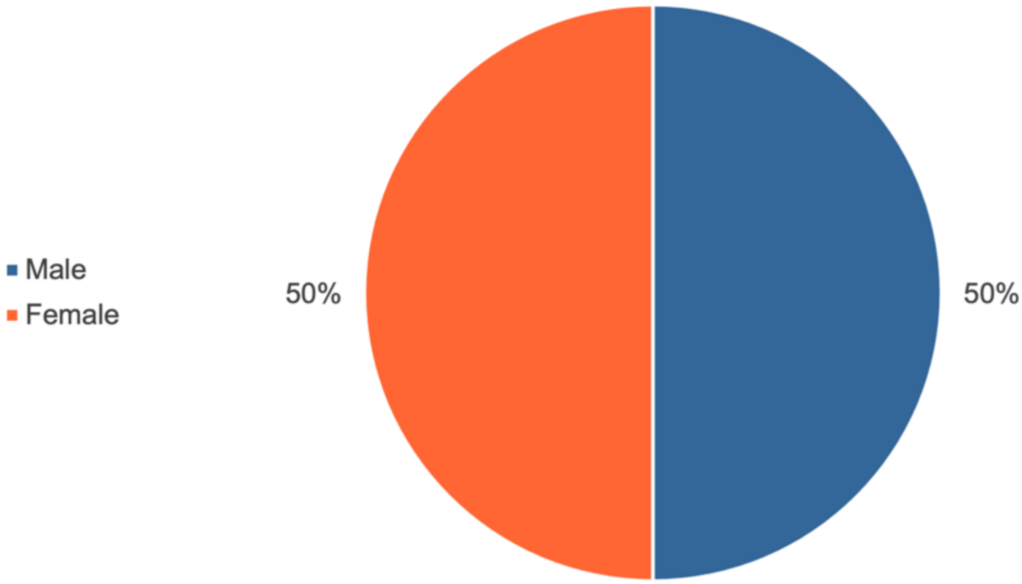


Figure A15: *Distribution of genders represented at the Uganda deep dive consultation.*

Five focus groups recorded the following strategies to connect with smallholder farmers:

- Leverage existing extension networks, both public and private;
- Media outlets, especially those consumed by the farming community;
- Religious and traditional institutions;
- Arm extension agents with simple tools such as apps which can be used as entry points.

The strengths, weaknesses, opportunities, and threats identified by the same five groups are summarised in Table A6.

Table A6: Responses to the strengths, weaknesses, opportunities, and threats analysis conducted by participants at the Uganda consultation.

SWOT Analysis	Nil
Strengths • Capacity building is included in the program • Data is easily accessible.	**Weaknesses** • Products may not be accessible to smallholder farmers • Access requires reliable internet connectivity • Access requires programming knowledge • The catalogue of datasets is not exhaustive • Spatial and temporal resolution can be perceived to be too low.
Opportunities • App developers can leverage the platform • Expand capacity building activities.	**Threats** • Sustainability of the program • Competition from other service providers • Ignored gender mainstreaming concerns may limit uptake of solutions • Reliance on operational satellites and data providers.

The diversity of stakeholders present meant that a useful range of well-informed suggestions were made for products and services, as follows:

- Soil information and soil type maps;
- Crop types, pathogens and diseases;
- Early warning systems for crop and/or pasture production (e.g. through a drought index or locust warnings);
- Market information and market linkages;
- Demonstration farms i.e. digital twins;
- Water extent and quality;
- Disaster risks monitoring and capacity building.

Appendix 2: Dissemination workshops

A2.1 Botswana

A2.1.1 Dissemination workshop

A dissemination workshop was held in Botswana on 20 June 2023 with 25 participants. The results of the initial and deep dive consultations were presented with a policy brief, the key messages of which are shown in Figure B1. An item of note for Botswana in particular was the limited technical capacity and access to resources among the agricultural sector, meaning intermediaries would need to play a strong role in supporting the use of EO.

Key messages

Timely, accurate and reliable information is critical for early warning to mitigate the impacts of climatic shocks.

Satellite data helps in monitoring crop conditions and performance, for instance through yield estimation and production forecasting.

Limited technical capacity to analyse satellite data, lack of cross-sector/industry/stakeholder collaboration, and spatial resolution are major challenges to harnessing the benefits of satellite data in Botswana.

DE Africa, ASARECA and CCARDESA offer opportunities to stakeholders to receive continuous training in the use of satellite data, processing tools, products, and services.

There is a need to strengthen the science-policy interface for more effective, evidence-based policies to facilitate the use of satellite data, products and services in agriculture and food security.

Figure B1: Excerpt from the policy brief presented at the dissemination workshop and policy dialogue in Botswana showing key messages.

A2.2 Ethiopia

A2.2.1 Dissemination workshop

The dissemination workshop in Ethiopia was held on 22 June 2023 with 26 participants. The policy brief included twelve key actions required to enhance utilisation of satellite technology for agriculture in Ethiopia, as follows:

- Improve temporal accuracy of weather forecasts;
- Develop local crop and pasture models suitable for African communities;
- Use satellite data for weather monitoring and forecasting in remote areas;

- Increase awareness and dissemination of the available EO data;
- Strengthen capacity of stakeholders and institutions to utilise EO data and tools;
- Scaling of pilot projects or interventions;
- Develop guidelines on the use of EO data for crop growth monitoring, yield prediction, in-season agro-advisory, and agricultural risk financing;
- Create an enabling policy environment;
- Planning and allocation of budget support for use of EO data;
- Direct purchase of high-resolution data in special cases;
- Identify and address barriers in science education during early years;
- Establishment of multi-stakeholder partnerships.

A2.3 Kenya

A2.3.1 Dissemination workshop

The Kenya dissemination workshop was held on 27 June 2023 (see image below). Participants heard a summation of findings from the initial and deep dive consultations. Separate panel discussions were held on the establishment of partnerships with state and non-state actors. The panels comprised representatives from NGOs and the government sector, respectively, which highlighted the importance of seeking avenues to impact through both state and non-state actors.

Caption: *Participants at the dissemination workshop in Kenya.*

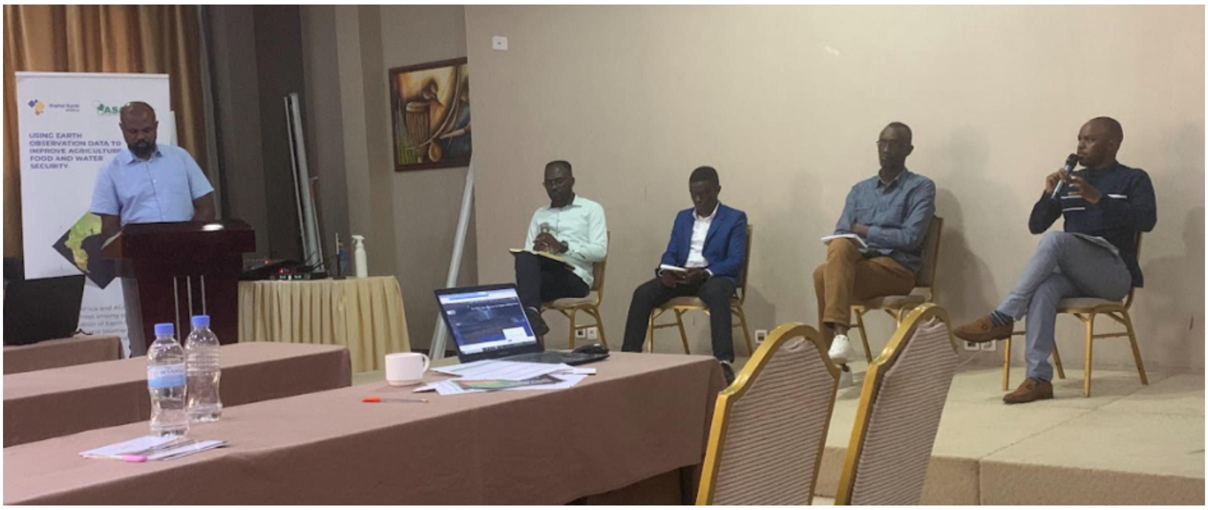
A2.4 Rwanda

A2.3.1 Dissemination workshop

The Rwanda dissemination workshop was held on 30 May 2023 (see image below). The Deputy Director General of Rwanda Agriculture and Animal Resources Development Board

(RAB) Dr Florence Uwamahoro opened the workshop by noting the importance of EO data to inform decisions in the agriculture sector and acknowledged the support from ACIAR.

A panel discussion was held with representatives from the private sector and government. Questions were posed about the role of state and non-state actors in the adoption of EO tools. Numerous common threads from the initial consultations and deep dive workshops arose, such as the identification of champions, the opportunity for capacity building activities, and the need for state support for necessary infrastructure, such as reliable internet connectivity.



Caption: *Panel discussion at the dissemination workshop in Rwanda.*

A2.5 South Africa

A2.3.1 Dissemination workshop

The South Africa dissemination workshop was conducted on 7 June 2023. This was particularly well attended by DE Africa personnel due to their proximity. This dissemination workshop delivered preliminary results from the Roadmap and proposed products and services arising from the initial and deep dive consultations.

A2.6 Uganda

A2.3.1 Dissemination workshop

The dissemination workshop in Uganda was held on 1 June 2023 and attracted 50 participants (see image below). A presentation was given by a representative from the National Agricultural Research Organisation who noted the role of EO in early warning systems, acknowledged the support of ACIAR, and the work of DE Africa and ASARECA.

Following a presentation of findings from consultations, participants noted the importance of ensuring that information from EO products and services was relevant and accessible to end users, which in many cases would involve regional and local specificity. It was noted that traditional field data collection methods and EO/remotely sensed data should be complementary.

Caption: *Participants reviewing and discussing materials at the Uganda dissemination workshop.*

Appendix 3: Policy Briefs

Australian Government
Australian Centre for International Agricultural Research

Australian Government
Geoscience Australia

Digital Earth AFRICA

CCARDESA

ASARECA
Transforming Agriculture for Improved Livelihoods

Satellite Data for Improved Monitoring of Farm Productivity and Early Warning Systems in Botswana

Joshua Sikhu Okonya[1], Enock Warinda[1], Moses Odeke[1], Baitsi Podisi[2], Futhi Magagula[2], Cliff Sibusiso Dlamini[2], Andrew Farrow[3], Felicia O. Akinyemi[4], Reason L. Machete[5] Benedict Kayombo[6], Joseph Tuyishimire[7], Kenneth Mubea[8], & Wellington Michael[9]

POLICY BRIEF
Botswana - June 2023

Key Messages

- Timely, accurate and reliable information is critical for early warning to mitigate the impacts of climatic shocks.
- Satellite data helps in monitoring crop conditions and performance, for instance through yield estimation and production forecasting.
- Limited technical capacity to analyse satellite data, lack of cross sector/industry/stakeholder collaboration, and spatial resolution are major challenges to harnessing the benefits of satellite data in Botswana.
- DE-AFRICA, ASARECA and CCARDESA offer opportunities to stakeholders to receive continuous training in the use of satellite data, processing tools, products, and services.
- There is a need to strengthen the science-policy interface for more effective, evidence-based policies to facilitate the use of satellite data, products, and services in agriculture and food security.

Background

Despite the adaptation and mitigation measures that have been put in place to counter the negative effects of climate change and food insecurity, more than 57.8 million people in the Southern African Development Community (SADC) population need food assistance in 2023 due to poor harvests (APA 2023). In Botswana, alone, close to 37,000 people need food assistance (FAO, 2022). This comes against the backdrop of declining agricultural productivity attributed to several factors including high cost of inputs, high incidence of pests and diseases, low input use and extreme weather conditions such as droughts, floods, and erratic rainfalls (FAO 2022).

The traditional methods of drought prediction (in-situ physical rain gauges) used in most of the rural areas of Botswana is unreliable and does not consider explicit information on risk profiles/sectors and provides short-term forecasts. Satellite technology helps in monitoring drought impacts and provides early warning information.

Satellite Technology

Satellite Technology entails continuous observation of land characteristics using a space-borne platform that orbits the earth's surface. It is specifically the process of detecting and monitoring the physical and biochemical characteristics of objects on the earth's surface through measuring their reflected and emitted radiation at a distance. A special sensor with the capability of detecting reflected and emitted radiation over a wide range of electromagnetic spectrum is used to gather target reflected and emitted radiation and form an image. Satellite Technology offers a synoptic view of objects on the earth's surface and has the advantage of obtaining earth's data in near-real time over large areas easily and effectively, and that gives it the capability to collect information on the weather, land use, crop health, and other important parameters. Satellite images are collected, processed, analysed, and converted into useful information that stakeholders within the food security programs can use to make informed policy decisions.

Contribution of Satellite Technology to Improved Food Security in Botswana

Satellites provides regular data on the weather, land use, crop production, and other important parameters to facilitate effective and better decision making. Among others, Satellite images provide useful information for:

1. Measuring and forecasting health, growth and yield of crops, pasture, and livestock
2. Monitoring excessive rainfall, floods, and drought to generate early warning systems.
3. Monitoring and reporting carbon footprint as required by United Nations Framework Convention on Climate Change (UNFCCC).
4. Mapping land boundaries and land cover types to avoid conflicts and encroachment on protected or gazetted areas such as game parks and forest reserves.
5. Crop suitability mapping based on soil health (PH, fertility levels, amount of moisture)
6. Weather-based insurance schemes based on evapotranspiration to ensure that farmers recover in case they suffer reduced crop yields, low milk production and weight loss in livestock.
7. Detecting pest and disease impacts over large areas during the growing season to minimize crop damage and the associated food insecurity and economic loss.
8. Providing forecasts on crop production, consumption, cross-border trade, and stocks using digital food balance sheets.
9. Monitoring quality and quantity of water in lakes and rivers for agricultural production to aid in allocation of irrigation water.

Barriers to Adoption of Satellite based Agricultural Solutions in Botswana.

Despite the immense benefits of using satellite data in monitoring agricultural production to ensure food security and multiple Sustainable Development Goals (SDGs), the following factors limit its use:

1. Low levels of awareness coupled with low accuracy of freely available satellite data, products, and services.
2. Absence of relevant policies or platforms for hosting and sharing of satellite data among institutions.
3. Limited Information and communication technologies (ICT) infrastructure to support data processing and management.
4. Insufficient availability and access to African agricultural datasets (such as censuses, surveys, rain gauges, and drone footage, area-specific historic crop harvest data), which are essential to train and validate Earth Observation (EO) data.
5. Inadequate data interoperability, sharing mechanisms and lack of collaboration among institutions within the EO data value chain, and
6. Over reliance on international models used in predicting crop yields which compromises accuracy at local scales. This is partly contributed by absence of sufficient ground-truth labels needed to train and evaluate models.

Key Actions required to Enhance Utilization of Satellite Technology in Agriculture for Botswana.

To enhance utilization of EO data for spatially and temporally explicit agricultural planning, food, and nutrition security, the following actions are recommended:

1. **Improve temporal accuracy of 6-hr and 10-day weather forecasts.** Botswana's Department of Meteorological Services to consider running models on daily basis and provide gridded values to end-users.
2. **Develop local models suitable for African communities.** Botswanan Geographical Information System (GIS) and Remote Sensing experts ought to develop local crop and pasture models suitable for their localities. Sufficient ground truthing publicly accessible agricultural data also needs to be collected to train and improve accuracy of the developed models.
3. **Use satellite data for weather monitoring and forecasting in remote areas:** Since ground weather station data are usually neither evenly distributed nor sufficient, augmentation of station data with remote sensing data is critical for seasonal weather monitoring and forecasting. In hard-to-reach areas or regions without ground weather stations, satellite data forms the basis for forecasts.
4. **Increase awareness and dissemination:** To increase awareness of the available EO data, products and services, there is need to diversify the types of knowledge products or materials but also increase dissemination channels targeting the different stakeholder categories. EO data and products should be regularly assessed to ensure that they are fit for supporting specific decisions. At local scale, the knowledge products and materials should be developed in simplified formats that are easily understandable by local communities. Access to ICT infrastructure for data collection, analysis, scientific research, and communication is key.
5. **Strengthen capacity of stakeholders and Institutions:** Generally, there is limited capacity of District, and sub-district agricultural experts to analyse EO data and provide insights in specific areas of agricultural production such as measurement of soil moisture, crop suitability analysis, crop type mapping, crop conditions monitoring, crop yield and production forecasting. This can be improved through the delivery of customised continuous short trainings and refresher courses for technical staff on how to use latest technology (the how) to enhance crop production and food security in Botswana. Additionally, more innovative opportunities to reach smallholder farmers (especially youth) should be explored, via participation in ground truthing and in competitions to apply EO data.
6. **Scaling of pilot projects or interventions.** Scaling ground truth data collection, use and sharing to promote advanced crop analytics through innovative EO applications (crop modelling) and phased pilots to strengthen validation should be considered (Tetra Tech, 2021). Sufficient data and research are needed to support evidence-based policymaking and the role of the private sector in scaling that utilization of EO data, products and services cannot be over-emphasized. Institutions (at subnational and nation levels) need to create a policy & compliance guideline to ensure that labelled agriculture (land cover, yield) research datasets are Findable, Accessible, Interoperable, Re-usable (FAIR).
7. **Create enabling policy environment:** Unclear or absence of relevant policies to guide the establishment and use of a national geospatial data infrastructure to

serve as a one-stop-centre for all users of satellite data is an impediment. Unclear, strict, or changing data protection policies that regulate quality of data or the use of artificial intelligence in agriculture also limit cloud computing, storage and sharing of some high-resolution data sets. For effective implementation, there is need to categorize EO data and mainstream EO data policies, laws, and regulations into sector planning processes at various administrative levels. Policies that support land consolidation and crop intensification are key.

8. **Open access for very high-resolution satellite imagery:** In special cases such as pest outbreaks, a supplementary budget needs to be availed to district and sub-district government staff with a foresight function (especially planners) to be able to access commercially very high-resolution imagery to increase the accuracy of predictions to reduce the impact of emerging pests and diseases on food security (early warning). Affordable high-resolution imagery will also improve yield predictions and field level monitoring (Nakalembe & Kerner, 2023).
9. **Identify and address barriers in science education during early years.** There is need to develop a curriculum and mentorship programs on the use of EO data in schools. This will interest students including women to study Science, Technology, Engineering and Mathematics (STEM). More opportunities and incentives need to be provided to women to study STEM and become experts in GIS and Remote Sensing.
10. **Establishment of multistakeholder partnerships:** Collaborative frameworks with national, continental, and global key stakeholders and programmes in the EO data value chain can facilitate capacity strengthening, sharing of data, but also reduce the cost of high-resolution data to complement the use of medium resolution open data. Such stakeholders include Geoscience Australia, Esri, African Space Agency, Radiat Earth, Regional Center for mapping of Resources for Development (RCMRD), Airbus, private companies in Analytics such as EOS Data Analytics Inc, Planet, Maxar and Agricultural boards. Relevant programmes include NASA Harvest Africa Program, SERVIR ESA, Geodata for Agriculture and Water (G4AW) Program by the Netherlands Space Office, the Global Monitoring for Environment and Security and Africa (GMES & Africa) Support Programme by the African Union Commission among others.

Acknowledgement

This work was supported by a grant from the Australian Center for International Agricultural Research (ACIAR), which is highly acknowledged. We are grateful to all participants of stakeholder consultation meetings under the "Information for Agriculture and Food Security (IAFWS)" project.

Bibliography

1. APA 2023. Over 15 percent of SADC population food-insecure – Bloc.
2. FAO 2022. Country Briefs – Botswana. FOOD SECURITY SNAPSHOT.
3. Nakalembe C. & Kerner H. (2023). Considerations for AI-EO for agriculture in Sub-Saharan Africa. Environmental Research Letters, 18(4).
4. Tetra Tech 2021. Agriculture and Economic Growth: Scaling Ground Truth Data Collection, Use and Sharing to Promote Advanced Crop Analytics.

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Figure C1: Botswana's Policy Brief — 'Satellite Data for Improved Monitoring of Farm Productivity and Early Warning Systems in Botswana'.

Australian Government
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CCARDESA

ASARECA
Transforming Agriculture for Improved Livelihoods

Remote Sensing and Drone Technology for Accelerated Decision-Making and Climate Resilience of Ethiopia's Agriculture

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POLICY BRIEF
Ethiopia - June 2023

Key Messages

- Timely, accurate and reliable information is critical for early warning to mitigate the impact of impending climatic shocks.
- Remote sensing and drone technology is a decision-aid tool that can be used in tracking biodiversity, land use change, natural disasters and crop production by monitoring crop growth, crop health and crop maturity as well as predicting, adapting to, and mitigating against climate change.
- Government and development agencies are increasingly using Earth Observation in agriculture.
- Nationally, there is limited technical capacity to analyse satellite imagery and provide insights along commodity value chains.
- ASARECA and its partners offer opportunities to stakeholders to receive continuous training in using satellite earth observation data, processing tools, products, and services.
- There is a need to strengthen the science-policy interface for more effective, research/evidence-based policies to facilitate the use of satellite data, products, and services in agriculture and food security.

Introduction

Despite the major humanitarian food assistance that reached out to 5 million people in the Tigray region of Ethiopia during 2021, 5.5 million people (61% of the people in the area) are facing high levels of acute food insecurity (IPC 2021). Ethiopia's deteriorating food security is mainly driven by drought compounded by the cascading effects of conflict, including population displacements, movement restrictions, limited humanitarian access, loss of harvest and livelihood assets, and dysfunctional or non-existent markets.

The slow growth in agricultural productivity can be attributed to several factors including high cost of inputs, high incidence of pests and diseases, low input use and extreme weather conditions. The traditional method of drought prediction (in-situ physical rain gauges) used in most of the rural areas of Ethiopia is unreliable since it has limited coverage and provide relatively short-term forecast. Satellite technology helps in monitoring extreme weather conditions.

Satellite Technology

Satellite Technology is a communication system that orbits the earth's surface. It is fundamentally the process of detecting and monitoring the physical and biochemical characteristics of objects on the earth's surface through measuring their reflected and emitted radiation at a distance. A special sensor with the capability of detecting reflected and emitted radiation over a wide range of electromagnetic spectrum is used to gather target reflected and emitted radiation and form an image. Satellite Technology offers a synoptic view of objects on the earth's surface and has the advantage of obtaining earth's data in near-real time over large areas easily and effectively, and that gives it the capability to collect information on the weather, land use, crop health, and other important parameters. Earth Observation (EO) data is collected, processed, analysed, and converted into useful information that stakeholders in food systems can use to make informed policy decisions.

Contribution of Satellite Technology to Improved Food Security in Ethiopia

1. **Pasture and crop health and growth monitoring:** Satellite data can be used for estimating the area under a given crop, crop type mapping, periodic monitoring of crop growth, crop health, crop maturity to guide harvesting time, and land use. Areas at risk of food (fodder) shortage can seasonally be identified based on predicted biomass, pasture, and crop yields.
2. **Famine Early Warning Systems:** By tracking the condition of vegetation using satellites, anomalies in crop growth can easily be spotted early enough. This enables decision-makers to design disaster risk management and early actions or response by proactively carrying out targeted interventions, gathering resources and organizing relief efforts.
3. **Real-time weather information:** Timely (daily, 10-day or monthly) access to accurate precipitation, temperature data aids planning of farm activities such as planting, irrigation, harvesting, and drying. The data can then be used for various purposes including seasonal weather monitoring and forecasting, climate analysis and drought prediction by monitoring fluctuations in extremities of presence or absence of moisture.
4. **Soil analysis:** Accurate data on soil moisture and fertility levels, soil acidity and salinity, soil type, soil temperature can provide useful information that aids input (lime, fertilizers, and pesticides) advisory thereby reducing misuse resulting from calendar spraying, improves efficiency and hence profitability through increased agricultural productivity.
5. **Agricultural produce traceability system:** Tracking and monitoring movement of livestock and agricultural produce within and across regions aids in prediction of regions at risk of food shortages but also for management of disease outbreaks such as foot and mouth disease in cattle.
6. **Land suitability mapping:** Matching the land characteristics and climate conditions with the crop requirement is vital for informative solutions to be deployed to improve crop system effectiveness and increase crop yield. Sustainable crop production could be secured by detecting allowable potential lands suitable for both irrigated and rainfed farming systems.
7. **Mapping of hot spots for climate shocks, insect vectors or disease outbreaks:** This involves mapping out areas prone to a particular crop or animal disease such as desert locusts and fall armyworm. These hot spots can then be targeted with specific interventions aimed at controlling the disease or pest problem.
8. **Index based agricultural insurance product:** Satellite data sets are now used to develop (weather and vegetation) index-based agricultural insurance products which serve as proxies to estimate the potential yield and total production from a given plot. Farmers whose yields go below the determined trigger level are then compensated for the lost yields which enables them to continue in production even after occurrence of an extreme weather event.

Barriers to Adoption of Satellite based agricultural solutions in Ethiopia

Despite the immense benefits of using satellite data in monitoring agricultural production to ensure food security and achieve the UN Sustainable Development Goals, the following factors limit its use:

1. Low awareness coupled with low accuracy of freely available the available satellite imagery.
2. Limited technical capacity of government officials and other stakeholders to analyse Earth Observation (EO) data and provide insights into specific areas of agricultural production.
3. Absence of platforms for hosting or sharing of EO data at community and national level
4. Monitoring heterogeneous landscapes with fragmented mixed cropped areas rotated seasonally requires high-resolution satellite images that cannot be achieved with the freely available satellite data (Nakalembe & Kerner 2023).
5. Limited Information and communication technologies (ICT) infrastructure to support data processing and management.
6. Inadequate data interoperability, sharing mechanisms and lack of collaboration among institutions within the EO data value chain.
7. Over reliance on international models used in predicting crop yields compromises accuracy at local scales.
8. Poor performance of satellites in acquiring relevant image data during the cropping season associated to significant cloud cover.
9. Absence of annual or seasonal crop masks at NASA's U.S. Geological Survey (USGS) portal and archives which often leads to overestimating crop and pasture performance due to confounding tree or cloud cover.
10. High cost of high resolutions imageries provided by commercial companies or acquired from un-manned aerial vehicles such as drones.

Key Actions required to Enhance Utilization of Satellite Technology for Agriculture in Ethiopia

For spatially and temporally explicit agricultural planning, food, and nutrition security, the following actions are recommended to enhance utilization of EO data:

1. **Improve temporal accuracy of 6 hr and 10-day weather forecasts:** To achieve this, the Ethiopia Meteorological Institute should consider running models on a daily basis and provide gridded values to end-users.
2. **Develop local models suitable for African communities:** Ethiopian Geographical Information System (GIS) and Remote Sensing experts ought to develop local crop and pasture models suitable for their localities. Sufficient ground truthing data also needs to be collected to train and improve accuracy of the developed models.
3. **Use satellite data for weather monitoring and forecasting in remote areas:** Since ground weather station data are usually neither evenly distributed nor sufficient, augmentation of station data with remote sensing data is critical for seasonal weather monitoring and forecasting. In hard-to-reach areas or regions without ground weather stations, satellite data forms the basis of forecasts.
4. **Increase awareness and dissemination:** To increase awareness of the available EO data, products and services, there is need to diversify the types of knowledge products or materials but also increase dissemination channels targeting the different stakeholder categories. At local scale, the knowledge products and materials should be developed in simplified formats that are easily understandable by local communities.
5. **Strengthen capacity of stakeholders and Institutions:** Generally, there is limited capacity of regional and zonal experts to analyse EO data and provide insights in specific areas of agricultural production. This can be improved through the delivery of customised continuous short trainings and refresher courses for technical staff on how to use latest technology (the how) to enhance crop production and food security in Ethiopia.
6. **Scaling of pilot projects or interventions:** There is need to scale-up ground truth data collection, use and sharing to facilitate advanced crop analytics through innovative EO applications (crop modelling) and phased pilots to strengthen validation. Private sector players are key in scaling up the utilization of EO data, products, and services.
7. Develop guideline on the use of EO data for crop growth monitoring, yield prediction, in-season agro-advisory, and agricultural risk financing.
8. **Create an enabling policy environment:** There is need for relevant policies to guide the establishment and use of a national geospatial data

infrastructure to serve as a one-stop-centre for all users of satellite data. Unclear, strict, or changing data protection policies that regulate quality of data limit cloud computing, storage and sharing of some high-resolution data sets. For effective policy implementation, there is need to categorize EO data and mainstream EO data policies, laws, and regulations into sector planning processes at various administrative levels.

9. **Planning and allocation of budget to support use of EO data:** Relevant Government ministries, departments and agencies commit to mainstream use of EO data in their plans and allocate budgets to support implementation of satellite related activities.

10. **Direct purchase of high-resolution data:** In special cases such as pest outbreaks, a supplementary budget needs to be availed to district local government staff with a foresight function (especially planners) to be able to access high resolution imagery to increase accuracy of predictions to reduce the impact of emerging pests and diseases on food security.

11. **Identify and address barriers in science education during early years:** There is need to develop a curriculum and mentorship programs on the use of EO data in schools. This will interest students including women to study Science, Technology, Engineering and Mathematics (STEM). More opportunities and incentives need to be provided to women to study STEM and become experts in GIS and Remote Sensing.

12. **Establishment of multistakeholder partnerships:** Collaborative frameworks with national, continental, and global key stakeholders and programmes in the EO data value chain can facilitate capacity strengthening but also increase access to high-resolution data. Such stakeholders include Esri, African Space Agency, Radiat Earth, Regional Center for mapping of Resources for Development (RCMRD), Airbus, private companies in Analytics such as EOS Data Analytics Inc, Planet, Maxar and Agricultural boards. Relevant programmes include NASA Harvest Africa Program, SERVIR ESA, Geodata for Agriculture and Water (G4AW) Program by the Netherlands Space Office, the Global Monitoring for Environment and Security and Africa (GMES & Africa) Support Programme by the African Union Commission among others.

Acknowledgement

We are grateful to the Australian Center for International Agricultural Research (ACIAR) for funding the "Information for Agriculture and Food Security (IAFWS)" project under which this work was done.

References

1. IPC (Integrated Food Security Phase Classification) 2021. Ethiopia: Acute Food Insecurity Situation.
2. Nakalembe C. & Kerner H. (2023). Considerations for AI-EO for agriculture in Sub-Saharan Africa. Environmental Research Letters, 18(4).

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[2]The Ethiopian Institute of Agricultural Research (EIAR), Addis Ababa, Ethiopia
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[5]IGAD Climate Prediction & Applications Centre (ICPAC), Addis Ababa, Ethiopia
[6]UN World Food Programme (WFP), Addis Ababa, Ethiopia
[7]Digital Earth Africa (DE-Africa), Kigali, Rwanda
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Figure C2: Ethiopia's Policy Brief — 'Remote Sensing and Drone Technology for Accelerated Decision-Making and Climate Resilience of Ethiopia's Agriculture'.

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ASARECA
Transforming Agriculture for Improved Livelihoods

Harnessing Satellite Technology for Climate Resilience and Increased Agricultural Productivity in Kenya

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POLICY BRIEF
KENYA - June 2023

Key Messages

- Timely, accurate and reliable information is critical for early warning to mitigate and verify the impact of climatic shocks.
- Satellite data helps in monitoring crop conditions and performance, e.g., through yield estimation and production forecasting.
- Limited technical capacity to analyse satellite data, lack of cross sector/industry/stakeholder collaboration, and spatial resolution are major challenges to harnessing the benefits of satellite data in Kenya.
- ASARECA and its partners offer opportunities to stakeholders to receive continuous training in the use of satellite data, processing tools, products, and services.
- There is a need to strengthen the science-policy interface for more effective, evidence-based policies to facilitate the use of satellite data, products, and services in agriculture and food security.

Background

Despite the adaptation and mitigation measures that have been put in place to counter the negative effects of climate change and food insecurity, over 5.4 million people are at risk of hunger in Kenya (IPC 2023). This comes against the backdrop of declining agricultural productivity attributed to several factors including high cost of inputs, high incidence of pests and diseases, low input use and extreme weather conditions (droughts, floods, erratic rainfalls, etc).

The traditional methods of drought prediction (in-situ physical rain gauges) used in most of the rural areas of Kenya is unreliable and does not consider explicit information on risk profiles/sectors and provides short-term forecasts. Satellite technology helps in monitoring drought impacts and provides early warning information.

Satellite Technology

Satellite Technology entails continuous observation of land characteristics using a space-borne platform that orbits the earth's surface. It is specifically the process of detecting and monitoring the physical and biochemical characteristics of objects on the earth's surface through measuring their reflected and emitted radiation at a distance. A special sensor with the capability of detecting reflected and emitted radiation over a wide range of electromagnetic spectrum is used to gather target reflected and emitted radiation and form an image. Satellite Technology offers a synoptic view of objects on the earth's surface and has the advantage of obtaining earth's data in near-real time over large areas easily and effectively, and that gives it the capability to collect information on the weather, land use, crop health, and other important parameters. Satellite images are collected, processed, analysed, and converted into useful information that stakeholders within the food security programs can use to make informed policy decisions.

Contribution of Satellite Technology to Improved Food Security in Kenya

Satellites provides regular data on the weather, land use, crop production, and other important parameters to facilitate effective and better decision making. Among others, Satellite images provide useful information through.

1. soil, crop, and pasture health monitoring, including yields and production forecasting.
2. weather and drought early warning systems.
3. weather-based insurance schemes.
4. mapping disease and pest prevalence, ed to early warning digital advisories.
5. providing forecasts on crop production, consumption, cross-border trade, and stocks using digital food balance sheets.

Barriers to Adoption of Satellite based agricultural solutions in Kenya.

Despite the immense benefits of using satellite data in monitoring agricultural production to ensure food security and multiple Sustainable Development Goals (SDGs), the following factors limit its use:

1. Lack of awareness and confidence in/of available satellite data, products, and services.
2. Absence of relevant policies or platforms for hosting and sharing of satellite data among institutions.
3. Limited Information and communication technologies (ICT) infrastructure to support data processing and management.
4. Inadequate data interoperability, sharing mechanisms and lack of collaboration among institutions within the Earth Observation (EO) data value chain, and
5. Over reliance on international models used in predicting crop yields compromises accuracy at local scales.

Key Actions required to Enhance Utilization of Satellite Technology in Agriculture for Kenya.

To enhance utilization of EO data for spatially and temporally explicit agricultural planning, food, and nutrition security, the following actions are recommended:

1. **Improve temporal accuracy of 6-hr and 10-day weather forecasts.** Kenya's Department of Meteorology to consider running models on daily basis and provide gridded values to end-users.
2. **Develop local models suitable for African communities.** Kenyan Geographical Information System (GIS) and Remote Sensing experts ought to develop local crop and pasture models suitable for their localities. Sufficient ground truthing data also needs to be collected to train and improve accuracy of the developed models.
3. **Use satellite data for weather monitoring and forecasting in remote areas:** Since ground weather station data are usually neither evenly distributed nor sufficient, augmentation of station data with remote sensing data is critical for seasonal weather monitoring and forecasting. In hard-to-reach areas or regions without ground weather stations, satellite data forms the basis of forecasts.
4. **Increase awareness and dissemination:** To increase awareness of the available EO data, products and services, there is need to diversify the types of knowledge products or materials but also increase dissemination channels targeting the different stakeholder categories. At local scale, the knowledge products and materials should be developed in simplified formats that are easily understandable by local communities. Access to ICT infrastructure to supports digitalization of farm operations is key.
5. **Strengthen capacity of stakeholders:** Generally, there is limited capacity of County, Subcounty and ward agricultural experts to analyse EO data and provide insights in specific areas of agricultural production such as measurement of soil moisture, crop suitability analysis, crop type mapping, crop conditions monitoring, crop yield and production forecasting. This can be improved through the delivery of customised continuous short trainings and refresher courses for technical staff on how to use latest technology (the how) to enhance crop production and food security in Kenya.
6. **Scaling of pilot projects or interventions.** Scaling ground truth data collection, use and sharing to promote advanced crop analytics through innovative EO applications (crop modelling) and phased pilots to strengthen validation (Tetra Tech, 2021). Sufficient data and research are needed to support evidence-based policymaking and the role of the private sector in scaling that utilization of EO data, products and services cannot be over-emphasized.
7. **Create enabling policy environment:** Unclear or absence of relevant policies to guide the establishment and use of a national geospatial data infrastructure to serve as a one-stop-centre for all users of satellite data. Unclear, strict, or changing data protection policies that regulate quality of data or the use of artificial intelligence in agriculture also limit cloud computing, storage and sharing of some high-resolution data sets. For effective implementation, there is need to categorize EO data and mainstream EO data policies, laws, and regulations into sector planning

processes at various administrative levels.

8. **Reduce the cost curve for very high-resolution imagery:** In special cases such as pest outbreaks, a supplementary budget needs to be availed to county government staff with a foresight function (especially planners) to be able to access commercial very high-resolution imagery to increase the accuracy of predictions to reduce the impact of emerging pests and diseases on food security (early warning). Affordable high-resolution imagery will also improve yield predictions and field level monitoring.
9. **Identify and address barriers in science education during early years.** There is need to develop a curriculum and mentorship programs on the use of EO data in schools. This will interest students including women to study Science, Technology, Engineering and Mathematics (STEM). More opportunities and incentives need to be provided to women to study STEM and become experts in GIS and Remote Sensing.
10. **Establishment of multistakeholder partnerships:** Collaborative frameworks with national, continental, and global key stakeholders and programmes in the EO data value chain can facilitate capacity strengthening, sharing of data, but also reduce the cost of high-resolution data to complement the use of medium resolution open data. Such stakeholders include SANSA, ASARECA, DE-Africa, Geoscience Australia, Esri, African Space Agency, Radiat Earth, Regional Center for mapping of Resources for Development (RCMRD), The United Nations Commission on Science and Technology for Development (CSTD), The Alliance of International Science Organizations (ANSO) and the Aerospace Information Research Institute (AIR) of the Chinese Academy of Sciences (CAS), the World Resources Institute (WRI), Airbus, private companies in Analytics and Agricultural boards. Relevant programmes include SERVIR ESA, The Global Monitoring of Environment and Security (GMES) Programme among others.

Acknowledgement

This work was carried out under the auspices of "Information for Agriculture and Food Security (IAFWS)" project funded by the Australian Center for International Agricultural Research (ACIAR). The IAFWS project was implemented by: (i) The Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA), (ii) The Centre for Coordination of Agricultural Research and Development for Southern Africa (CCARDESA), (iii) Digital Earth Africa (DE Africa) and (iv) Geoscience Australia.

Bibliography

1. FAO, IFAD, UNICEF, WFP and WHO 2021. The State of Food Security and Nutrition in the World (SOFI) 2021. FAO 240 p.
2. *FAO, IFAD, UNICEF, WFP and WHO. 2022. In Brief to The State of Food Security and Nutrition in the World 2022. Repurposing food and agricultural policies to make healthy diets more affordable. Rome, FAO.*
3. *IPC (Integrated Food Security Phase Classification) 2023. Kenya: Acute Food Insecurity Situation.*
4. *Tetra Tech 2021. Agriculture and Economic Growth: Scaling Ground Truth Data Collection, Use* and Sharing to Promote Advanced Crop Analytics.

[1]Association for Strenghening Agricultural Research in Eastern and Central Africa (ASARECA), Entebbe, Uganda
[2]Geo-Spatial Research International, Nairobi, Kenya
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[5]International Centre of Insect Physiology and Ecology (ICIPE), Nairobi, Kenya
[6]Regional Centre for Mapping of Resources for Development (RCMRD), Nairobi, Kenya
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Figure C3: Kenya's Policy Brief — 'Harnessing Satellite Technology for Climate Resilience and Increased Agricultural Productivity in Kenya'.

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Transforming Agriculture for Improved Livelihoods

Harnessing the Utilization of Satelite Technology to Boost Food Security and Enhance Adaptation to Climate Change in Rwanda

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POLICY BRIEF
RWANDA

Key Messages

- Timely, accurate and reliable information is critical for early action to mitigate the impact of impending shocks.
- Satellite technology is a decision-aid tool used for planning and monitoring food security at national level through estimating the area under a given crop, monitoring crop growth, crop health and crop maturity.
- Nationally, there is limited technical capacity to analyse satellite data and provide insights in specific areas of agricultural production.
- ASARECA and its partners offer an opportunity to its stakeholders to receive continuous training in the use of satellite data, products, and services.
- There is need to strengthen the science-policy interface for more effective, research/evidence-based policies to facilitate the use of satellite data, products, and services in agriculture.

Introduction

Around 2.3 billion people in the world were moderately or severely food insecure in 2021 and almost 3.1 billion people could not afford a healthy diet in 2020 (FAO et al. 2022). In Africa, 278 million people were affected by hunger in 2021. In Rwanda, nearly 3 million people are food insecure with high levels (32.4%) of chronic malnutrition among children under 5 years (WFP, 2023). The situation is exacerbated by conflicts, pandemics, climate change and related disasters disrupting the supply chain—all of which tend to hit sub-Saharan African (SAA) countries the hardest.

Just as the rest of SSA countries, Rwanda continues to face food and nutrition insecurity despite adaptation measures put in place against the negative effects of climate change. Agricultural production and productivity in Rwanda is on the decline due to several factors including high cost of inputs and extreme weather conditions (droughts, floods, erratic rainfalls). The traditional methods of drought prediction (in-situ physical rain gauges) used in most of the rural areas of Rwanda are unreliable, have limited coverage and only provide a relatively short-term forecast.

What is satellite technology?

The term "Satellite Technology" describes the use of artificial a self-contained communications system that orbit the earth, receive/collect signals/data from the Earth and retransmit those signals back to Earth using a transponder (an integrated receiver and transmitter of radio signals). These satellites have got a variety of sensors and tools that give them the capability to collect information on the weather, land use, crop health, and other important factors. Then the data is processes and analysed then converted into information that policymakers and other stakeholders within the food and nutrition security programs can use.

In what ways can satellite technology contribute to improved food security?

1. Pasture and Crop health and growth monitoring using NDVI: High resolution satellite images can be used for estimating the area under a given crop, monitoring crop growth, crop health, crop maturity to guide harvesting time, land use, and crop health. This can aid in prediction of seasonal yields if models that estimate radiation conversion and water utilization are used. Regions at risk of food shortages can easily be identified.

2. Famine Early Warning Systems: Identifying potential food crises early enough through tracking vegetation patterns and spotting out anomalies in crop growth. This enables decision-makers to design a disaster risk management and emergency response by proactively carrying out targeted interventions, gathering resources and organizing relief efforts.

3. Real-time weather information: Timely (daily, 10-day or monthly) access to accurate precipitation (rains), temperature, humidity, and wind speed information aids planning of farm activities such as planting, irrigation, harvesting, and drying. The data can then be used for various purposes including seasonal weather monitoring and forecasting, climate analysis and drought prediction by monitoring fluctuations in extremities of presence or absence of moisture (rains).

4. Soil analysis: Accurate data on soil moisture levels, soil fertility levels, crop health, aids input (fertilizers and pesticides) use which reduces on wastage, improves efficiency and profitability through increased agricultural productivity.

5. Tracking and monitoring movement of livestock and agricultural products across and between regions

6. Hot spot analysis: monitoring of natural resource base such as land cover change, forest cover change, changes in size of water bodies, hot spot analysis to avoid over exploitation, degradation, deforestation, or coastal erosion especially in rural and hard to reach communities.

What limits the use of satellite technology in Rwanda's Agricultural sector?

Despite the immense benefits of using satellite data in monitoring agricultural production to ensure food security and achieve the UN SDGs, the following factors limiting its use:

1. Low awareness of the available satellite data, products, and services
2. Limited technical capacity of government officials to analyse EO data and provide insights in specific areas of agricultural production,
3. Absence of relevant policies to guide utilization of unmanned aerial vehicles.
4. High cost of high-resolution satellite data, products, and services,
5. Lack of appropriate ICT infrastructure to support data processing and management.
6. Lack of data interoperability and sharing mechanisms between institutions
7. Over reliance to international models used in predicting crop yields compromises accuracy.
8. Absence of annual or seasonal crop masks at NASA's USGS portal and archives resulting in overestimates crop and pasture performance due to confounding due to tree or cloud cover.

What actions are needed to enhance the utilization of satellite technology in Agriculture?

To address some of the key challenges identified above the following actions are recommended to enhance utilization of EO data for spatially and temporally explicit agricultural planning, food, and nutrition security:

1. To improve accuracy of weather forecasts, Meteo Rwanda should consider running models daily.
2. Rwanda's GIS and Remote sensing experts ought to develop local models suitable for their localities.
3. In hard-to-reach areas or in areas without ground weather stations, it's only logical to use satellite data for seasonal weather monitoring and forecasting,

4. To increase awareness of the available EO data, products and services, there is need to increase the dissemination channels e.g. bulletins
5. Limited capacity of district local government officials to analyse EO data and provide insights in specific areas of agricultural production such as measurement of soil moisture and monitoring changes in size of water bodies.
6. Scaling Ground Truth Data Collection, Use and Sharing to Promote Advanced Crop Analytics through innovative EO applications and phased pilots to strengthen validation (Tetra, 2021)
7. Unclear or absence of relevant policies for instance to support the use of unmanned aerial vehicles (UAV) are hindering the use of drones in crop type mapping.
8. Allocate appropriate levels of domestic funding to district local government staff with a foresight function (especially planners) to be able to access high resolution imagery and use sufficient data to aid in accurate predictions to avoid food shortages.
9. Invest in human capital through capacity strengthening in the analysis of EO data for institutions such as NFA that provide national datasets which serve as a reference in hotspot analysis.
10. Identify and address barriers in science education during early years in schools to interest students especially women to study Science, Technology, Engineering and Mathematics (STEM). More opportunities and incentives need to be provided to women to study science become experts in GIS and Remote sensing. This will ensure that more GIS and Remote sensing experts graduate from universities.

11. Establish partnerships with owners of high-resolution data to complement the use of open data from Landsat (30m resolution), Sentinel (10m resolution) and Planet (3m resolution).
12. To improve understanding and use of EO data in drawing insights for agricultural planning, there is need for continuous training in the methodology – highest and latest technology (the how).
13. Relevant Government agencies to establish collaborative frameworks with key stakeholders in the EO data value chain in within the region and globally such as ASARECA, DE-Africa, ACIAR, The United Nations Commission on Science and Technology for Development (CSTD), The Alliance of International Science Organizations (ANSO) and the Aerospace Information Research Institute (AIR) of the Chinese Academy of Sciences (CAS), the World Resources Institute (WRI), Air Bus, etc…
14. Strengthen the science-policy interface for more effective, research/evidence-based policies.
15. Expand access to ICT infrastructure that supports digitalization of smallholder farmers.
16. Institutionalization of EO policies into sector planning processes to ensure that EO data and infrastructure is budgeted for by both the central government and the district local government.
17. Encourage the use of Public Private Partnership to ensure that the capacity of farmer organizations to use EO data, products and services for informed decisions is strengthened.

Acknowledgement

This work was carried out under the auspices of "Information for Agriculture, Food and Water Security (IAFWS)" project funded by the Australian Center for International Agricultural Research (ACIAR).

References

1. *Tetra Tech Agriculture and Economic Growth, 2021. "Scaling Ground Truth Data Collection, Use and Sharing to Promote Advanced Crop Analytics." Published on October 15, 2021. [FAO, The State of Food Security And Nutrition in the World 2021]*
2. *FAO, IFAD, UNICEF, WFP and WHO. 2022. In Brief to The State of Food Security and Nutrition in the World 2022. Repurposing food and agricultural policies to make healthy diets more affordable. Rome, FAO.*
3. *WFP 2023. Rwanda country brief*

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Figure C4: Rwanda's Policy Brief — 'Harnessing the Utilization of Satellite Technology to Boost Food Security and Enhance Adaption to Climate Change in Rwanda'.