The Potential for Digital Adaptation in Agriculture in the Zambezi River Basin Countries

Regional Assessment Report

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The content of this report is the sole responsibility of the authors and does not necessarily reflect the views of their various respective institutions.

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Acronyms and Abbreviations

AAAP	Africa Adaptation Acceleration Program
AfDB	African Development Bank
ATM	Automated Teller Machines
BTC	Botswana Telecommunications Corporation
FAO	Food and Agriculture Organization
GCA	Global Center on Adaptation
GDP	Gross Domestic Product
GIS	Geographical Information System
GPS	Global Positioning System
IDI	ICT Development Index
IoT	Internet of Things
IPCC	Intergovernmental Panel on Climate Change
ITCZ	Inter-Tropical Convergence Zone
ITU	International Telecommunication Union
Mbps	megabits per second
NAPA	National Adaptation Programme of Action
NDS1	Strategic National Development 1
PIDACC	Program on Integrated Development and Adaptation to Climate Change
RCP	Representative Concentration Pathways
RWIMS.SNR	Rural Wash Information Management System SMS Notification Response
SADC	Southern African Development Community
SIM	Subscriber Identity Module
SMS	Short Message Service
SSA	Sub-Saharan Africa
TMG	Turning Matabeleland Green
VFM	Virtual Farmers Market
WaPOR	Water Productivity Open-access Remote sensing portal
WBII	Weather-Based Index Insurance

WFP	World Food Programme
ZAGP	Zimbabwe Agricultural Growth Program
ZAMCOM	Zambezi Watercourse Commission
ZMD	Zambia Meteorological Department

Executive summary

The objectives of this assessment were to study the prevalent and most challenging climate risks that smallholder farmers and small businesses face in the Zambezi River Basin countries, understand the role of digital technology in climate adaptation, and thereby propose interventions to accelerate and scale up the use of digital technology in climate adaptation.

To reach these objectives, a two-step methodology was followed, consisting of a literature review and secondary data analysis on the one hand and stakeholder consultations on the other. These processes yielded data and information that shed light on key climate risks, current adaptation strategies, digital technologies, constraints for digital adaptation, and interventions that may be put in place to enhance adaptation. The major findings are highlighted below:

The nature and extent of climate risks in the Zambezi basin countries vary across countries, but they are increasing in severity over time, calling for context-specific solutions

Drought, dry spells, rising temperatures, floods, and changing seasons are becoming more frequent, and the future will be characterized by an increase in climate risks across the Zambezi River Basin countries. The levels of significance for each of these risks vary by country. Floods, for example, are more frequent and deadly in Mozambique, Malawi, and Zimbabwe, while dry spells, rising temperatures, and droughts are more frequent in Namibia and Botswana.

In all the Zambezi riparian countries, significant efforts, including adaptation initiatives and legislative reforms, are underway to attempt to build basin resilience to climate change.

The extent and use of digital technologies in climate adaptation are in their infancy but vary across countries and are increasing

Climate adaptation through digital technology is not prevalent; however, in each country there are some developments in this area that can be considered steps toward better climate adaptation using digital technology.

The most common digital adaptation technologies vary in popularity and extent of usage from one country to another, but weather-indexed crop insurance is introduced in Zambia, Malawi, and Zimbabwe and is mentioned in Tanzania and Angola as well. The use of the Internet of Things

(IoT) to improve farm management is emerging in Botswana, Namibia, and Angola through specific initiatives often sponsored by outside agencies.

Digital technologies are also being used across various stages of the value chains, including production, processing and marketing, where they improve efficiency. The most frequently used digital technologies with the potential for climate adaptation include radios, satellite televisions, mobile phones, drones, computers, mobile applications and data-enabled insurance services.

While digital technologies are useful, their adoption and scaling are replete with challenges and constraints

The major constraints that undermine the adoption and use of digital technologies across the Zambezi River Basin countries are related to availability, access, affordability, gender and inclusivity during technology design, enabling environment, cultural and family norms, and poor user skills.

Low skills/literacy, cyber-safety concerns and poor requisite infrastructure constrain adoption and scaling

Some countries have low ICT skills which undermines the adoption and usage of digital technology. For example, Malawi and Mozambique lag behind the rest of the countries in adult literacy levels with considerable gender gaps in internet adoption. Energy is important for the operationalization of digital technology, but 80 percent of the rural population is generally lacking electricity in most Zambezi River Basin countries. Even where rural electricity availability is relatively good in the region, access to electricity is less than 27 percent, and as low as 4 percent in Malawi and 4.9 percent in Mozambique.

Meanwhile, cybercrime industry is booming in the Zambezi River Basin countries, with the potential to undermine trust in digital solutions. For example, some stakeholders in Malawi, Zimbabwe, Zambia, and Mozambique voice concerns regarding mobile money applications and internet banking, which support both farm and non-farm transactions. In Zimbabwe, there is a different concern of the potential of state departments leveraging national security laws to monitor private communications.

Current low levels of digital penetration and the costs of mobile data reduce the adoption of data-enabled technologies

The current levels of digital penetration are low. Mobile infrastructure needs strengthening as the current state of the infrastructure leaves out significant portions of the rural population. Network signals are significantly poor in rural areas in all the Zambezi River Basin countries and where mobile networks are available, high cost of data is a barrier to internet usage. Malawi and Zimbabwe record the highest data costs, compared to the others.

Key development stakeholders who fund agriculture, such as development partners, fund remitters in the diaspora or urban centres within a country, banks, and others, could play a leading role in addressing the high cost of technology and speeding up technology adoption.

Furthermore, information generation is often undermined by poor or weak early warning systems which require significant investments in automatic weather stations, other equipment, and human capital skills. Weak coordination and information sharing mechanisms are worsening the situation across the Zambezi River Basin countries and yet many of the climate issues of interest are transboundary in nature, such that addressing them requires international collaboration. For example, water accounting across the basin and building the capacity of the Southern African Development Community (SADC) climate services center for sustainability relies on international cooperation.

Poor macroeconomic, policy, and regulatory environments constrain adoption by undermining the availability of technology and business predictability

Macroeconomic conditions, particularly inflation and lack of foreign exchange, also undermine growth prospects of digital technology use in adaptation, as many of these technologies need to be imported. Therefore, not surprisingly, most digital tools are simply unavailable or too expensive, especially for women. The lack of national policies or the legal framework to support digital innovation expansion is undermining the availability and adoption of these technologies. For example, liberal use of drones requires legislation that protects others from abuse. In some cases, digital technology concepts are absent in national climate adaptation strategies blocking resource availability for digital technology development.

Cultural factors increase the gender gap in technology adoption and use

Reducing gender gaps in using phones or other technologies is not only about providing phones to women. Cultural factors, including family consent, can negatively influence women's access to and use of mobile internet, particularly where social media engagement is stigmatized. Such sentiments were echoed during consultative meetings in Zambia, Zimbabwe, and Malawi. In these cases, men who exert control over household resources can discourage internet use by women.

While the gender gap is a general issue, there are cross-country and within-country variations on specific issues. For example, the gender gap in literacy is highest in Angola (27%), Mozambique (22.3%) and Malawi (14.6%). However, the mobile ownership gender gap data suggests that this is the worst in Mozambique. There are also variations in the economic status of women across and within countries. The complex intersectionality of these factors (including location, income status, and literacy) implies that there are many unique groups of women, therefore no one-size-fits-all solution can be prescribed for women. Rather, solutions must be tailor-made to specific audiences. An ultra-poor, illiterate rural female farmer is likely going to need different interventions from a rich, literate peri-urban farmer for purposes of increasing technology use in climate adaptation. While the former may require only awareness to adopt technology use, the latter may need access to finance/low-cost production, technology that does not require reading, translation from a foreign language, and liberation from negative cultural strangleholds.

Lead farmers and extension services can help spur technology adoption among women through innovative extension services, including digitization and mobilizing lead farmers for climate adaptation through technology adoption. Farmers find it easy and perhaps convenient to learn from fellow farmers on matters of technology adoption and roll-out rather than learn from pre-packed extension messages that often omit context specific information that is key for the success of technology use. Zimbabwe is capitalizing on this through the Pfumvudza program, but challenges remain.

Recommendations depend on the context, but addressing the enabling environment, capacity, skills, and technological characteristics can improve adoption and scaling

Awareness campaigns and skills development should continue

Awareness creation in respect to the availability and relevance of digital technology, through regional basin-scale campaigns as well as national programs (both formal and informal education), is needed to ensure a higher proportion of small business owners and farmers are aware of the potential of technology to transform their businesses as well as agricultural activities, regardless of where they stand on the agricultural value chain (e.g., production, processing, distribution, retailing, and consumption).

Capacity development programs targeting individual, institutional, and policy levels can support adoption. Enhancing digital skills through education programs in schools and public institutions (increasing human capacity to generate and use data) can reduce the risk profiles of adopters and also increase the quality of predictions of climate information, leading to an increase in adoption rates.

Addressing technology cost issues requires a holistic approach

Since cost is identified as crucial for technology adoption, reducing costs of procurement of technology via faster and cheaper mobile money services, reduced internet and mobile phone service charges, and engaging and incentivizing the private sector to introduce technology to remote areas can improve adoption. It is important to also understand the needs and characteristics of those who underwrite the agricultural sector. Whereas many households get capital from their own savings, some farmers rely on family remittances to power their small businesses and farm activities. Therefore, creating awareness among diasporas about the potential of technology in adaptation can spur the rate of digital adaptation.

Again, to address the gender gap in mobile phone ownership, which is wider in rural areas, expanding access and use of mobile phones to more women through gender-sensitive business models can contribute to the expansion of digital technologies in climate change adaptation. Lowering or removing sector-specific taxation for ICT can also ensure that digital technologies are available at affordable prices, even to underprivileged women. In addition, since the Zambezi region has transboundary-related challenges, providing incentives for infrastructure sharing across the Zambezi region will benefit technology adoption.

Addressing cultural institutions can improve the gender gap in technology adoption

Besides addressing the issues of ownership of mobile phones, usage skills, and financial access, focusing on awareness creation and communicating cultural change may liberate women from cultural barriers that prevent them from using mobile technology for livelihood activities. It is important to also recognize the cross-country variation in the gender gap as well as within-country variations among women, such as by location (urban vs. rural), income category (poor, ultra-poor, well-to-do), education status (literate vs. illiterate), etc. Smart mobile phones may benefit poor but literate women, while older-generation mobile phones with voice facilities might be better suited for adoption among the illiterate and poor.

Some water conservation and management technologies can significantly improve adaptation

Chameleon sensors [1] and other sensor-based technologies have also proven to be productivity-enhancing, raising productivity by 40 percent for adopters in some cases and as much as 20 percent for observers who understudy the adopters. Water accounting across the basin, as well as building the capacity of the (SADC) climate services center sustainably, are recognized as immediate needs. Popularizing these to improve water resource management can improve the resilience of households.

Improving the policy and regulatory environment can support digital adaptation

To address issues of cyber security and encourage digital adaptation to climate change, there ought to be a concerted effort in the Zambezi region to ensure the sharing of cyber security technology. A regional framework on digitization and a stringent cyber security regulatory framework for the region and its member states are needed. Further, in countries where national digitalization policies are missing, such as Angola, Botswana, Namibia, Tanzania, and Zimbabwe, policies should be put in place. In Zimbabwe, the Cyber Security Policy and Cyber and Data Protection Act of 2021 should be better harmonized with the National Security Council Act (Act No. 2 of 2009) to avoid contradictions that cause uncertainty among investors.

The SADC and the Zambezi Watercourse Commission (ZAMCOM) should consider collaborating in procuring guidelines and frameworks that can govern investments in climate adaptation infrastructure, including mobile money service provisions, to ensure that new entrants on the market adhere to secure standards and that users are protected.

Investment in energy infrastructure can support digital technology adoption

Since energy is a critical prerequisite infrastructure for digital technology development, it is important to invest in alternative energy sources such as solar power. These can support mobile phones, TVs, drones, and other digital technologies in rural areas. Equally important is expanding telecommunication infrastructure, such as towers for internet and mobile network coverage, to

[1] The Chameleon Soil Moisture Sensor (CSMS) is a prototype sensor designed to provide information to farmers and irrigation managers that provides insight on when to irrigate and how much water to apply.

cater to rural areas that currently face network challenges. For this prerequisite infrastructure to help effectively in regional climate adaptation, it is also useful to approach its development with a regional outlook. The SADC climate services center is an important facility that can be used to strengthen early warning systems and information flow in the region. Strengthened coordination in the development, management, and use of such infrastructure is useful and should be encouraged to scale up digital adaptation.

Extension services should be strengthened

Extension services need strengthening and digitization in many countries. While the concept of lead farmers is useful in spurring technology, it is important to note that for such lead farmers to be effective in scaling up the adoption of technology, they have to be selected in such a way that they are representative of the farmers of the locality in terms of gender, economic status, culture, etc.; otherwise, their effect may be underrealized. Again, programs that invest in strengthening the role of lead farmers in demonstrating technologies need to include measures that incentivize these lead farmers to share their knowledge and experiences. Alternatively, investment programs can invest in more formal extension models that include accountability mechanisms and may or may not include lead farmers, depending on local circumstances. It would also be important to improve e-government while ensuring that messages are carried in all local languages to overcome language barriers in extension services.

Information centers strategically located in remote areas with poor people and networks and stocked with digital tools for extension and advisory purposes can act as one-stop shops or digital hubs that significantly improve access to digital technologies for men and women alike.

Non-farm income including remittances and other sources of resilience are important and should supported in program design

The design of adaptation interventions needs to also focus on off-farm income activities. For example, a household that has productive assets or other sources of income rather than agriculture can refinance agriculture by selling assets during a bad agricultural year, while social safety nets and formal and informal transfers, including remittances, can provide the needed capital for technology adaptation. Where feasible, programs should seek to strengthen smallholder farmers' access to such assets, adaptive capacities, and social safety nets, besides investing in agriculture activities.

1. Introduction

The Zambezi River Basin

The Zambezi River Basin (ZRB) is shared among eight countries — the Zambezi riparian countries of Angola, Botswana, Malawi, Mozambique, Namibia, Tanzania, Zambia and Zimbabwe. The Zambezi River is the fourth largest river in Africa. It is the largest river basin in the Southern African Development Community (SADC) region with a total drainage area of approximately 1.34 million km^2. The main River, with a total length of 3,000 km, originates in the Kalene Hills in northwest Zambia at an altitude of 1,500 m and flows eastwards to the Indian Ocean (McCartney et al. 2013). The river has three distinct stretches: The Upper Zambezi from its source to Victoria Falls, the Middle Zambezi from Victoria Falls to Cahora Bassa, and the Lower Zambezi from Cahora Bassa to the delta. Typically, for planning purposes, the basin is divided into 13 major sub-basins (Figure 1).

The Basin has significant water resources, fertile soils for agriculture, mineral-rich deposits, and diverse habitats including prominent wetlands (e.g., Barotse Flood Plains and Bangweulu in Zambia; Okavango Delta, shared between Botswana and Namibia; Elephant Marsh in Malawi; the Chobe Swamps in north-eastern Namibia, etc.) that are home to large populations of wildlife (SARDC et al. 2012). These natural capitals are associated with the basin's economic activities, which include agriculture, forestry, manufacturing, mining, conservation and tourism. For example, the river flow directly or indirectly affects livelihoods and aspirations of human society by providing fundamental needs such as water for drinking and irrigation; industrial, aesthetic and recreational purposes; food such as fish; numerous life-sustaining ecosystem services such as water purification; carbon sequestration; prevention of floods; and the easing of droughts.

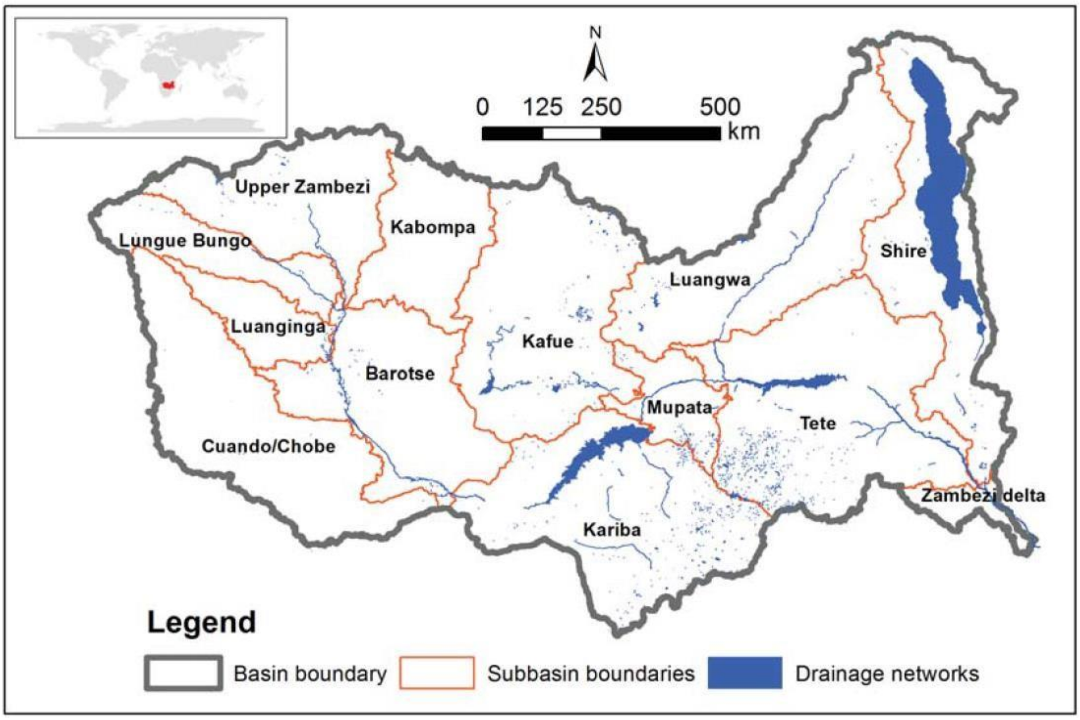

Figure 1: Zambezi drainage network and its 13 major sub-basins
Source: Adapted from McCartney et al. 2013.

The main tributaries of the Zambezi River are the Shire, the Luangwa, the Kafue and the Kabompo rivers (World Bank 2010).

The Zambezi economy, and challenges around food, land, and water

The combined Gross Domestic Product (GDP) for the Zambezi Riparian countries is upward of US$259 billion at the constant 2015 US$, with a combined population of over 181 million people and a GDP per capita of just over US$1,400 (Table 1).

Table 1: The economies of the Zambezi riparian states

	GDP at current prices (US$ million)	GDP at Constant 2015 (US$ million)	Population (Millions)	GDP per capita (Current US$)	GDP per capita Constant 2015 US$)
Angola	58375.98	104128.68	32.86627	1776.17	3168.25
Botswana	15061.92	14813.38	2.35163	6404.89	6299.20
Malawi	12182.35	7537.26	19.12996	636.82	394.00
Mozambique	14019.45	17959.22	31.25544	448.54	574.60
Namibia	10619.19	10285.28	2.54092	4179.27	4047.86
Tanzania	62409.71	61522.71	59.73421	1044.79	1029.94
Zambia	18110.63	23418.95	18.38396	985.13	1273.88
Zimbabwe	18051.17	19426.05	14.86293	1214.51	1307.01
All	208830.4	259091.53	181.12532	1152.96	1430.45

Source: Authors computation from the World Bank data 2022.

The region is thus vast and has the potential to provide a wider market for internal and extra-regional goods and services.

The Zambezi River Basin is home to a population of over 40 million people who live within the margins of the basin. Their main economic activities include agriculture, mining, fisheries, tourism, and manufacturing. Agriculture remains the mainstay of most economies within the region which has an estimated agricultural area of about 5.2 million hectares (ha). As it is highly dependent on rain-fed agriculture, rainfall plays a key role in determining the welfare of the population. Statistics show that only 0.25 million ha is currently under irrigation. Annual precipitation ranges from about 700 mm/year to as high as 1,200 mm/year. The main rainy season covers a period between October and March and the region has a hydropower potential of 20 Gigawatt (GW).

The Zambezi region, however, is ravaged by widespread and persistent poverty, with 44 percent of the population below the international poverty line of US$1.9 per day. Agriculture is predominantly subsistent with an overwhelming 64 percent of farmers categorized as subsistent and rain dependent. Disaster risk is widespread across the region, and floods, droughts, and dry spells are frequent, exacerbating poverty and causing resilience to be very weak (ZAMCOM 2019). While agriculture plays a greater role in shaping the livelihoods of people in these countries, environmental degradation is also rampant, with 51 percent of land in the basin being classified as moderately degraded, and as much as 14 percent highly degraded. Whereas both natural and built-in infrastructure holds a key to the Basin's resilience to climate change, the region is experiencing substantial built-in infrastructural deficits throughout, on top of the poor natural infrastructure that is also substantially degraded, causing basin resilience to be twice-over vulnerable to climate change. As the economies of the Zambezi slowly grow and the population increases, competition for Zambezi watercourse resources intensifies, suggesting the need for a better and balanced development model that considers decision and equity trade-offs, and the inherently transboundary nature of the basin resources (ZAMCOM 2019).

The climate risks that the region faces are not uniform across countries, and there are also considerable variations within each country and their internal locations. While all the countries in the basin are implementing programs in support of climate mitigation and adaptation, the adaptation efforts are not sufficient for rapid resilient building, as evidenced by the poverty and infrastructural statistics provided above, as well as the frequent havoc created by climatic events including flash floods, riverine floods, dry spells, droughts and the shifting of seasons. It is also noted that while digital technology has been touted to provide solutions for upscaling climate adaptation, its use in climate adaptation in the region is still limited and requires upscaling. Thus, identifying the factors which undermine or speed up the adoption of digital technology in climate adaptation efforts is crucial in any effort that seeks to build climate resilience with the aid of digital technology.

Globally, there are increasing levels of organizations around key adaptation opportunities. The Africa Adaptation Acceleration Program (AAAP) was developed jointly by the Global Center on Adaptation (GCA) and the African Development Bank (AfDB). The AAAP comprises four pillars: Climate Smart Digital Technologies for Agriculture and Food Security (CSDAT), the African Infrastructure Resilience Accelerator, Empowering Youth for Entrepreneurship and Job Creation in Climate Adaptation and Resilience and Innovative Financial Initiatives for Africa. The CSDAT of the Africa Adaptation Acceleration Program (AAAP) of GCA and AfDB aims to scale up access to climate-smart digital technologies. The pillar envisages the scaling up of the availability, access, affordability, and applicability of digital and data-enabled solutions in African agriculture. Interventions under the pillar will ensure that digital technologies are designed and targeted for smallholders and agri-SMEs, including women farmers; deliver commercially viable business models, deliver digital solutions to smallholders and agri-SMEs at scale; and build the capacity of smallholders and other value chain actors to use digital technologies and integrate them into agricultural practices.

The main goal of this pillar is to scale up access to climate-smart digital technologies, and associated data-driven agricultural and financial services for at least 30 million farmers and improve food security in 26 countries in Africa by 2025. Detailed impacts of the ClimSmart DigitAg Pillar include:

- Malnutrition eliminated for 10 million people;
- 40 percent increase in yields and 40 percent increase in incomes for 30 million users;
- 50 percent increase in digital literacy across agri-sector actors, of which 80 percent are women and youth;
- 30 percent de-risked credit via the use of DCAS (Digital Climate Advisory Services) and DFS (Digital Financial Services); and

- 30 percent increase in the use of weather index insurance products by smallholders.

Under the Plan for the Integrated Development and Adaptation to Climate Change (PIDACC) Zambezi program, AfDB, in partnership with GCA and the International Water Management Institute (IWMI), undertook feasibility studies to identify the actions that are needed to mainstream relevant climate smart digital agriculture technologies into the PIDACC program. The purpose of this assessment report, therefore, is to present the climate risks facing the Zambezi River Basin countries; to understand the climate adaptation efforts currently being undertaken by the eight Zambezi riparian countries; to map the challenges and constraints that slow down or prevent the use of digital technologies in climate adaptation; to identify key opportunities for scaling up of technologies; and to provide recommendations for enhancing digital adaptation in the region.

This assessment report is organized as follows: The next chapter presents a theoretical framework linking digital technology with adaptation to climate change, while also presenting the methods for the assessment. Chapter 3 presents regional perspectives and the economies of the Zambezi River Basin countries, while Chapter 4 presents the climate risks and vulnerabilities of each country in the region. Chapter 5 presents digital adaptation, while digital adaptation readiness (opportunities) is presented in Chapter 6, followed by a discussion of key challenges for digital adaptation in Chapter 7. Chapter 8 presents the conclusions of this regional assessment report. The annex 1 presents context-specific interventions based on the findings of the feasibility assessment identified to leverage different digital and data-enabled climate-smart agriculture technology interventions to accelerate climate adaptation in the region. Annex 2 provides a case study from each country on the use of digital platforms.

2. Study methods and conceptual framework for digital technology adoption and upscaling

Theory of change

This conceptual framework takes on a theory of change approach that is expected during the transformation process as farmers adopt digital technologies (Figure 2).

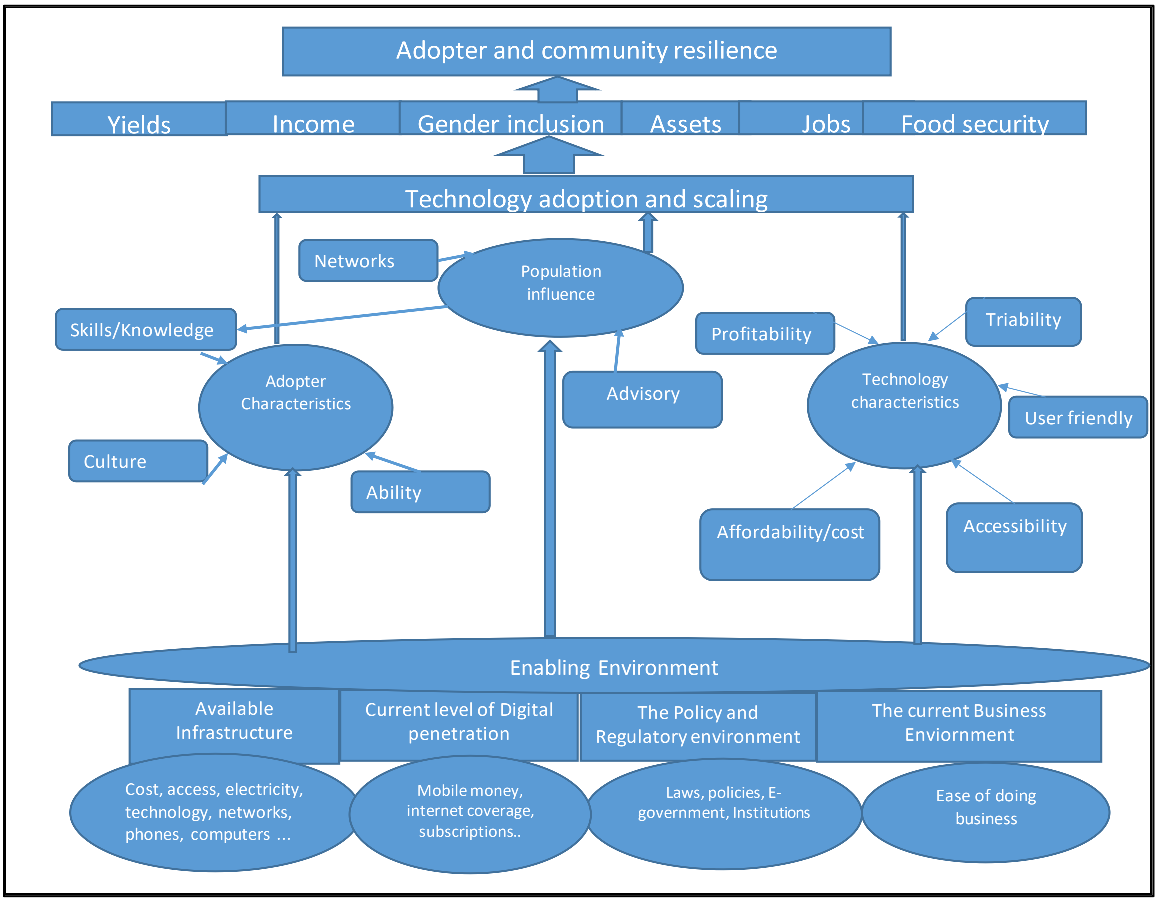

Figure 2: Digital technology adoption, scaling, and resilience.

Source: Authors illustration.

Figure 2 shows that digital technology adoption is influenced by several factors, directly and indirectly. An enabling environment, for example, is of paramount importance in influencing the adoption of digital climate adaptation technology. Key elements of the enabling environment include the current levels of essential infrastructure required to sustain digitalization investments: Electricity, middleware infrastructure, for example, mobile towers, other technologies, mobile phones, as well as computers (FAO and ITU 2022). The other vital element that affects the enabling environment is the current level of digital penetration, which refers to the availability of digital services in the agricultural sector. Here, factors impacting the digital agriculture transformation process within a country, including internet users, active subscriptions, cost of mobile phones, digital finance, among others, are considered important to determine whether digital technologies will be adopted widely or not. This includes digital analytics, middleware infrastructure, hardware as well as software.

Policy and regulatory environment of the Zambezi River Basin countries as well as of their respective regional economic communities such as the SADC, and indeed the African Union, is also a key element for an enabling environment. This encompasses the levels of e-Government services in the country, as well as the existing mechanisms and institutional support, policies, laws and regulatory frameworks that are needed to nurture and support digital agriculture transformation (FAO and ITU 2022). They are also vital in influencing availability, costs, and hence the adoption of technologies. Finally, the general business environment is also as important as the regulatory environment. For example, whether the country scores better on ease of doing business is a decisive factor as it may approximate the attractiveness of the country for digital technology businesses. Aside from the enabling environment, factors at the technology, adopter, and the environment (population) level are also significant.

Technology factors/characteristics

Under the technology factors level, investment costs, accessibility, user friendliness, trialability, and profitability are considered crucial for influencing the adoption of new technology by farmers and small-scale businesses. For example, where the technology is perceived as affordable, user-friendly (i.e., both male, female, and youth farmers can use it easily) and profitable, it stands a better chance of being adopted — other factors being equal. Accessibility and availability as well as trialability are vital for adoption as farmers and small-scale businesses often learn by doing.

Adopter Characteristics

Correctly identifying the decision makers in the agriculture sector and adopter characteristics can shape adoption. Key characteristics include the adopter's skills/knowledge, age, education and awareness of adopters as well as fund remitters for technology adoption, prevailing culture, and their ability. Where such characteristics are favourable the chances of adoption increase, and their absence may suppress technology adoption as farmers may not realize the relative advantages of using technology.

Population influence

The environment, and more importantly the population around smallholder farmers, also influence sub-elements of the adopter characteristics. For example, networks, cooperatives and advisory services all influence adoption, but they do so indirectly by influencing adopter characteristics such as knowledge of technologies and how to use them.

It is also important to note that many of these technology-level factors, adopter characteristics, and population influences are also influenced by various aspects of the enabling environment, together with other factors that shape the decision to adopt technologies. When all these factors are strengthened, they contribute to shaping the nature and speed of technology adoption. The benefits of technology adoption depend on the nature of the technology adopted, but in general, the adoption of useful technology then leads to better yields, more income, gender inclusion, accumulation of assets, increased local employment, and enhanced food security. These in turn lead to better resilience of households to climate change and its negative effects.

The research therefore gathers information for each of the elements in the conceptual framework to understand which elements of the levers that shape adoption need strengthening, and then propose interventions based on the findings.

Study approach

To understand the potential for digital technologies in climate adaptation in the Zambezi River Basin countries, this assessment employed desk studies and stakeholder consultations. The researchers conducted desk reviews of the literature on climate risks, adaptation strategies, available digital tools for climate adaptation, country preparedness for digital adaptation, and the opportunities and challenges for scaling up those technologies in each of the eight riparian countries. The researchers conducted library searches for published documents focusing on climate adaptation, digital technology, opportunities, and associated constraints. The conceptual framework presented in the previous section was used as a guideline for the information the researchers sought to analyze throughout the study.

Stakeholder consultations were another important component of the study approach. At least eight multi-stakeholder consultation workshops involving a total of approximately 200 participants (representing the government, the private sector, development partners, farmer and youth organizations, civil society, and research institutions) were held throughout the assessment to gather ideas on climate risks, climate adaptation strategies currently in practice by stakeholders, digital technologies in use, opportunities, constraints, and recommendations for intervention. Specifically, national consultation workshops were held in Zambia (in partnership with the Indaba Agriculture Policy and Research Institute), Zimbabwe (in partnership with the Centre for Agriculture and Food Policy), Malawi (in partnership with the Ministry of Agriculture), and in Mozambique (in partnership with the Ministry of Agriculture). Two regional workshops were also held in Lilongwe, Malawi, involving 50 participants from the eight riparian states of the Zambezi; and also in Maputo, Mozambique, involving 50 participants from the region. Two further workshops were held in Zambia and Zimbabwe for the validation of national profiles, whereas the regional meeting in Maputo served as a platform for validating the findings of the assessment reports at the Zambezi regional level.

The stakeholder consultation workshops drew diverse stakeholders, carefully selected to represent the various interest groups existing within the Zambezi River Basin countries. While degrees of representation varied from one workshop to another, all consultation workshops comprised farmer representatives including women and youth farmers, government, civil society, and private sector groups. The outcomes of the stakeholder consultation workshops, which comprised of information on climate risks frequently mentioned by stakeholders, lists and inventories of digital technologies used in climate adaptation, opportunities, constraints, and recommendations, were then integrated into the national and thereafter the regional assessment report. Backed by the literature review, secondary data analysis results alongside the outcomes of the consultation workshops provided better insights into the key issues around digital adaptation in agriculture within the Zambezi River Basin countries.

Geographically, the regional assessment focused on all eight Zambezi River Basin countries (Angola, Botswana, Malawi, Mozambique, Namibia, Tanzania, Zambia, and Zimbabwe). The country profiles summarizing climate risks, digital technology use, and constraints have been produced for each of the countries. Figure 3 summarizes the process and shows that the technical studies sought to identify digital tools for adaptation, their constraints, and factors for success. At the time of finalizing this report, the results from this assessment were being mainstreamed into the PIDACC program, which is a key step towards science-based investments in digital technologies for effective adaptation.

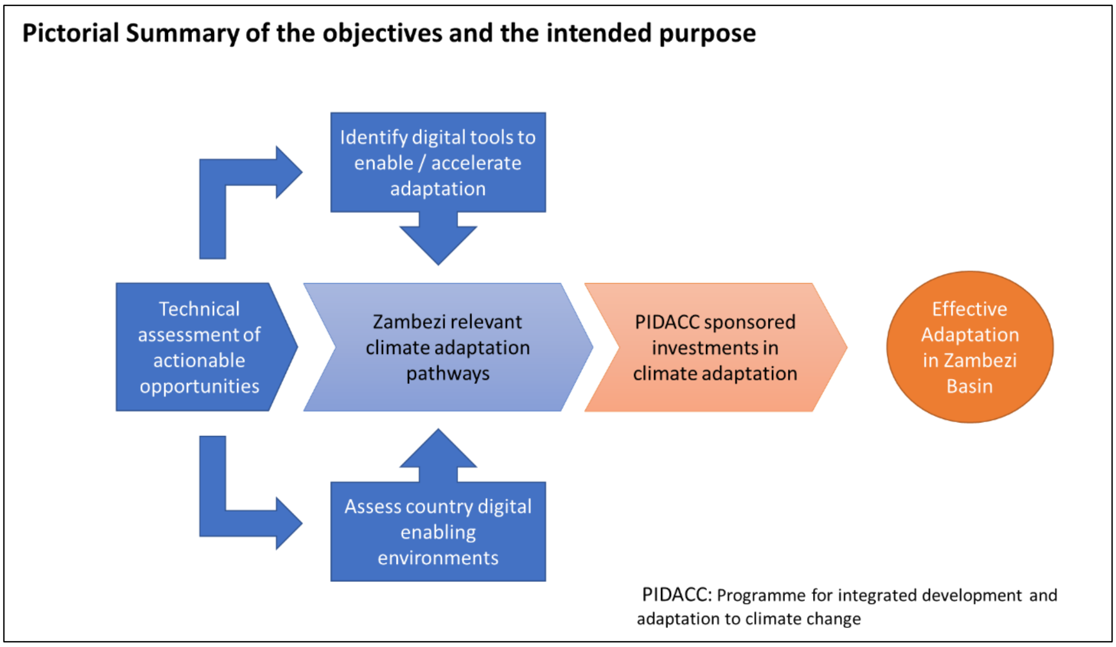

Figure 3: Summary of the research approach and objectives.

Source: Programme for Integrated Development and Adaptation to Climate Change.

The research approach captures the research process, starting by carrying out a situation analysis that helps us understand the current levels of climate risk, digital technology, and constraints thereof that influence smallholder farmers' decisions to adopt digital technologies. The situation analysis forms the background that will guide the identification of the digital solution that best suits farmers in their contexts.

3. Regional perspectives and country context

As highlighted earlier, the Zambezi River Basin countries are diverse economies with a combined GDP of over US$259 billion and a per capita income of just above US$1,400. The region has a mix of lower-middle-income countries (Zambia, Angola, and Zimbabwe), upper-middle-income countries (Botswana and Namibia), and low-income countries (Mozambique Malawi, and Tanzania) (World Bank 2022a). Most of the population in these countries live in rural areas where agriculture is the major source of income and livelihood.

Economic relevance of agriculture, water, and energy

Agriculture remains an important sector, contributing significantly to the national GDP of a range of countries within the Basin. For example, agriculture contributes significantly to national GDP in countries like Malawi (23%), Tanzania (26.6%), Mozambique (25.6%), Namibia (9.2%), Zimbabwe (7.6%) and Angola (9.5%) (Table 2). Although agriculture accounts for under 2.1 percent in Botswana, and only 3 percent in Zambia, it plays a significant role in the economy. For instance, agriculture employs close to 50 percent of the labor force in Zambia. It should be noted that in Angola, Botswana, Namibia, Zambia, and Zimbabwe, the contribution of agriculture to national GDP is low compared to the other three Zambezi River Basin countries because these economies are also dependent on mining, manufacturing, and services sectors, which constitute a larger share of their GDPs.

GDPs per capita, malnourishment by country

Gross Domestic Product (GDP) per capita varies significantly across the Basin countries. At the lower end of the spectrum, there are countries like Malawi and Mozambique with very low DGP per capita, while at the high end of the spectrum, Botswana and Namibia have GDPs per capita of over US$4,000 (Table 2). These differences in incomes imply that there are bound to be differences in the needs of smallholder farmers across countries. There is also a considerable prevalence of wasting and undernourishment among children in the region. For example, an overwhelming 46.7 percent and 29.3 percent of children in Zambia and Angola are reported as being undernourished, whereas in Namibia and Tanzania, as much as 19.8 percent and 25.1 percent are undernourished. There is also a high proportion of children who are underweight in Botswana (11.8%) and Tanzania (13.7%).

The role of agriculture in employment provision

In all eight countries, agriculture remains a key activity, and a significant portion of the total land is under agricultural production. The proportion of land that is allocated to agriculture ranges from about 32 percent in Zambia to as high as 53 percent in Malawi. The rest of the countries also devote a considerable proportion of the total land to agriculture, underscoring the importance of agriculture as a key activity for many households in the basin countries (Table 2). Further, in countries such as Malawi, Mozambique, Tanzania, and Zimbabwe, the majority of the population is actively engaged in primary agricultural production. In Malawi, Mozambique, and Zimbabwe, for instance, 76.4 percent, 70.2 percent, and 66.2 percent of the population, respectively are actively employed in primary production agriculture. In these countries, women's involvement in agriculture is also very high. In Malawi, for example, 82 percent of all the women are actively employed in primary agriculture production, while in Mozambique, the proportion of women in primary agriculture production stands at 80 percent. Even in mineral-rich countries including Botswana and Namibia, women still constitute an important part of the agricultural labor force.

Other key economic drivers

In most of the Zambezi River Basin countries, the population is predominantly rural. The proportion of the rural population ranges from 30 percent in Botswana to over 82 percent in Malawi. Further, it is widely acknowledged that access to electricity is an important economic driver and a key determinant of the role of digital technology in climate change adaptation in the Basin. The statistics show that access to electricity remains a big challenge within the Basin countries, with the population in Malawi and Namibia having access to electricity from 4 percent to around 34 percent respectively. Further, the utilization of digital technology requires high levels of literacy. The statistics show that most of the adult females, adult males, and youth are literate across all eight Zambezi countries (Table 2). Among adult females, for example, literacy rates range from 50 percent in Mozambique to as high as 90 percent in Namibia. The literacy levels offer an opportunity for the deployment of digital technologies in climate adaptation. It should be noted that though there are significant variations in literacy rates for both males and females across the basin countries, there are also significant gender differences in literacy levels. For example, in Malawi and Mozambique, literacy rates are 20 percent more among men than women.

Table 2: Agriculture and the Economy in the Zambezi Region in 2020

INDICATOR	Angola	Botswana	Malawi	Mozambique	Namibia	Tanzania	Zambia	Zimbabwe
GDP per capita (2015 US$)	316,825	629,920	39,400	574.6	404,786	102,994	127,388	130,701
Contribution of agriculture to national GDP (%)	9.5	2.1	23.0	25.6	9.2	26.6	3.0	7.6
Value of total agricultural exports (US$ million)	-	-	585.5	-	2,542.7		415	1,128.2

Value of total agricultural imports (US$ million)	-	-	407.3	-	-	604.19	439	320.3
Agricultural area (M ha)	569,525	259,000	57,000	412,003	388,100	396,500	23,836	162,000
Agricultural area as a percentage of total land area (%)	46	45.6	52.9	52.4	47.14	46.7	32.1	41.88
Total population in the country (million)	31.2	2.30	19.6	31.25	2.541	58.1	18. 92	14,65
Rural population in the country (%)[	33	29.83	82.3	62.9	47.98	65.5	55.9	67.79
People actively employed in primary production agriculture (%)	51	19.9	76.4	70.2	24.85	65.1	49.6	66.2
Women actively employed in primary production agriculture, as a percentage of female employment (%)	57	15.3	82.0	79.8	20.1	66.7	54.7	69.48
Population living on less than US$1.90/day (%)	49.9	14.5	73.5	63.7	13.8	49.40	58.7	39.50
Rural population with access to electricity (%)	7.3	27.6	4.1	4.9	34.47	19.0	13.9	20.05
Adult male literacy rate (%)	80	86.12	69.8	72.6	91.63	83.2	90.6	89.19
Adult female literacy rate (%)	53	87.45	55.2	50.3	91.44	73.1	83.1	88.28
Youth literacy rate (%)	77	97.46	72.9	70.9	95.2	85.8	92.1	90.43
Gender Inequality Index		0.465	0.6	3.5	0.44	0.6	0.73	1.03

Prevalence of people undernourished (%)	17	29.3	17.3	31	19.8	25.1	46.70	
Prevalence of children underweight (%)	19	11.8	9	15.6	13.2	13.7	11.6	9.7
Prevalence of children wasting (%)	5.6	7.3	0.6	4.2	7.1	4.5	4.2	3.30

Source: Computed from various sources including World Bank (2022)

These statistics are indicative of the range of varied contexts seen across the Zambezi River Basin countries. They characterize the challenges associated with agriculture development in the region, as well as potential opportunities for agriculture in contributing to economic development. They specifically establish the context for the climate change adaptation challenges and the potential of digital solutions to help farmers and the region as a whole respond to those dynamics. The section that follows presents specific details of the agricultural and economic backdrop of each Zambezi country, providing the necessary background for the reader to understand the interventions proposed thereafter in the report.

Angola

The leading sub-sectors in Angola's economy are the retail sector (consumer-oriented food products), poultry, and wheat grains. Angola's agricultural sector was devastated by the 27-year civil war that ended in 2002 and millions of people were displaced. Before the civil war, Angola was a major exporter of coffee, sisal, sugar cane, banana, and cotton, and it was self-sufficient in all food crops except wheat. The Angola Ministry of Agriculture has made strategic policies to revive the agriculture sector and make Angolan coffee competitive again in the region. This is not surprising because the country has fertile soil suited for a variety of crops and livestock, with the potential to become one of the leading agricultural countries in Africa (USAID 2017). However, only 10 percent of the 35 million hectares of arable land is under cultivation in Angola, and the country's agricultural productivity and crop yields are extremely low. More than half of Angola's poor reside in rural areas and depend almost exclusively on agriculture for their livelihoods. The agriculture sector is comprised of 90 percent smallholder farmers who produce on a subsistence scale and practise rain-fed agriculture. The increase in temperature and rainfall has a huge impact on both rain-fed and irrigated crops. The common crops grown in Angola are cassava in the north, maize in the centre, and sorghum and millet in the south. Other crops include bananas, potatoes, sweet potatoes, citrus, and pineapples.

In 2020, agriculture contributed almost 9.5 percent to the US$104 billion GDP of Angola (World Bank 2020a) and it provides both formal and informal employment for more than 46 percent of the Angolan population. Currently, Angola imports more than half of its food, making the country's food insufficient for local consumption needs. Angola is the United States of America's fifth largest market for poultry products in the world and the third largest market in Africa for all agricultural exports. The increase in poultry products increased significantly in 2018 due to an increase in the availability of foreign exchange. The agriculture sector was slightly affected by the COVID-19 pandemic, the repeated lockdowns and shutdowns of processing units initially affected the supply chain and limited trade movements of agricultural products. The leading agricultural products produced in 2019/20 in Angola are roots and tubers which are the highest, followed by fruits, cereal, vegetables, and lastly, legumes and oilseeds. As presented later, the country also faces a series of climate risks that threaten a sustainable agriculture sector, among others.

Botswana

The Republic of Botswana is a landlocked state located between latitudes 18 and 27°S and longitudes 20 and 29°E. It has a total land area of approximately 582,000 km^2 and shares borders with Zambia and Zimbabwe to the northeast, Namibia to the north and west, and South Africa to the south and southwest. The topographic elevation ranges from 516 m to 1488 m above mean sea level (msl). The Kalahari desert, located in Botswana's southwest, covers nearly 70 percent of the country, with the remaining areas being primarily tropical grassland and savannah (Batisani and Yarnal, 2010). The total population of Botswana is currently just over 2.4 million[2]. Botswana is one of the world's most sparsely populated countries with a population density of just four people per square km[2].

Agricultural production in Botswana consists of both crop and livestock production. Crop production is dominated by grains and horticulture. There are two main farming systems, traditional or subsistence farming and commercial farming. Traditional farming is the most

[2] https://worldpopulationreview.com/countries/botswana-population

prevalent. Rainfed crop production is dominated by small traditional farms of an average size of 5 ha (Government of Botswana 2002). The traditional farming system relies on animal draught power providing inadequate tillage, low use of fertilizer, and the absence of row planning, all contributing to a very low crop yield. Most of the subsistence farms are situated in the eastern hard-veld areas of the country, with better rainfall, better soils, and better access to water than in the western region. The main crops grown are sorghum, maize, and millet (Government of Botswana 2019)

The contribution of agriculture to gross domestic product (GDP) has declined drastically from 40 percent at the country's independence in 1966 to 1.6 percent in 2007 (Government of Botswana 2019) and currently stands at 2.1 percent, mainly due to rapid growth in the mining sector during the same period. More than 80 percent of the sector's GDP is from livestock production; crop production contributes slightly less than 20 percent. Both livestock and crop production are dominated by communal farms. The agricultural sector accounts for 20 percent of the country's employment. The total agricultural area is estimated at 25.9 million ha (Table 2) and at present, diamond mining contributes 50 percent of the government revenue[3]. As would be expected, Botswana faces numerous climate-related risks, and resilience building is paramount if the country is to survive future climate changes.

Malawi

Situated in the Southeast part of Africa, Malawi borders Mozambique, Tanzania and Zambia, Malawi's economy is significantly represented by agriculture. Rural areas in the country are characterized by poverty and a lack of decent work opportunities, the majority of which are in the agriculture sector (FAO 2011). The average Gross Domestic Product (GDP) per capita for the country for the period between 2007 and 2020 is US$394 (Table 1). The agriculture sector supports the majority of livelihoods in the country and accounts for nearly 77 percent of the total employment. The arable land to the total percentage of land area in 2019 is about 52.9 percent. In 2020, agriculture contributed 23 percent of the GDP (Table 2) and generated over 80 percent of

[3] https://en.wikipedia.org/wiki/Economy_of_Botswana

export earnings[4]. Smallholder agriculture, which is dependent on rain-fed farming, contributes more than 70 percent of the total agricultural production.

Crop production is currently the most important sub-sector, making the biggest contribution to trade (domestic and international) and food security, with maize as the main staple food grown on 80 percent of the arable land (Government of Malawi 2020). Although livestock production constitutes a relatively small sub-sector in the overall agricultural contribution to the economy, contributing about 7 percent to the total GDP and 12 percent of the total value of agricultural production, recent trends show an increase in its contribution (Government of Malawi 2020). Livestock production is concentrated in the northern region and mostly under extensive grazing in communal lands (CIAT& World Bank 2018). Climate change continues to undermine the development potential of both the country and its agricultural sector, although adaptation efforts are underway by the government and various stakeholders, underscoring the importance of further climate adaptation efforts.

Mozambique

Mozambique is located on the eastern coast of southern Africa, with a 2,770 km long coastline hosting many critical ecosystems, such as mangroves, reefs, bays, and dunes[5]. Savannah and secondary forests are dominant across the rest of the country. Its population was 13 million in 1990, which reached 27.9 million and 29.5 million, respectively, in 2017 and 2018, at a growth rate of 2.9 percent per annum. In 2021[6], the population was 32.71 million and consisted of 52 percent of women. The average life expectancy is 54 years, 51 years for men and 56.5 years for women. About 45 percent of the population is under the age of 15[7] providing a relatively large potential pool of labor. However, weak economic opportunities, widespread poverty, gaps in the education system, low life expectancy, and high mortality rates hamper Mozambique from benefitting from these important economic resources. Meanwhile, the illiteracy rate is above 50 percent. Most of the population, around 60 percent, live in the coastal regions, and they are

[4] https://www.jica.go.jp/malawi/english/activities/activity01.html

[5] USAID. Mozambique Marine and Coastal Resources Market Assessment: A Reference Guide. URL: https://pdf.usaid.gov/pdf_docs/PA00XF9M.pdf
[6] World Population Review-Mozambique. URL: https://worldpopulationreview.com/countries/mozambique-population
[7] CIA. The World Factbook: Mozambique. URL: https://www.cia.gov/the-world-factbook/static/4b91441f47ccbc26fb9bd94552e46ef6/MZ_Mozambique_atlas.pdf

vulnerable to climate change, and risks of floods, cyclones, erosion, and the threat of sea-level rise are on the rise.

Many Mozambicans have low income and are food deficient. In fact, 80 percent of people cannot afford an adequate diet and 31 percent of children under five are stunted (World Bank 2020b). About 63.7 percent of the population live below the poverty line set at US$1.90/day (adjusted for purchasing power parity) in 2021[8], but the absolute number of poor people has increased by 30 percent between 1996 and 2014 (World Bank 2020b). The country is ranked 181 (out of 189 countries) in the 2020 Human Development Index, 103 (out of 107) in the 2020 Global Hunger Index, and 127 (out of 162) in the 2019 Gender Inequality Index.[9]

The topography of Mozambique is predominantly rugged highlands in the northwest and lowlands in the south and along the eastern coast. These topological regions are divided by the Zambezi River which enters the country from Zambia and flows out to the Indian Ocean. Other key rivers include the Limpopo River in the south and the Ruvuma River in the north. Lakes are also a key feature of northern Mozambique.

Mozambique is a large diverse country that is administratively divided into 11 provinces, 154 districts, and 407 administrative posts. There are 10 different agroecological zones, classified based on topography, climate, biodiversity, and soil profiles of the country. The country is humid tropical with some pockets of semi-arid tropics, characterized by having two very distinct seasons, one hot and a rainy season from October to May in which most of the rainfall occurs between November and April. The wettest period within the season is December-January with January being the wettest month across the country. The other season is cold and dry from May to September. High rainfall areas include the four northern provinces of Cabo Delgado, Niassa, Nampula, and Zambezia. Zambezia receives over 200 mm/year of rainfall and is considered the wettest province. The Driest provinces of the country are Maputo, Gaza, and Tete (WFP, 2021a).

Even as the economy diversifies, agriculture is still a dominant economic sector largely driven by smallholder farmers. The agriculture sector in Mozambique includes cropping, forestry, fisheries, and livestock-rearing activities and contributes to the overall economy with approximately a

[8] https://www.statista.com/statistics/1243825/extreme-poverty-rate-in-mozambique/#:~:text=In%202021%2C%2060%20percent%20of,to%20decrease%20to%2048%20percent.
[9] https://www.wfp.org/countries/mozambique

quarter of the Gross Domestic Product (GDP) in 2018[10] (with some fluctuation across the years) while creating employment for 75 percent of the workforce. Agriculture is primarily based on rain-fed farming for subsistence and export gains. Due to the climate sensitivity of the agricultural sector, without effective climate action, the incomes and well-being of the population may be negatively affected in the long run, undermining efforts to eradicate poverty and hunger. As per IFAD (2018), the major issues associated with smallholder farmers are scarcity of water for irrigation and animal and human consumption; operation of land without secure tenure; lack of inclusive financial services; timely unavailability of improved inputs and extension, veterinary and mechanization services; poor infrastructure; and risks associated with increasing climatic uncertainty.

The total land area of the country is 801,590 million km^2 consisting of 36 million ha of arable land. However, less than 10 percent of the arable land is in use (FAO 2007a), and only 1 percent is under commercial agriculture (i.e., medium and large farms mainly focus on the cultivation of cash crops like sugar, tobacco, cotton, and more recently fruit). The remaining 99 percent of the cultivated land is in the hands of subsistence farmers and is distributed by close to 4 million small farms of slightly above 1 ha and less than 10 ha in size. The average farm size is estimated at 1.2 ha (CGAP 2016). The area of land under irrigation is 40,000 ha. Irrigation infrastructure is mainly used to cultivate commercial sugarcane and other export cash crops (World Bank Group 2019). Crops are grown in largely rain-fed systems, primarily low-input and low-output farming, making the sector highly vulnerable to climate-related shocks.

Rice, maize, and cassava are the main food crops grown, followed by pulses, sesame, and vegetables (World Bank Group 2019). These crops are mainly produced for local consumption, except maize in the northern region, which can be exported to neighbouring countries. The country is self-sufficient in terms of maize, cassava, beans, and pulses, but the fragmented markets make it hard to access these widely. Poor access to extension support, irrigation, seeds, fertilizers, pesticides, fodder, veterinary services, grazing areas, and financing options for investment in production are the major challenges faced by smallholder farmers. Markets are generally inaccessible to smallholder farmers. Market fragmentation is characterized by limited traders, low prices, large distances, and a lack of market information, among other factors. The impact of climate change over the next 40 years would lead to a 2–4 percent decrease in yields of the major

[10] World Bank. The World Bank Open Data. URL: https://data.worldbank.org/indicator/ NV.AGR.TOTL.ZS

crops, especially in the central region, which is predicted to decline agricultural GDP by 4.5 percent (conservative) and 9.8 percent (most pessimistic).

The livestock sector is crucial to the country because households use it as a means of wealth accumulation, not only for food security. According to the National Agricultural Survey of 2018, about 88 percent of households across the country engage in the livestock sector. Livestock production is generally integrated with crop production. Therefore, it is mainly a sedentary sector without any pastoral trends.

Food insecurity prevalence in 2015 was 24 percent of the population, which is a reduction of 32 percent compared to the figure of 2003. Frequent and intense shocks occurring with a small gap is not permitting households to recover, causing a negative trend in food security. According to WFP (2017), the most food-insecure provinces in the country, including Tete, Sofala, Manica, Inhambane, and Gaza, are greatly exposed to natural hazards such as drought, floods, and cyclones. Malnutrition is more pervasive when compared to food insecurity. The national stunting prevalence of 43 percent of children aged below five years in 2011 was relatively unchanged from 1997 (45%). Historical trends indicate there is a strong relationship between food insecurity and exposure to climate hazards. As 70 percent of the population depends on climate-sensitive agricultural production for their food and livelihoods, increased frequency and intensity of storms, droughts, and floods are likely to pose pressure on agricultural income, undermining 25 percent of the country's economy, 70 percent of livelihoods, and country-wide food and nutrition security.

Namibia

Namibia, which borders Angola, is divided into three major regions: the Namib Desert, the Central Plateau, and the Kalahari Desert. The Namib Desert is largely endowed with rich mineral deposits and has no vegetation growth. The Central Plateau forms 50 percent of the total land area of Namibia and lies between two deserts. The plateau is the most fertile area in the country and the most suitable for human settlement. In addition, the plateau is suitable for cattle rearing and crop production, and the mountains within the plateau are rich in mineral deposits. The Kalahari Desert mainly consists of terrestrial sands and limestones, and its northern region is most suited to crop production, while the southern and eastern regions are suited for livestock production.

Due to the unconducive climate (hot and dry, variable climate, and infertile soils), surviving on agriculture is difficult. However, communities have managed to practise agriculture in such environments by adopting different coping mechanisms (Spear and Chappel 2018). Agriculture, therefore, remains one of the crucial sectors in Namibia, with the majority of the population depending directly or indirectly on agriculture for their livelihoods, employing people on both communal and freehold land. According to Spear et al. (2018), more than 54 percent of the Namibian population resides in rural areas and is dependent on rain-fed subsistence farming. The share of the rural population has not changed much since 2018, and the World Bank reports that as of 2020, 48 percent of Namibians lived in rural areas. Subsistence farming is a major source of income for 40 percent of the rural population in the country (Spear et al. 2018). The sector contributes approximately 9.2 percent to the country's gross domestic product (GDP), of which 70 percent represents the output of the livestock sub-sector.

Of late, the contribution of the sector to the economy has been minimal due to the delayed rainfall experienced by the country and the recurring and prevalent drought. Despite the challenges faced by the agriculture sector, the government has continued to provide support through programs aimed at increasing productivity to ensure food security and the creation of jobs. The sector is dominated by subsistence farming, which is common in the "communal lands" of the country's populous north. Subsistence farmers include smallholder farmers and small-scale operators who rely on the rainy season for agricultural production. The main crops under production are millet, sorghum, corn, and peanuts. The other crops grown are beans, watermelon, squash, and pumpkin. Along the coastline, the fishery is very common and productive, supporting the fishing communities. Cattle, goats, and chickens are the main livestock animals that are kept by households.

Tanzania

Tanzania is located just south of the equator on the coast of East Africa, sharing borders with Kenya, Malawi, Mozambique, Rwanda, Uganda, and Zambia. It is one of the largest countries in East Africa and has a rapidly growing population and economy. Economic growth has significantly contributed to the reduction of poverty in recent years. However, 28 percent of Tanzanians remain below the nationally determined poverty line. Rising temperatures, longer dry spells, more intense heavy rainfall, and sea-level rise make Tanzania the 26th most vulnerable country to climate risks. The current population of 56 million is expected to increase to 130 million by 2050. Thirty-two percent of the population lives in urban areas, and 75 percent of that population lives in informal settlements that are increasingly at risk from water scarcity, flooding, and extreme heat. In rural areas, there is a high dependence on rainfed agriculture and limited access to health care, education, and electricity. Yields for critical crops, including maize, beans, sorghum, and rice, are projected to decrease in the coming decades, endangering livelihoods and food security in the country. Livelihoods and the food supply also depend on coastal and inland fisheries, which are increasingly threatened by warming ocean and freshwater temperatures and sedimentation after heavy rains. Sea-level rise is putting coastal infrastructure, coastal populations (about 25 percent of the total population), and coastal ecosystems at risk of inundation, salinization, and storm surge (UNDP 2022a).

The agriculture sector contributed 26.6 percent to the national gross domestic product in 2019. Seventy percent of the population living in rural Tanzania is employed in farming (Gaddis 2016). The land is an important asset in ensuring food security in the country, and the agricultural industry contributes more than US$1 billion from cash crop export earnings (Gaddis 2016)[11]. However, the country's agricultural sector is plagued with challenges like lack of finance, inadequate training, small farm size (around 2.5 ha per farming household), climate change (resulting in drought, and temperature shocks), and lack of agricultural technology, contributing to hunger, malnutrition, starvation, unemployment, and an increase disease infestation (Gollin and Goyal 2017). This has prompted the government to identify the reduction of poverty and the increase of productivity as top priorities (Gaddis 2016; Mbiha and Ashimogo 2010). Therefore, the agricultural sector requires re-vamping, structural investment, and modern technology (IFAD 2018) to gear up to face these challenges.

Due to the rising temperatures experienced in the country, yields of priority crops like rice, beans, sorghum, and maize are declining. This situation poses a danger to national food security and the standard of living. Similarly, dry spells are observed more frequently than before. The rise in sea level and heavy rainfalls are exacerbating the vulnerability context to climate change in Tanzania and making it one of the most susceptible countries to climate change risks. As a sequel to the sea

[11] Major food crops are maize, millet, rice, beans, sorghum, cassava, bananas, wheat, and potatoes. Main cash crops are cashew nuts, sisal, tea, tobacco, cotton, and tea (Tanzania Coffee Industry Profile 2015)

level rise experienced in the country, coastal populations and ecosystems (about 25 percent of the total population) are at risk of torrents, storm surges, and salination (UNDP 2022b).

Zambia

Although landlocked, Zambia is a resource-rich country with sparsely populated land situated in the center of southern Africa. It has a population density of 25 per km^2 (Statista 2020) and covers approximately 75 million ha of land, of which only about 15 percent is under cultivation. However, 42 million ha, representing 58 percent, are classified as having medium to high potential for agriculture production. Zambia has eight neighboring countries, including Angola, Botswana, the Democratic Republic of Congo, Malawi, Mozambique, Namibia, Tanzania, and Zimbabwe, which provide an expanded market for its goods. The country is divided into ten administrative provinces, namely Central, Copperbelt, Eastern, Luapula, Lusaka, Muchinga, North-Western, Northern, Southern, and Western provinces, with Lusaka as the capital city[12].

Zambia has one of the world's youngest populations by median age (16.8 years). Its population is estimated at above 17.9 million, much of which is urban (44%), with an annual growth rate of about 2.8 percent (World Bank 2021). The rapid population growth is linked to high fertility levels at 4.5 births per woman, resulting in the population doubling close to every 25 years (World Bank2021). As the large youth population enters reproductive age, this trend is expected to continue, putting even more pressure on the demand for jobs, health care, and other social amenities.

Due to the outbreak of coronavirus in 2019 (COVID-19), the Zambian economy fell into a deep recession. The real gross domestic product (real GDP) contracted by an estimated 4.9 percent in 2020, after a growth of 4 percent in 2018 and 1.9 percent in 2019 (ADB, 2020). During this period, all key sectors of the economy deteriorated, manufacturing output fell sharply as supply chains were disrupted, and the service and tourism sectors were hurt as private consumption and investment weakened due to measures taken to contain the spread of COVID-19.

It is, however, worth noting that even before the pandemic, the economy was already experiencing serious macroeconomic challenges, such as high inflation, widening fiscal deficits, unsustainable debt levels, low international reserves, and tight liquidity conditions (ADB 2020; MacroTrends

[12] https://www.citypopulation.de/en/zambia/admin/

2020). Between 2010 and 2020, the government borrowed approximately US$20 billion in debt (US$14 billion in external debt and US$5 billion in domestic debt). However, the borrowed funds did not result in economic growth.

Agriculture remains the main economic activity in rural Zambia and forms an integral part of the economy's poverty reduction strategies for rural households (Middelberg et al. 2020). Despite the agriculture and agribusiness sectors' high contribution of 20 percent to the GDP, Zambia was ranked as the 15th hungriest country in the Global Hunger Index in 2018. Poverty rates remain high with 64 percent of its population living below US$2 a day, out of which 59 percent are considered to live below the US$1.9 a day threshold, and 40 percent are considered to live below US$1.25, a state of extreme poverty. Despite these levels of poverty, particularly in the rural areas, Zambia is food secure in terms of maize production, which is a staple food for the country. Although maize production fluctuated substantially in recent years, it showed an increase through the 1971–2020 period. In 2020, the yield was estimated at 3,387 thousand tons (Knoema 2020).

Nonetheless, Zambia's agricultural production is vulnerable to weather shocks such as inconsistent rainfall patterns associated with floods, droughts, and dry spells. This variability in rainfall patterns has been a challenge in transforming the agriculture sector since most farmers depend on the rain-fed crop production system (Ngoma et al. 2021). The evidence further shows that rainfall is expected to reduce by 0.87 percent by 2050, with the southern and western provinces of Zambia being the worst affected (Mulenga and Chapoto 2021; Ngoma et al. 2021). As more than 50 percent of people who are dependent on agriculture live in rural areas and are very poor (Matchaya et al. 2022), it becomes imperative to improve agricultural incomes and agricultural productivity to significantly improve the livelihoods of many people in Zambia and other countries in similar situations in Africa (Binswanger and Townsend 2000). Evidence-based policy planning and implementation aimed at understanding drivers of agricultural performance can improve productivity and lead to positive livelihood change.

Zimbabwe

Zimbabwe is a landlocked African country with an estimated population of 14.65 million people as of 2019, with females accounting for 52 percent of the population, resulting in a sex ratio of almost 92 percent (ZimStat 2017). The population of Zimbabwe is relatively young, with 40 percent of its population estimated below the age of 15 and about 6 percent aged 65 years and older. 70 percent of the population is based in rural areas, with the rest residing in urban areas. The average household size is estimated at 4.2 people per household (ZimStat 2017). There is a high number of female-headed households, which highlights the need for gender-inclusive strategies to ensure these households have equal access to climate change adaptation technologies.

Zimbabwe has experienced major structural changes, including hyperinflation, changes in the land tenure system, disruption of the agriculture sector, and increased dependence on natural resources to spur economic growth. The period 2000–2008 saw the country experience a sustained decline in economic activities, with real gross domestic product (GDP) growth declining by close to 20 percent in 2008 and the inflation rate increasing, substantially pushing the country into hyperinflation in 2007 before it peaked at the end of 2008 (AfDB 2010). Following the introduction of the multicurrency system, the real GDP growth rate rose by more than 10 percent per annum, reaching a peak of 19.7 percent in 2010 before declining to minus 8.30 percent in 2019 (GoZ 2020). The currency reforms increased inflation, which further impoverished the population, with the percentage of people in extreme poverty increasing from 29.5 percent in 2018 to 42.5 percent in 2019 (GoZ 2020). In 2020, the real GDP growth rate was projected to decline to minus 4.1 percent, owing to the impacts of the COVID-19 pandemic, which stalled economic activities (GoZ 2021).

The economy is heavily dependent on mining and agriculture. However, political instability and the continued instability of the economic environment have severely undermined the country's economic potential. Agriculture is the backbone of Zimbabwe's economy, contributing 12–15 percent to Zimbabwe’s GDP, although this figure declined in 2020 and stood at 8 percent. About 70 percent of the population lives in rural areas and is dependent on climate-sensitive livelihoods such as rain-fed arable farming and livestock rearing, among others. Agricultural activities provide employment and income for 60–70 percent of the population, supply 60 percent of the raw industrial materials, and contribute 40 percent of total export earnings (FAO 2021).

Zimbabwe is divided into five agro-ecological regions, also known as natural regions (NR), based on the rainfall regime, soil quality, and vegetation, among other factors. The regions are classified into the highest rainfall areas: regions I and IIA (>750 mm annual rainfall), medium rainfall areas, regions IIB and III (650–750 mm), and the lowest rainfall areas, region IV (450–650 mm) and region V (<450 mm). In terms of land fertility, the most suitable areas for agriculture are in regions

I, II, and III. Regions I and II are suitable for intensive crop and animal production, while regions IV and V offer opportunities for extensive livestock production and irrigated crops (GOZ 2016a).

The total agricultural area is estimated at 16.2 million ha, of which 4.1 million ha are cultivated and 12.1 million ha are under permanent pastures. The country's forested area declined from over 22 million ha in 1990 to around 15 million ha in 2012 (FAOSTAT 2015). The country produces a variety of crops which include grain crops, such as maize, sorghum, mhunga, and rapoko (finger millet); oilseeds (e.g., sunflower, groundnuts, and soybeans); and other industrial crops such as tobacco, cotton, edible dry beans, and paprika. In terms of market value, the most important crops are tobacco, cotton, and maize in that order, but in terms of strategic importance, maize ranks first as the staple food. Maize is cultivated on one-half of the agricultural land and accounts for 80–90 percent of the domestic staple crop production. However, maize yields have been on the decline since the country's independence in 1965. Maize is particularly vulnerable to rising temperatures and a lack of precipitation, with temperatures over 35°C resulting in lower yields (USAID 2019a).

The next chapter focuses on the nature of climate risks facing the eight riparian countries of the Zambezi River Basin and is followed by a discussion of the adaptation techniques currently in place and the role of digital technology in the process.

4. Climatic risks, vulnerability, and resilience

The Zambezi is categorized by the Intergovernmental Panel on Climate Change (IPCC) as exhibiting the worst potential effects of climate change among the 11 major African basins. Historically, there has been a continuous cycle of climate-change-related extreme floods and droughts in the Zambezi Basin. In recent decades, extreme floods were experienced in 2017, 2014–15, 2008–09, 2007, 2005–06, and 1999–2000. Intermingled with droughts in 2015–16, 2012–13, 2004–05, and 2001–2003, this heavily undermined food production (IPCC 2021). The 2016 drought, for instance, reported to be the worst in the past 35 years, affected 39 million people across the Zambezi Basin, many of whom were food producers. Tropical cyclones are expected to become more intense, with higher peak wind speeds and heavier precipitation associated with increases in the tropical sea surface temperature (IPCC 2021). With producers and food systems not adapting to this, impacts on the economy and food security can be severe. The Zambezi River flow is highly sensitive to climate variations, and with irrigation being unavailable for small-scale producers, irrigation deficits will increase, undermining the productivity of farmers.[13] Taken together, climate variability is leading to an estimated 1 percent GDP loss annually. With persistent poverty and food insecurity, Zambezi's economic and human development are severely hampered by climate impacts.

There are several important climate hazards in the Zambezi Basin. These include rising temperatures, ranging from 0.33°C per decade in Angola to as high as 2°C in Botswana. Projections show that temperature rises by 2050 will exceed 1.5°C in Zambia and reach as high as 3.7°C in Mozambique. The region also suffers a decline in average rainfall**,** and projections indicate that this will continue in the future. In some countries, like Namibia, total precipitation rates are likely to decrease by as much as 19 percent by the 2080s. All the countries in the region also suffer from prolonged dry spells and droughts, posing a serious threat to the health of wetland ecosystems, agriculture, and livestock communities. Flash floods are becoming commonplace, notably in southern Malawi, Mozambique, and Zimbabwe, leading to loss of life, livelihoods, and the resilience of economies.

Thus, the Zambezi River Basin is highly vulnerable to the impacts of climate change and adverse weather events. These have serious environmental, economic, and social consequences for

[13] https://oneworldgroup.co.za/wp-content/uploads/2019/06/Zambezi-RV-Mapping-Synthesis-Report-final.pdf

millions of people living there. Vulnerability is high due to high dependence on rain-fed farming, poverty, low adaptive capacity, and unsustainable agro-ecological systems.

Whereas the observed increases in temperatures, frequency of floods, droughts, and other extreme weather events are undermining livelihoods, the effects in the future are expected to worsen as these climate risks escalate. It is generally expected that climate change will negatively affect crop production, livestock farming, aquaculture, and forestry in the future.

Zambezi runoff is highly sensitive to variations in climate; a small change in rainfall produces large changes in runoff, and future climate projections show a general increase in temperature (>2°C in mid-century) and a decrease in rainfall in the Zambezi Basin. The increase in temperatures across the Zambezi Basin will result in a higher rate of evaporation and evapotranspiration, and increased evaporation will in turn reduce the energy generation capacity (affecting hydropower in the Zambezi). The basin population suffers frequently from droughts and floods, due to their limited coping capacity to extreme weather events. It is further projected that there will be an increase in the length of the dry spell during the dry season across southern Africa. This may render the dry season more intense, negatively impacting perennial crops and crops grown during the dry season.

The region is already experiencing climate change, and its effects on agriculture are obvious, ranging from low agricultural productivity, drying rivers, and poor livestock production as pests and diseases become prevalent to the general erosion of livelihoods. All countries in the Zambezi River Basin are vulnerable to climate change, but some, including Malawi, Mozambique, and Tanzania, are more vulnerable owing to overdependence on agriculture, whereas Namibia, Botswana, Zambia, Zimbabwe, and Angola are also considerably vulnerable despite having significant mining activities, perhaps because ownership of mines is not in the hands of ordinary citizens.

Climate warming in the Zambezi will happen faster, and erratic rainfall, drought, and flash floods will intensify. These climatic hazards will affect many of the region's farmers, leading to an erosion of livelihoods unless adaptation efforts are escalated.

Adaptation to natural hazards and climate variability in the Zambezi River Basin

The Zambezi is a region strongly affected by short-term climate-related natural hazards and climate variability. Floods are commonplace in many of the countries in focus; for example, in the 2021–2022 growing season, floods ravaged many parts of southern Malawi, the central and northern parts of Mozambique, and Zimbabwe. Northern and central Mozambique were particularly hard hit by the tropical storm Ana, which destroyed thousands of houses, dozens of schools and hospitals, downed power lines, and washed away bridges.[14] The effects of climate variability are already visible in rainfed systems and small businesses. The floods sweep away livestock and drown fields, destroying livelihoods. Waterborne and vector-borne illnesses follow, including acute watery diarrhoea, malaria, and cholera, as in the cases of Malawi and Mozambique following recent floods. Recent cholera outbreaks happened in Munhava, Beira, after Cyclone Idai in 2019; Nampula Province in 2020 during the rainy season and Caia District, Sofala, in September 2021. Climate change has led to an increase in diseases, conflicts, and poverty, and in some cases, seed losses owing to the shifting of seasons.

There are underlying factors that increase the sensitivity and exposure of farmers to climate-related risks while at the same time undermining their adaptive capacity. These factors include social, economic, educational, institutional, policy-related, market-related, and infrastructural issues. The most exposed farming households in each country show relatively low adaptive capacity and vulnerability to climate change and variability (Tessema and Simane 2019). A country's vulnerability to climate change and other global challenges in combination with its readiness to improve resilience is measured by the ND-GAIN index, which evaluates a country's overall vulnerability by considering its main sectors, including food, water, health, ecosystem services, human habitat, and infrastructure (Table 3)

Table 3: ND-GAIN country indices for the Zambezi River Basin countries

Country	**ND-GAIN index country rank***	**ND-GAIN index**	**Vulnerability country rank***	**Vulnerability score**	**Readiness country rank****	**Readiness score**
Angola	160	37.45	131	0.506	176	0.255
Botswana	87	48.95	112	0.450	86	0.429

[14] https://reliefweb.int/report/mozambique/

Malawi	162	36.7	160	0.548	163	0.282
Mozambique	154	38.1	139	0.513	168	0.275
Namibia	107	45.7	104	0.47	107	0.378
Tanzania	147	39.2	146	0.520	153	0.301
Zambia	137	40.5	139	0.52	143	0.33
Zimbabwe	174	33.1	159	0.55	187	0.21

Source*:* Notre Dame Global Adaptation Initiative. URL: https://gain.nd.edu/our-work/country-index/rankings/.

The ND-GAIN index essentially distils a complex set of interacting factors into a simple metric useful for understanding vulnerability at the country level. The most vulnerable ones in the region are Malawi, Tanzania, and Zambia, which have the three highest vulnerability indices in the region. In general, though, almost all these countries are vulnerable to climate risk and associated impacts. They all rank upwards of 100, implying they are more vulnerable than many other countries elsewhere, whose ranks on vulnerability are lower. Highlights of climate risks and climate change projections for each country are summarized in Table 4.

Table 4: Climate projections for the Zambezi riparian countries

Country	Temperature	Rainfall
Angola	Between 1960 and 2006, the mean annual temperature increased by about 1.5°C with an average increase of 0.33°C per decade.	Mean annual rainfall declined at an average rate of about 2 mm per month (2.4%) per decade between 1960 and 2006.
Botswana	under the high emission scenario (Representative Concentration Pathways [RCP] 8.5) for the period 2040–2059 annual temperature increases by +2.5°C.	Under RCP 8.5 annual precipitation decreased by 5.3 mm.
Malawi	Projected to increase 1–3°C by 2050.	Projected precipitation for the same period showed a general decrease in monthly rainfall in the early part of the rainy season.
Mozambique	Temperatures are expected to increase by 1.4–3.7°C by 2060, with warming more rapid in southern and coastal areas.	The number of heavy rainfall events is projected to increase by 2060, particularly during the dry season.
Namibia	Increased mean, maximum, and minimum temperatures since the 1960s; warming is higher than the global average.	Likely to reduce by s 19% by the 2080s with the largest reduction in the dry season.
Tanzanian	Projected to increase the average annual temperature of 1.4–2.3°C by 2050.	Increase heavy rainfall event frequency (7–40 percent) and intensity (2–11%) by 2050.

Zambia	All regions within the country would experience temperature increases exceeding 1.5°C by 2050, especially during the growing seasons.	Southern and Western regions of Zambia will likely experience more reduced rainfall over time and in the worst-case scenario, rainfall may reduce by 20–30%.
Zimbabwe	The number of days/years with a maximum temperature greater than 35°C is expected to increase by 39 days in the period from 2040 to 2059 under RCP8.5.	The number of days of consecutive dry spells per year (or days without significant rainfall of at least 1mm) is projected to increase by 13 days from 2040 to 2059, under RCP 8.5.

Source: Authors compilation from literature and stakeholder consultations.

Angola

Angola is endowed with diverse climate zones that are influenced by maritime currents and geography. The narrow coastal region of Angola is semiarid, with an average annual rainfall of 600 mm, with higher rainfall in the north and lower rainfall in the south. The broad interior plateau can be subdivided into three agro-ecological zones. These zones are a warm, wet north with heavy rainfall that exceeds 1,500 mm annually and high average annual temperatures of more than 22°C; a central zone whose tropical climate is tempered by altitudes of 1,000–2,500 meters with 1,250–1,500 mm of rainfall per year and annual temperatures of 18–20°C; and a semiarid south-west zone, near the Kalahari desert, whose low temperatures in the hot season are driven by tropical continental air masses and the Benguela Cold Current (USAID 2017).

Since 1960, Angola has experienced an increase of 0.33°C per decade in average temperature and a more rapid increase from June to August (USAID 2017). On the other hand, the country experienced an increase in the frequency of hot days in all seasons and an increase in hot nights except for June to August. There was also a decrease in average annual rainfall of around 2.4 percent per month per decade. Temperature observations show that Angola has warmed significantly in recent decades. Between 1960 and 2006, the mean annual temperature increased by about 1.5°C 1960 and 2006, an average rate of 0.33°C per decade (USAID 2011). The temperature has been increasing more rapidly in winter, at approximately 0.47°C per decade, and the slowest in summer, at about 0.22°C per decade. On the other hand, the mean annual rainfall has shown a decline at an average rate of about 2 mm per month (2.4 percent) per decade between 1960 and 2006 (USAID 2011). There has been an increased frequency of hot days in all seasons and an increase in hot nights except June–August, a decrease in the annual frequency of cold nights, whereas during the same period, mean annual rainfall has declined at an average rate of 2.4 percent per month per decade, with a stronger decrease in the southern region. The majority of climate models project average temperature increases of more than 1°C by the 2030s compared to the 1970–1999 mean, and rainfall variability is projected to increase. These gloomy future climate projections underscore the importance of climate adaptation efforts.

Botswana

Botswana's climate is semiarid, characterized by warm winters, hot summers, low rainfall, and high levels of evapotranspiration (Hachigonta et al. 2013). In the centre of the country is the Kalahari Desert Sand veld,[15] which covers two-thirds of the country and is suitable mainly for livestock and wildlife. The eastern part of the country consists mostly of loamy clay soils that are more fertile and better suited to crop production. In the north-eastern part of the country is the wet sand veld, characterized by green wetlands and an abundance of wildlife. The remainder of the country is transition sand veld. The climate of Botswana is sub-tropical, arid, or semi-arid, depending on the area.

The mean annual rainfall ranges from 145 mm/a in the south to 616 mm/a in the north. The mean annual precipitation is 396 mm, about 74 percent of the annual rainfall occurs from December through March, with extremely low precipitation occurring between June and August. Temperatures for the country are generally warm to hot, with mean monthly maximum temperatures ranging from 29.5°C to 35°C in summer, and 19.8°C to 28.9°C in winter. Mean monthly minimum temperatures range from 14.6°C to 20.8°C in summer and 2.9°C to 11.6°C in winter.

Botswana is highly vulnerable to climate variability and changes, mainly due to its high dependence on rain-fed agriculture and natural resources, high level of poverty (about 29% of the population is undernourished), and low adaptive capacity to deal with climate shocks. According to Cardona et al. (2012), vulnerability is defined as the propensity of exposed elements such as human beings, their livelihoods, and assets to suffer adverse effects when impacted by hazard events. This section thus examines climate vulnerabilities and resilience in Botswana across a series of key themes (agriculture, water resources, health, etc.).

[15] Sandveld, in the general sense of the word, is a type of veld characterized by dry, sandy soil, typical of certain areas of the Southern African region.

Agriculture: Botswana's agriculture is mainly rain-fed, which is more sensitive to climate variability and change. Approximately half of the population lives in rural areas and largely depends on subsistence crop and livestock farming. Rural areas have a low adaptive capacity to deal with these expected changes.[16] The domestic agriculture sector meets only a small portion of local food needs and contributes little to GDP. The country imports about 90 percent of its food from South Africa (World Bank, 2020d). Most of the land under cultivation is in Botswana's eastern region. Climate-smart agriculture approaches used in Botswana include minimum tillage, conservation agriculture, irrigation, and water management, and new crop variations (FANRPAN 2017).

Water Resources: Water resources in the country are highly driven by climatic variables, mainly temperature and rainfall. The high evaporation rate, accompanied by a lack of permanent surface water over large parts of the country, makes Botswana more vulnerable to climate change.[17] Climate change also affects groundwater through increased abstraction due to increased demand for water and reduced recharge due to decreased rainfall. Climate change is expected to increase water scarcity in the northern, central, and eastern areas of the country (World Bank 2020e).

Health: changes in temperature and precipitation patterns due to climate change will likely have multiple negative health impacts. Reduced water quality and quantity due to changing rainfall patterns may increase the distribution of vector- and waterborne diseases, while increased frequency, intensity, and duration of extreme events likely result in fatalities, loss of life, and damage to property and infrastructure (USAID 2016).

Ecosystems: climate change negatively affects fisheries, forestry, and other ecosystem services, affecting the poor who depend on these ecosystem services for food, firewood, income sources, construction materials, and others. Increased soil erosion due to climate change also results in reservoir sedimentation, reducing water availability. Deforestation may also result in a change in baseflow and recharge, which has a direct impact on water availability. Intense rainfall and

[16] UNDP (2017). Botswana Climate Change Response Policy, Draft. Version 2 – December 2017. URL: https://info.undp.org/docs/pdc/Documents/BWA/DRAFT%20CLIMATE%20CHANGE%20RESPONSE%20POLICY%20%20version%202%20(2).doc

[17] National Disaster Management Office (2013). National Disaster Risk Reduction Strategy 2013–2018. URL: http://www.bw.undp.org/content/dam/botswana/docs/Gov%20and%20HR/Botswana%20National%20Disaster%20Risk%20Reduction%20Strategy-April%202013.pdf

flooding may also result in soil erosion and waterlogging of crops, thus decreasing yields and increasing food insecurity (World Bank 2020f). Overgrazing and intense rainfall may result in flash flooding in some areas. This is likely to drive rural-to-urban migration patterns further and contribute to urban population pressures (World Bank 2020f).

Botswana is exposed to numerous hazards, including droughts, floods, earthquakes, strong winds, land fires, and pest infestations. Climate change is expected to increase the risk and intensity of flooding as well as the likelihood of water scarcity in northern, central, and eastern areas of the country (World Bank 2020f). Intense rainfall and flooding may also result in soil erosion and water logging of crops, thus decreasing yields and increasing food insecurity. Floods are the most frequently occurring disaster event in Botswana and are primarily caused by heavy rains that affect communities in flood-prone areas. Disasters have historically been concentrated along rivers such as the Zambezi River, the Okavango River and its delta, the Boteti River, and the Limpopo River (World Bank 2020f).

Botswana as a whole is also prone to drought, recurrent dry spells, and desertification. Nearly 2/3 of the country is covered by the Kalahari Desert. Expected changes in weather patterns are thus likely to increase the country’s vulnerability to scarce water resources. Additionally, the heavy reliance on cattle and livestock as a key livelihood generator increases population vulnerability to drought. Overgrazing and intense rainfall may result in flash flooding in some areas. This is likely to drive rural-to-urban migration patterns further and contribute to urban population pressures (World Bank 2020f).

Recurring droughts and floods have the most severe impact on the population, and the country has a long history of both recurring floods and droughts. However, the magnitude, frequency, and impact have increased (World Bank 2020f). Droughts and floods are the most destructive climate-related natural hazards in Botswana. According to Tsheko (2003), areas around Mahalapye town are prone to drought and hence too risky for rain-fed agriculture, while, areas around Shakawe and Maun towns, located in the north, have reliable rainfall and are good for commercial dry-land farming or rain-fed agriculture. Palapye and Serowe were the most vulnerable areas for flooding during the 1995 floods; 87 percent of casualties were in these areas. Flooding in Botswana affects an average of 8,000 people per year, which equates to approximately 0.4 percent of the total population of the country. A majority of the affected people are concentrated in the central district, which is the most populous district, and in Ngamiland, where the delta of the Okavango River is located (CIMA 2018). Data from the Emergency Event Database: EM-Dat database[18] shows the country has suffered multiple droughts and flood events (7 droughts and 12 flood events) occurring between 1900 and 2022, affecting a million people.

Mozambique

Based on the average annual rainfall, the country is divided into three climatic zones: A, B, and C. Climate Zone A is the wettest zone, with around 1,165 mm of rainfall per year. The annual rainfall pattern in zone B is more mixed across the zone compared to the other climate zones, with the annual rainfall of around 940 mm/year ranging from around 500 mm in the north to around 1200 mm in some areas in the south of the zone. Climate zone B has a high risk of drought events across the central and western parts of the zone and a high risk of flooding events in the eastern part of the zone around the major river basins, for example, the Zambezi and Buzi rivers. Climate Zone C is the driest of the three climate zones with annual rainfall amounts of about 680 mm/year, and these range from around 300 mm in the north-west of the zone to around 700 mm in the north-east.

Ambient temperature is relatively uniform across the country, and there is a north-south rainfall gradient, which results in higher, more reliable rainfall amounts in the north and lower, more variable rainfall amounts in the south. Temperature ranges from daily maximum values of around 25 °C during winter (June to August) to around 32 °C during October to December over the 1981–2017 period (WFP 2018). The warmest months coincide with the rainy season, which typically lasts from October to April (WFP 2021b).

Although Mozambique contributes only 0.1–0.2 percent to global emissions, it is the 38th most vulnerable and the 13th least ready country to address the effects of climate change. In 2019, it was the most affected country worldwide by the impacts of extreme weather events. The country scored fifth in the global climate risk index over the period 2000–2019 (Eckstein et al. 2021). The country has experienced 68 climate-related disasters over the last 50 years, killing more than 100,000 people.[19] Extreme weather events such as floods, droughts, tropical cyclones, and heatwaves are projected to increase in frequency and intensity compared to now (WFP 2021b).

[18] https://public.emdat.be/
[19] Republic of Mozambique. Nationally Determined Contributions. URL: https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Mozambique%20First/MOZ_INDC_

The average annual loss from floods induced by cyclones in Mozambique stands at US$440 million[20]. Two out of three people who live in highly populated coastal areas are vulnerable to the rapid onset of disasters such as cyclones, storms, and flash floods (WFP 2021a). Of the total number of 128 districts in Mozambique, 57 are subjected either to drought, flooding, or both hazards, making 48.2 percent of the population vulnerable (FAO 2007b). Many sectors, especially agriculture, food security, and water resources, are strongly impacted by variations in temperature and precipitation. The impacts are likely to pose an additional challenge for the country to achieve various Sustainable Development Goals (SDGs) and other national targets.[21]

Historical climate analysis for the country shows that temperatures are already increasing, and rainfall trends are dominated by year-to-year variability. Livelihoods and agricultural production systems are already being affected by the changing and more variable climate (WFP 2021b). The results of the detailed climate analysis conducted for the period 1981-2017 indicate a warming of 0.1–0.25°C per decade in Mozambique, especially in the southern part of the country, where the country never recovered from the last El Nino in 2015 (WFP 2018). According to the World Bank Group, mean temperatures across the country rose by an average of 0.9°C (0.15–0.16°C per decade) since 1960, especially during the rainy season[22]. All future scenarios predict that Mozambique will face an increase in temperature up to 1°C and 3°C by 2050, but no strong trend for changes in rainfall (WFP 2021b). The number of hot days increased by 25 in the last 40 years, and much of this has occurred during the southern hemisphere autumn (World Bank Group 2019).

Rainfall is mainly driven by the Inter-Tropical Convergence Zone (ITCZ), which results in higher and more reliable rainfall amounts in the northern regions (around 1000 –1500 mm per year), and lower and more variable rainfall amounts in the southern regions (less than 500 mm per year in some parts) (WFP 2018). The position and intensity of the ITCZ vary from year to year and they are influenced by large-scale dynamics in the climate system, such as the El Niño Southern Oscillation (ENSO). The El Niño phase is often associated with drier conditions in the south and wetter conditions in the north during the winter, whereas the La Niña phase brings wetter conditions in the south (WFP 2021b). Rainfall projections are mixed, with most models projecting

Final_Version.pdf
[20] https://qz.com/africa/1965013/mozambique-zimbabwe-malawi-worlds-worst-hit-by-climate-change/
[21] https://qz.com/africa/1965013/mozambique-zimbabwe-malawi-worlds-worst-hit-by-climate-change/
[22] World Bank climate change knowledge portal. URL: https://climateknowledgeportal.worldbank.org/country/mozambique/climate-data-historical

decreases in average annual rainfall and some models projecting small increases. The projected changes in rainfall are small, and the year-to-year variability in rainfall amounts exceeds any climate change signal (WFP 2021b).

According to the World Bank Group (2019), since 1960, mean rainfall has decreased by an average of 2.5 mm per month (3.1%) per decade. Spatial manifestations varied, with increased rainfall over the northern regions, highly variable conditions in the central regions, and persistent drought periods coupled with episodic floods in the south. The proportion of days with heavy rainfall events has increased by 2.6 percent per decade or an estimated 25 days per year.

Two scenarios of climate are reported in WFP (2021b), based on projections from two different climate models for Mozambique. Scenario 1 represents a hotter and drier future, where the key features are reduced water availability, increased heat stress, and increases in drought conditions. Scenario 2 represents a future climate that is warmer than now, with more extreme rainfall events. Increased evaporation as a result of higher temperatures means that any increases in average rainfall are likely to be offset, resulting in reductions in water availability under all future climate scenarios.

The CORDEX-Africa initiative projected that spatial and temporal changes (for three, 30-year periods, the present (2011–2040), mid (2041–2070), and the end (2071–2100)) in temperature and precipitation under the representative concentration pathways (RCP) 2.6, RCP 4.5, and RCP 8.5 are analyzed and compared relative to the baseline period (1961–1990). Results show that there is a tendency towards an increase in annual temperature as we move toward the middle and end of the century, mainly for RCP 4.5 and RCP 8.5 scenarios. This is evident for the Gaza Province, north of the Tete Province, and parts of Niassa Province, where variations will be maximum temperature (0.92–4.73 ^{o}C), minimum temperature (1.12–4.85 ^{o}C), and mean temperature (0.99–4.7 ^{o}C) (Mavume et al. 2021). Precipitation shows substantial spatial and temporal variations, both on annual and seasonal scales. The northern coastal zone region shows a reduction in precipitation, while the entire southern region, except the coastal part, shows an increase of up to 40 percent and up to 50 percent in some parts of the central and northern regions, in future climates for all periods under the three reference scenarios. At the seasonal scale (DJF and MAM), the precipitation in much of Mozambique shows above-average precipitation, with an increase of up to more than 40 percent under the three scenarios. In contrast, during the JJA season, the three scenarios show a decrease in precipitation. Notably, the interior part will have the largest decrease, reaching a variation of −60 percent over most of the Gaza, Tete, and Niassa Provinces (Mavume et al. 2021).

World Bank Group (2010) has projected the climate change effects on crop yields of six cash crops and eight food crops under both irrigated and rainfed conditions (mm/ha). The findings indicate that there will be reductions in yield both due to the lack of available water and the overabundance of water that causes waterlogging. The average yield reduction in the selected crops will be 2.05 percent, with a 3.65 percent reduction in cassava yield and a 0.66 percent reduction in maize yield. Adaptation to present and future climate risks is thus extremely important.

Namibia

Namibia's climate ranges from semi-arid in the northeast to hyper-arid in the south and west. The climate is hot and dry, with uneven rainfall. The wettest month occurs from December to March (World Bank 2022a). The mean annual rainfall received by Namibia is estimated to be around 25 mm in the southern and coastal areas, with an upper limit of about 600 mm per year in the north-east areas. The north and north-east have stable and predictable rainfall. The temperature is usually hot with an average annual temperature of below 16 °C along the southern coast, between 20 °C and 22 °C in the country's central and eastern parts, and above 22 °C in the northern part of the country (World Bank 2022a).

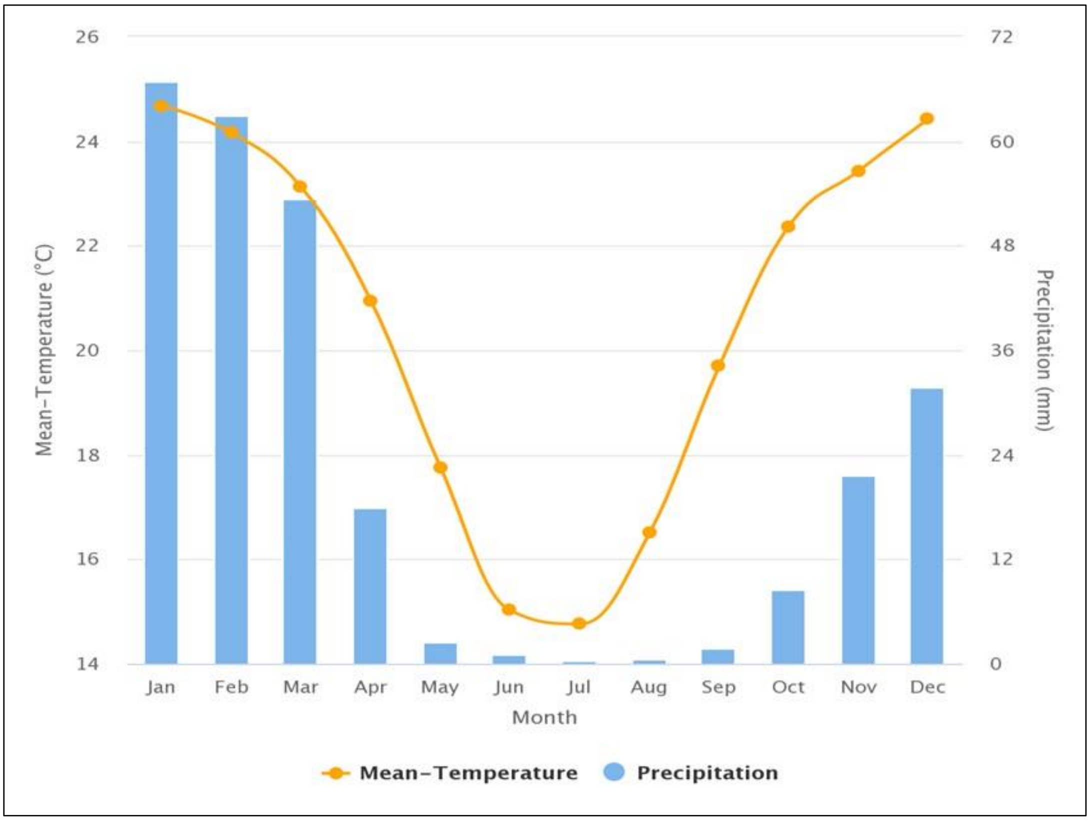

Figure 4: Monthly climatology of mean temperature and precipitation in Namibia from 1991 to 2020

Source: World Bank 2022.

The climate conditions in Namibia have been associated with an unprecedented increase in the frequency and intensity of natural hazards. As such, it is acknowledged that Namibia is most vulnerable to the impacts of climate change. According to MET (2010), the climate in Namibia has changed, with increased occurrences of droughts and water scarcity, and the maximum daily temperatures have been increasing consistently. Daily maximum temperatures exceeding 40 ^{o}C are frequent, and average temperatures below 0 ^{o}C have never been recorded. The frequency of hot days, heatwaves, and droughts has been increasing. Evaporation is at least five times greater than the average rainfall in most parts of the country. Those areas where rainfall is minimum, experience higher evaporation rates (GoN 2021). Thus, it is important to understand the patterns and the mechanisms to be adopted for the development of adaptation and resilience strategies to enhance people's capacity to respond to natural disasters. The expectation is that the climate change adaptation and resilience strategies that exist in Namibia will vary among individuals since different people are impacted differently by climate change.

In the future, temperatures are set to rise around the globe due to global warming, and more specifically, temperatures in Namibia are set to rise more than the global average and at a faster rate. In 2050, the temperatures will rise by 2 ^{o}C globally, and in Namibia, they will rise by an average of 1.5–2.5 ^{o}C in the south and 2.5–3.0 ^{o}C in the north when compared to 1961–1990 (Ragab and Prudhomme 2002). The temperature rise is a threat to ecosystems. The increase in temperatures will have a negative impact on crop productivity, affecting mainly subsistence farmers. It is estimated that crop productivity will drop by approximately 5–20 percent at an increase of 1.5–3 ^{o}C, and livestock productivity will decline by 20–50 percent (Reid et al. 2008).

Crop productivity will be impacted negatively. Increases of 1.5°C and above will have severe impacts on crops. Crop productivity is expected to drop by 5–10 percent at 1.5°C and 2°C, with a decrease of 20 percent at 3°C. This loss will be even larger for subsistence farmers with expected decreases of 20–80 percent between 1.5°C and 3°C (Reid et al. 2008). Increasing temperatures negatively impact livestock productivity because of lower feed intake, milk production, fertility, and longevity. Livestock productivity is expected to drop by 5–20 percent at 1.5°C and 2°C, with further decreases of 50 percent at 3°C (Reid et al. 2008).

The acceleration of global warming calls for strengthening community capacity to respond to the impacts of climate change through diversified crops and farming practices, soil and water conservation, and training and information sharing.

Tanzania

Tanzania has extensive water resources (96 km^2 per year, renewable); however, large swaths of arid and semiarid land (up to 50 percent of the country) and strong rainfall seasonality lead to spatial and temporal water scarcity (Arce and Caballero 2015). Water availability will also depend on the development of rivers upstream by neighbouring countries, as 13 percent of Tanzania’s renewable water resources are transboundary. Diarrheal diseases and malaria, both leading causes of death in Tanzania, are likely to escalate due to increasing temperatures and heavy rainfall events. While health indicators have been improving overall, life expectancy is just 65. Rising temperatures reduce food crop and coffee yields due to heat stress, reduced reproduction in livestock, growth rates, and milk production, resulting in higher morbidity and mortality. There is damage to crops and land from heavy rainfall, flooding, erosion and waterlogging, and increased pest and disease damage.

Projected increased flooding threatens further outbreaks of waterborne diseases such as cholera and typhoid, as just 61 percent of the population has access to improved drinking water sources and only 19 percent to improved sanitation. About 40 percent of Tanzania's limited electricity supply comes from hydropower, which is vulnerable to increasing evaporation, siltation from heavy rainfall events, and longer dry spells. A prolonged dry spell in October 2015 led to a near cessation of hydropower production across the country. While future flows may increase in the Pangani and Rufiji basins, both important for hydropower, increasing evaporation and siltation will constrain Tanzania's inadequate electric supply, which only reaches 16 to 18 percent of the population (FAO 2015). From coral reefs to the Serengeti to the highest point in Africa, Mount Kilimanjaro, Tanzania has globally significant ecosystems and biodiversity. The country includes four internationally recognized wetlands (Ramsar sites) and the southern portion of the Coastal Forests of Eastern Africa biodiversity hotspot. Tourism, which accounts for more than 20 percent of foreign exchange earnings, is largely derived from Tanzania's ecosystems and biodiversity, which are now at risk from combined climate and non-climate stressors such as land conversion, deforestation, and unsustainable fishing. Increasing ocean temperatures, sea level rise, and saline intrusion threaten mangrove forests and coral reefs, important for fisheries, wildlife, and storm surge protection. The warming of Tanzania's freshwater lakes has led to decreased nutrient cycling and reduced fishery productivity. Sedimentation, exacerbated by heavy rains, further threatens fisheries, which provide more than 4 million jobs and are an important protein source in coastal and inland regions (Hemp 2009). Tanzania is the most flood-affected country in East Africa. Intensifying heavy rainfall events are likely to increase flood impacts on infrastructure and associated energy, water, and transportation services. Each year from 2014 to 2017, floods affected critical infrastructure from the coast to the highlands, destroying roads, bridges, and public and private buildings. Sea level rise is expected to cost about US$200 million per year by 2050 in lost land and flood damage.

The adverse impacts of Climate Change are already having their toll on the livelihoods of people and in the sectors of the economy in the country. Frequent and severe droughts in many parts of the country are being felt with their associated consequences on food production and water scarcity among others. The recent severe droughts which hit most parts of the country, leading to severe food shortages, food insecurity, water scarcity, hunger, and acute shortage of power signify the vulnerability of the country to the impacts of climate change. The extreme drop in water levels of Lake Victoria, Lake Tanganyika, and Lake Jipe in recent years and the dramatic recession of 7 km of Lake Rukwa in about 50 years are associated, at least in part, with climate change and are threatening economic and social activities. Eighty percent of the glacier on Mount Kilimanjaro has been lost since 1912 and it is projected that the entire glacier will be gone by 2025. The intrusion of seawater into water wells along the coast of Bagamoyo town and the inundation of Maziwe Island in Pangani District, of the Indian Ocean shores, is yet another evidence of the threats of climate change.

Tanzania is, therefore, obligated by the United Nations Framework Convention on Climate Change (UNFCCC) to develop a National Adaptation Programme of Action (NAPA). The NAPA is the main strategic document of the Tanzanian adaptation policy. The environmental department of the vice president is responsible for the development of NAPA; however, many other actors are also involved. The research team is interdisciplinary, and the data on vulnerability and adaptation measures were collected collaboratively. Stakeholders from academia, government, the private sector, and the local level were involved in the development of the NAPA. An important goal of involving stakeholders was to foster the collection of information and climate data because, as with many other developing countries, the current database on expected climate impacts is very limited. Therefore, planning processes and specific adaptation measures are often based on local knowledge and those climate impacts that can already be observed. The drawback to this approach is that it does not allow for any long-term planning. Hence, the primary goal of NAPA is to identify the most urgent measures. NAPA adaptation projects are targeted at the technical level; they include, for example, irrigation and water storage infrastructure plans and electrification measures using micro-hydropower. Further priorities are the sustainable use of scarce natural resources and the development of drought-resistant seeds. The implementation of the identified projects is not centralized; rather, it is distributed among the responsible ministries. Many adaptation projects are funded by international organizations like the United Nations Development Programme and the International Bank for Reconstruction and Development (UNDP 2022a).

Zambia

Zambia is considered vulnerable to climate change. The main impact pathway is through increasing variability in rainfall amounts during the agricultural season across the various agroecological regions and shifts in the duration of the rainy season (National Policy on Climate Change Zambia). Zambia is considered vulnerable to the impacts of climate change because most of the population relies on agriculture for their livelihoods, and changes in rainfall patterns have a negative impact due to the rainfed nature of production. Current evidence suggests that the temperature is likely to increase by 1.82 ^{o}C and rainfall will reduce by 0.87 percentage points by 2050 (Ngoma et al. 2021). This means that the occurrence of extreme climate events such as droughts and floods will become more frequent (Kalantary 2010). Rainfall intensity results in heavy storms that result in floods that cause damage to property and crops (Zambia Climate Today).

Zambia has been experiencing adverse impacts of climate change, including an increase in the frequency and severity of seasonal droughts, occasional dry spells, increased temperatures in valleys, flash floods, and changes in the growing seasons. In response to these impacts, Zambia is working to develop sustainable and appropriate programs for both crops and livestock in the face of climate change. Some of Zambia's adaptation measures include the promotion of irrigation and efficient use of water resources, strengthening early warning systems and preparedness, and using GIS (Geographical Information System) and remote sensing for mapping drought- and flood-prone areas (UNDP 2022b).

Climate change impacts are disproportionately affecting Zambia’s agriculture and health sectors in the forms of water stress, food insecurity, health risks, loss of biodiversity, decrease in economic production, and loss of livelihoods. Climate change is projected to increase the poverty gap and incidents of crop failure, affect the length of the growing season, and lead to a 13 percent reduction in water availability by 2050 (Hamududu et al 2019). The impacts of climate change on the agricultural sector may reduce the national GDP by 4 percent.

Therefore, more focus and effort are required to build resilience and enhance the adaptive capacity of vulnerable stakeholders to climate change along key agri-food value chains. This also requires multiple sectors and actors to work together seamlessly to address the multi-dimensional challenges posed by climate change and variability. Regional cooperation in addressing this cross-cutting issue has important benefits such as conflict prevention, socio-economic development, and human well-being. Climate change adaptation within the region requires strong cooperation between the countries, at all levels and across all sectors and demands the involvement of many stakeholders with conflicting and competing needs.

Zimbabwe

Zimbabwe is a landlocked country bordering Botswana, Zambia, Mozambique, and South Africa. This makes the country highly vulnerable to climate impacts within its borders and to spillover effects from climate change on neighbouring countries. Around 80 percent of the population is concentrated in areas where rainfall is unreliable, making them extremely vulnerable to climate change impacts (GoZ 2016).

Mutekwa (2009) noted that Zimbabwe has been experiencing frequent droughts alternating with periods of very high rainfall, in some cases, floods and midseason prolonged dry spells are experienced in the same season. As per another prediction, all districts in Malawi, Zimbabwe, and the whole of Zambia, except parts of the Northern Province, will be hotspots of climate variability and extreme weather events by 2050 (Davies et al. 2010). Climate hazards such as severe droughts and flash floods are anticipated to become more frequent and intense in the coming decades in Zimbabwe (Davies et al. 2010).

Coupled Model Inter-comparison Project Phase 5 (CMIP5)[23] utilized within the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC), provides projections for future temperature and precipitation in Zimbabwe. These models project consistent warming that varies by emissions scenario, with projected trends in rainfall that are less certain and vary widely across both scenarios and models (GoZ 2016). Accordingly, the annual likelihood of encountering severe drought in Zimbabwe is expected to increase by 21 percent from 2040 to 2059 and by 47 percent from 2080 to 2099 compared to the baseline period of 1986 to 2005 under the representative concentration pathway (RCP) 8.5 scenario. It is projected that western Zimbabwe is more likely to experience severe drought conditions. Extreme temperatures and precipitation events will be more prominent across the country. The number of days or years with a maximum temperature greater than 35°C is expected to increase by 39 days in the period from 2040 to 2059 and by 108 days from 2080 to 2099, from the reference period under RCP 8.5. The

[23] WBG Climate Change Knowledge Portal (CCKP, 2021). Climate Data: Projections. URL: https://climateknowledgeportal.worldbank. org/country/zimbabwe/climate-data-projections

number of days of a consecutive dry spell per year, or days without significant rainfall of at least 1 mm, is projected to increase by 13 days from 2040 to 2059 and by 25 days from 2080 to 2099. Climate change is expected to negatively impact the future occurrence, intensity, and magnitude of floods, droughts, and epidemic episodes, which can consequentially lead to enormous social and economic costs across multiple economic sectors (GoZ 2016).

GoZ (2021) reports, based on CORDEX data for RCP 4.5 and RCP 8.5 scenarios, that Zimbabwe's mean annual temperatures will increase with high confidence by 1–1.5°C by 2040 from a 1986–2005 baseline. Droughts will increase in frequency and intensity. The increase in mean annual temperatures could potentially exceed 3°C by 2050, depending on the actual global emissions pathway achieved. Another analysis shows that temperature trends in Zimbabwe from 1933 to 1993, show a rise in maximum temperatures, a decrease in minimum temperatures, and a substantial rise in the diurnal temperature range (Balling 2005).

Annual median precipitation is projected to decrease by roughly 1.2 percent (RCP 2.6) and 4.4 percent (RCP 8.5) in 2040–2059. By 2080–2099, annual median precipitation is projected to increase by 2.8 percent (RCP 2.6) and decrease by 10.7 percent (RCP 8.5). The rainfall reductions compared to the baseline period (1986–2005) are more pronounced during the wet season, especially from October to March. Northern and eastern parts of the country are projected to experience above-normal precipitation, while western and southern parts will tend to receive less levels of precipitation than historically recorded (World Bank Group 2021).

Results from the Global Circulation Model (GCM) as described by Davis and Hirji (2014) that, if the business-as-usual continues, annual average precipitation will decrease in all Zimbabwean catchments, except Mazowe and Manyame where it would remain around current levels. The drier catchments of Runde and Mzingwane will be affected most, with declines in mean annual precipitation of between 12 percent and 16 percent by 2050 depending on the emissions scenario. Even under the best greenhouse gas emissions scenario and a low population growth scenario, national per capita water availability per year declines by 38 percent from 2.45 million liters in the year 2012 to 1.52 million liters by 2050. Under medium or high population growth scenarios, a continuous decline in national per capita water availability would push the country from the UN's category of "water stress" to "absolute water scarcity" by 2080.

Rainfall patterns have become more erratic, unevenly distributed, uncertain, and unpredictable, resulting in crop failures that occur three out of every five years (World Bank 2017). Weather uncertainty is contributing to enormous strain on smallholder production systems, leading to high poverty rates (63 percent), and adversely impacting food security, health, water security, and freshwater ecosystems (World Bank 2020e).

Zimbabwe has experienced negative impacts associated with climate variability and change, especially in the past decades such as a significant increase in frequency and extreme events of droughts and flash floods. The rainfall distribution has changed with a trend of late-onset and early cessation of the rainy season. In Zimbabwe, 11 and 12 of the 52 districts are at risk of severe and moderate droughts respectively (Mudombi 2013). Based on the EM-Dat database[24]From 1900 to 2017, Zimbabwe experienced 7 droughts, 22 epidemics, 12 floods, and 5 storms. These occurrences have caused human life loss; 7000 people have been reported to have died, and more than 20 million people were affected, causing an estimated total damage of US$950 million.

Groundwater is the main drinking water source in rural parts of Zimbabwe. According to the 2012 census, about 38 percent of the total Zimbabwean households fetched their water from boreholes and protected wells (Zimbabwe National Statistics Agency 2012).

Common factors that determine the climate vulnerability of Zimbabwe across sectors include insufficient water availability due to the predominant dry climate, poverty that limits access to socioeconomic and financial services, heavy reliance on rainfed agriculture and natural resources, high population growth putting added pressure on infrastructure and natural resources, gender issues and intersectionality, and weak/inadequate early warning systems without fully mainstreamed disaster risk reduction planning and climate proofing investment (GoZ 2021).

It is expected that in the future, temperatures will increase by about 1.2–2.2°C between 2040 and 2059 in Zimbabwe, and there will also be an increase in days with maximum temperatures >35°C by 39 days between 2040 and 2059. There will be more variable precipitation, with some models projecting an increase in the long term, and others projecting a decrease. Furthermore, considerable reductions in rainfall in the south and west and dry spells lasting 13 days longer than the average current duration are expected between 2040 and 2059, while there will be a 21 percent increase in the incidence of severe drought between 2040 and 2059.

[24] EM-DAT: The Emergency Events Database - Universite catholique de Louvain (UCL) - CRED, D. Guha-Sapir - www.emdat.be, Brussels, Belgium. https://www.emdat.be/database

Since agricultural production is primarily dependent on smallholder rainfed farming, it is highly sensitive to fluctuating weather patterns. Increasingly frequent and intense extreme weather events, including tropical cyclones, droughts, mid-season dry spells, floods, and localized intense rainfalls, are also having a negative impact on other sectors of the economy such as energy, infrastructure, and industry. The level of awareness of climate change in Zimbabwe is low which negatively affects climate change reporting and implementation of related initiatives (GoZ 2016). A study conducted in Zimbabwe indicated that most of the farmers (53%) were ignorant about climate change and its potential consequences, whilst 47 percent opined of a level of changes observed in recent years (Mutekwa 2009).

Smallholders have limited access to existing adaptation solutions or weather information that could help them cope with acute weather patterns and climate change, which in turn affects food security, nutrition, and household incomes. About 85 percent of women in Zimbabwe depend on agricultural activities for their livelihoods and rural women make up the majority of smallholder farmers who are also dependent on rain-fed agriculture and climate-sensitive economic activities like farming and rearing livestock. The livelihoods of men are also climate-sensitive, but men have better access to productive resources like land, finances, and jobs. Men and boys whose main source of livelihood is rearing cattle must walk long distances in search of pastures and water for their livestock. Poor rainfall has resulted in the depletion of pastures and water sources, further increasing the vulnerability of people pushing to poverty and loss of livelihoods. Adaptation techniques using modern technology are important for the long-term survival of many Zimbabweans.

Summary

In summary, the Zambezi region is one of the worst hit regions by climate change.

a. Hazards vary in frequency and severity across Zambezi River Basin countries

b. The common ones are floods, droughts, dry spells, rainfall variability, and flash floods

c. All countries face significant risks from climate change in the Zambezi. Less diversified economies that rely mostly on agriculture, such as Malawi, Tanzania, and Mozambique show considerable vulnerability.

d. The high-risk hazards include floods and dry spells facing almost all the Zambezi countries, and they claim many livelihoods instantly when they occur.

Table 5 summarises the perceived hazards per country based on literature review and stakeholder consultations. The climate hazards are ranked from highest to lowest for each country, but it should be noted that the fact that a hazard is not mentioned at all for a country does not imply it is not important nor does it imply such does not exist, rather, it simply implies that it is not among the top 6 commonly mentioned hazards in that country.

Table 5: Common hazards experienced by the Zambezi riparian countries

	Level of Hazard					
	Highest		**Medium**		**Lowest**	
Angola	Drought	Cyclones	Dry spells	Drought	Extreme heat	Wildfires
Botswana	Drought	Extreme heat	Dry spells	Riverine floods	Water scarcity	Wildfires
Malawi	Floods	Cyclones	Dry spells	Drought	Extreme heat	Wildfires
Mozambique	Floods	Cyclones	Dry spells	Drought	Extreme heat	Wildfires
Namibia	Drought	Extreme heat	Dry spells	Riverine floods	Water scarcity	Wildfires
Tanzania	Floods	Cyclones	Dry spells	Drought	Extreme heat	Wildfires
Zambia	Droughts	Dry spells	Changing seasons	Floods	Extreme heat	Wildfires
Zimbabwe	Droughts	Dry spells	Changing seasons	Floods	Extreme heat	Wildfires

Source*:* Authors compilation from literature and stakeholder rankings.

5. Digital adaptation to climate change: Current status

Key messages

a. There are many promising examples of the use of digital technology in climate adaptation efforts across the Zambezi River Basin countries. Solutions range from mobile apps for choosing crops for an area (crop-wise) in Zambia to those seeking to enhance water productivity (e.g., Water Productivity Open-access Remote Sensing Portal [WAPOR]) in Mozambique and Chameleon sensors in Botswana’s Ramotswa area. At a higher level, e-

Government systems such as SMART Zambia and the e-Government in Malawi seek to facilitate the efficiency of government activities by leveraging data and general information transfer.

b. Thus, it appears that data-driven digital services can indeed support farmers' decision-making around some types of adaptation, as in the cases of moisture sensors that guide irrigation decisions and WARMA's digital maps in Zambia, which are instrumental in input and crop choices per location.

c. However, while digital technology is critical for adaptation, its upscaling is hindered by a series of factors including the requisite investments in the middleware infrastructure, limitations in skills by the intended users of the technologies, poverty, prohibitive legislation, and policies, as well as insensitivity to gender in the design. Addressing these issues would better enable digital technologies to be upscaled.

d. From the stakeholder consultation workshops carried out across the Zambezi Basin, it is evident that farmers can adapt to climate change using various tools, including digital technology. Where necessary, farmers respond to government programs and do things differently. For example, as climate change continues to change growing seasons, farmers have also responded by changing crop varieties in favour of early-maturing ones or crops that do not require a lot of rainfall. Others have resorted to irrigation farming to respond to water scarcity.

e. Each government of the Zambezi basin's riparian countries is undertaking significant efforts to build resilience against climate change at various levels. For example, many pieces of legislation, policies, and programs have been put into action by many of the Zambezi governments to fight climate change. Programs in conservation agriculture, infrastructural development, reforestation, irrigation development, and many more are either being implemented or under development at various stages.

f. Many of those efforts are led by governments with a significant amount of collaboration with the private sector, non-governmental organizations, development partners, and farmer groups.

g. Across the Zambezi Riparian countries, stakeholders mentioned various digital tools being used in adaptation, but in general, mobile telephony, radios/TVs, remote sensing-based applications (early warning systems), drones, and insurance systems were frequently mentioned as critical for adaptation.

Water accounting in climate adaptation in the Zambezi

Water accounts provide a framework for understanding and reporting on water resource use and availability at the catchment and basin scale. Just as financial accounts provide an overview of income, expenditure, and balances, so water accounts present an overview of water inflows, outflows/uses, and the water balance for a given area over a period of time. Water accounts allow policymakers and other stakeholders to better understand their water, develop water budgets, and understand whether aggregate water uses are in line with policy intentions. Water accounts are designed for use at the basin or catchment scale rather than for specific farms, factories, or households.

The significant data needs of water accounting approaches have traditionally limited their widespread use, but the development of the remote sensing-based "Water Accounting +" methodology means that water accounts can be developed just about anywhere. The WA+ methodology can be applied with an acceptable degree of accuracy to catchments of around 4,000km^2 or larger, and the approach provides a way to report on water resource use and status regularly, using a consistent set of indicators as the data are available across river basins and national borders.

Relevance of water accounting to climate resilience in the Zambezi River Basin

Water availability across the Zambezi basin already varies significantly and changes in water demand over time and are expected to result in increasing pressure on water allocation among the eight countries, a situation which will be exacerbated by the projected effects of climate change and socioeconomic development.

Periodic droughts are already having a significant impact on local livelihoods as well as higher level economic impacts due to crop failures, reduced hydroelectric power generation, etc. At the local level, there are also examples of tensions between farmers and hydroelectric power producers over water use. Establishing the data to properly manage trade-offs is a key challenge for climate resilience in the Zambezi, and exists at several levels:

1. At the transboundary level, between countries;
2. At the sector or industry level, between uses of water (e.g., between agriculture and industrial development); and
3. At the local level, between groups of farmers, towns, hydroelectric power producers, and other large users of water.

Water security for smallholder farmers is both an 'on-farm' issue (crop choice, soil treatment, rainwater harvesting, small-scale infrastructure, etc.) as well as an 'inter-farm/inter-stakeholder' issue (trade-offs with other water users). The latter requires a deliberate and deliberative approach based on data about the availability of water at the catchment scale, key types of water use, and the availability of water for further allocation. Importantly, it requires data that can be updated on a regular (seasonal and annual) basis, particularly during unusually dry years where standard allocations cannot be met. The remote sensing-based Water Accounting + methodology provides both historical records and seasonal updates that would allow for more dynamic water trade-off management, resulting in better-informed investment planning. The key users of this approach would be governments and large-scale water users.

Currently, there is no system in place for regular reporting on water resource use and availability across and no large-scale applications of water accounting for the Zambezi River Basin. There are, however, several examples of relevant building blocks including the WaPOR[25] platform, which provides access to key remote sensing data (including precipitation and actual evapotranspiration) needed to calculate water accounts and Zambezi Water Resources Information System (ZAMWIS)[26], which provides access to river discharge data to validate and calibrate the remote sensing data and water accounts.

[25] https://wapor.apps.fao.org/

[26] http://zamwis.zambezicommission.org/INFO

For the Zambezi, water accounts could be developed at several scales, for the entire Zambezi basin, for individual catchments within the Zambezi, or with a focus on the river basins and catchments within an individual country.

Potential areas for investment include:

- Capacity building and exploration of water resource management issues, and
- Application of water accounting approaches in particular catchments, including linking irrigation planning/agricultural expansion into long-term water availability plans as well as basin or national water resources strategies.

Weather indexed crop insurance in the Zambezi

Weather-based indexed crop insurance is an insurance system whereby a farmer who subscribes is paid compensation in the case of crop failure resulting from weather-related events. This is an important innovation because agriculture in Africa is underinsured owing to insurers' difficulties in devising better business models for the sector. Insuring farmers against crop failure faces challenges, including too-frequent risks owing to climate change and potential moral hazards on the part of the insured, which could seriously undermine the insurers.

However, innovations in remote sensing and machine learning can now help reduce morally hazardous[27] behaviour, such as crop development and agronomic practices, can be constantly monitored from space. Based on this, insurers can easily understand the real causes of crop failure, and premiums and payouts may be determined depending on such information. However, crop insurance based on weather is still new, and in the Zambezi River Basin, many farmers are not insured.

This type of innovative insurance is taking traction in Malawi, Mozambique, Zambia, and Zimbabwe through the Africa Risk Capacity Program (https://www.arc.int/countries), but it is yet to be fully introduced in Angola, Namibia, Tanzania, and Botswana.

[27] A moral hazard is a risk one party takes knowing it is protected by another party. The basic premise is that the protected party has the incentive to take risks because someone else will pay for the mistakes or behavior changes they make.

Digital technologies in use per country

Angola

In Angola, the use of social media platforms by farmers and extension workers is common. Social media platforms are used for the dissemination of information on early warning, planting dates, weather projections, pests and diseases, market prices and availability, and other related information. Some commercial farmers use drones to monitor their fields. This technology may be expensive, by an effective tool for monitoring as drones allow surveillance from all angles.

Drones, or unmanned aerial systems (UAS), have the potential to transform smallholder farming and help increase crop production in Angola, especially when used in the context of precision agriculture. They provide farmers with real-time, actionable data on their land, crops, and livestock to help maximize input efficiency, minimise environmental impacts, optimize product quality, and minimize risks.

It is reported, for example, that through crop monitoring with unmanned aerial vehicles (UAVs) or drones, farmers analyze and detect the most water-deprived areas to reduce costs related to irrigation and power consumption. Some farmers have used UAVs to carry out plant counting, detect missing plants, and provide suggestions on suitable areas for crop expansion, making use of land mapping with digital elevation models, accurate dimensions, and geographic information. Once the required farm areas and interventions are identified, UAVs are also used to spray chemicals, apply fertilizer, and plant crops. Usually, these call for a combination of techniques to be used together for field monitoring, and these often include, satellites, weather tracking algorithms, and remote soil sensors (PwC 2020).

Some farmers in Angola also use irrigation sensors, which are interconnected sensor networks that work together with intelligent water management systems (PwC 2020). The sensors are used to apply the optimal amount of water to parts of the field, generating maximum return from incremental irrigation and avoiding water and energy waste and waterlogging. It should be noted that the start-up capital costs for precision irrigation make implementation challenging compared to other precision agriculture technologies. As stated by Revich et al. (2016), precision irrigation has the potential to increase crop yields by at least 10 percent and, in some areas, by up to 80 percent while reducing water consumption by up to 50 percent. But the use of these technologies is undermined by the initial large capital required.

Mobile phones, TVs, and radios are also widely used to receive information on weather forecasts in Angola, but these are limited by insufficient radio signals in remote areas, poor mobile networks in rural areas, and the limited reach of electricity in rural areas. Table 6 summarizes frequently cited upscaling technologies and challenges in Angola.

Table 6: Top 10 digital tools for climate adaptation in Angola

	Technology	Constraints	Recommendations
1	Social media	• Low ICT skills and the extent of penetration of platforms that disseminate information	• Encourage the acquisition of ICT skills.
2	Drones/UAVs	• Equipment is costly • Lack of user skills • Absence of enabling legislation	• Put in place legislation to govern the use of drones • Targeted training of users • Remove import duties on technology for climate adaptation
3	Mobile telephony	• Smartphones are expensive for women farmers • Limited coverage of signal in rural and remote areas	• Target farmer cooperatives with smartphones to selected leaders for joint use as communities • Improve signal coverage by funding tower infrastructure
4	Internet of Things (IOT) with water sensors	• Equipment is costly • Lack of skills to use them	• Simplify their importation by removing import tariffs • Launch domestic production of similar technology • Build skills of users/farmers through targeted programs
6	Mobile Apps	• Low app user skills • High data costs • Low mobile ownership among women	• Remove taxes from mobile service providers that demonstrate a significant working relationship with remote farmers • Improve ownership of phones by women through cooperatives.
7	Radios/TVs	• Limited signal coverage in remote areas • Cost of TVs • Cost of energy for TVs	• Launch community radios and TVs • Remove import duties for TVs and encourage domestic production • Promote clean and cheaper energy

Sources: Authors compilation from stakeholder consultations and literature.

Botswana

In Botswana, early warning systems are available and are used for weather predictions. Remote sensing is also widely used for predicting production changes across space. These are useful for climate adaptation as they minimize the impact of climate change by improving the decisions taken by farmers. Similarly, drones and other forms of UAVs are also used currently in small-scale precision farming in Botswana. Drones are used to make timely decisions on fertilizer applications, irrigation, re-planting, as well as harvesting. As with many of the technologies in Botswana, the limitation is the level of usage. Generally, only very few smallholder farmers use advanced technologies and require interventions for upscaling.

Since Botswana has arid and semi-arid areas, and drought and dry spells are common, their prediction is important to avoid wastage of seeds and farm inputs, as well as to limit the impacts of climate change. The drought early warning system established in 1984 in Botswana is operational. As climate change intensifies into the future, would be useful to upgrade the system and gear it up to predict droughts with greater locational precision. On the other hand, in response to water scarcity and depleting underground water resources, irrigation efficiency is vitally important. Farmers in some parts of Botswana, including Ramotswa, are reported to have adopted better irrigation decision support technology. In Ramotswa, there are smallholder farmers who use wetting front detectors or chameleon sensors to detect the moisture content of the soil to inform their irrigation decisions. These equipment are used in the observation and recording of soil water, irrigation water use, frequency of irrigation, nutrient loss, and crop yields. Chameleon sensors and wetting front detectors (WFD) are used to enhance the management of soil-water and nutrients in an irrigation field by remotely monitoring farms of all types using the Internet of Things (IoTs). The system is configured to measure relevant parameters used in Agricultural applications, including the calculation of evapotranspiration. Other applications used in Botswana within the framework of IoT include mAgri, blockchain, Modisar (a platform that helps farmers to analyze and better manage their farms). The top ten digital applications for climate adaptation used in Botswana are given in Table 7.

Table 7: Top 10 digital tools for climate adaptation in Botswana

	Technology	Constraints	Recommendations

1	Remote sensing	• Insufficient skills in using remote sensing devices • Lack of equipment and software	• Make software for remote sensing readily available in schools and climate departments • Improve skills of personnel in this field
2	Drones	• Costly equipment • Lack of user skills • Absence of governing legislation	• Put in place legislation to govern the use of drones • Targeted training of users • Remove import duties on technologies for climate adaptation
3	Drought early warning system	• Insufficient numbers of automatic weather stations in rural areas • Insufficient skills	• Skills building in predicted areas Increase the number of automatic weather stations in rural areas
4	Internet of Things (IOT) (with chameleon sensors)	• Costly equipment • Lack of user skills	• Simplify their importation by waiving import tariffs • Launch domestic production of similar technologies • Build farmer/user skills through targeted programs
5	Automatic Agro-Meteorologic Station Botswana College of Agriculture Gaborone, Botswana	• Insufficient number of automatic weather stations in rural areas • Insufficient skills	• Building in areas of predictions • Procure more automatic weather stations for rural areas to improve predictions
6	Mobile telephony	• Smartphones are expensive for women farmers • Limited coverage of signal in rural remote areas	• Target farmer cooperatives with smartphones for selected leaders for joint use in communities • Improve signal coverage by funding tower infrastructure
7	Mobile Apps	• Lack of user skills • High data costs • Low mobile ownership among women	• Remove taxes from mobile service providers who demonstrate a significant working relationship with remote farmers • Improve ownership of phones by women through cooperatives
8	Radios/TVs	• Limited signal coverage in remote areas • High cost of TVs • High cost of energy for TVs	• Launch community radios, TVs • Remove duties from TVs and encourage domestic production • Promote clean and cheaper energy

Source: Authors compilation from stakeholder consultations and literature.

Table 7 also summarizes some constraints for upscaling digital technology in climate adaptation in Botswana. While various technologies have been mentioned as important for digital adaptation, such technologies are associated with considerable challenges for upscaling. The key challenges associated with digital climate adaptation in Botswana are:

- Knowledge, awareness, and lack of digital skills
- Availability, affordability, and access to mobile phone subscriptions and internet
- Access to finance for digital innovation and lack of funding for climate adaptation initiatives that involve the use of digital technologies
- Access to digital technologies for the rural poor, especially women
- Poor network coverage particularly in rural areas
- Lack of electricity to recharge mobile phones or computers in rural areas
- Lack of national policies or legal framework to support digital innovation expansion

Malawi

There are many programs that the Malawi government is undertaking to limit the impacts of climate change on rural and urban populations. It should be noted, though that Malawi is at the infancy stage of digital transformation. Malawi was ranked 167 out of 176 countries in the ICT Development Index (IDI)[28] in 2017. The digital sector is faced with many challenges including inadequate ICT infrastructure, high investment costs for ICT infrastructure, inequitable access to internet services across social and economic groups, lack of awareness of ICT and e-services, and lack of digital skills and competencies (Ernst & Young Private Limited 2021). About 60 percent of the population in Malawi lacks the basic competence of operating computers and accessing the internet on mobile devices, which poses a major challenge to digitalization and access (Ernst & Young Private Limited 2021).

However, Malawi developed the National ICT Policy in 2013 to contribute to socio-economic development through maximum integration of ICT in all sectors and the provision of ICT services to rural areas and vulnerable and disadvantaged groups. Some of the key priorities of the policy include the development of ICT infrastructure and human capacity. The country’s long-term development strategy, Malawi 2063, places high emphasis on ICT as a key enabler of the inclusive wealth creation agenda. It places ICT as a key catalyst in promoting agriculture productivity and commercialization, as well as in industrialization and urbanization. Malawi 2063 aspires toward

[28] https://www.itu.int/net4/ITU-D/idi/2017/index.html

having a robust ICT infrastructure with cross-country coverage of reliable and affordable services fostering technological adoption and digital access. These policy milestones can be considered as opportunities for deploying digital technology for climate adaptation.

Various stakeholders use digital technologies for climate adaptation, but at lower scales, so capacity building is vital. Table 8 shows some key digital tools that are used for climate adaptation in Malawi, as identified both through literature and stakeholder consultations.

Table 8: Top 10 digital tools for climate adaptation in Malawi

S/N	Technology	Constraints	Recommendations to resolve the constraint and increase use of the technology
1	Early Warning Systems M-CLIMES and PICSA, etc	• Limited to project districts and limited coverage within the districts • Depends on ICT/mobile equipment which is expensive and requires network coverage • Introduced as projects, as such, susceptible to discontinuation after project wrap-up	• Scaling up coverage to other districts and increasing coverage within the districts • Continued engagement through Public-Private-Partnership (PPPs) platforms • Institute sustainability mechanisms of the project interventions for continuity
2	Mobile technologies	• Very costly to access and manage in terms of credit and data bundles, for most rural folks • Depends on mobile network services • Relies on the availability of other services such as electricity • Susceptible to cybercrime	• Continued engagement through Public-Private-Partnership platforms to upscale mobile coverage and reduce credit and data charges • Increase electricity coverage • Introduce stringent cyber security regulatory frameworks
3	Automatic Weather Stations	• Limited automated weather stations across the country	• Procure more automated weather equipment
4	Agricultural Information Management Systems – eSOKO and 3 2 Airtel for delivery of agricultural extension services	• Affected by network coverage issues • Depends on electricity availability • Gender imbalances where the phones are used and controlled by males, while the females are mostly working in the fields	• Increase network coverage through PPPs • Increase electricity infrastructure • Promote civic education on gender equality

S/N	Technology	Constraints	Recommendations to resolve the constraint and increase use of the technology
5	Last-mile infrastructure – Telecenters	• Limited coverage • Inadequate equipment	• Increase the number of Tele centers in rural areas • Provide adequate material for clients
6	Integrated GIS and Remote sensing	• Requires in-depth capacity building • ICT equipment and licenses • Susceptible to poor network coverage issues	• Streamline capacity-building programs in the academic curriculum for remote sensing and GIS • Expand ICT infrastructure
7	Internet of Things (IOT) – Smart Agriculture	• Adversely affected by high internet data charges • Inadequate network coverage • Outdated information duel to slow in uploading updates	• Increase network coverage • Ensure up-to-date information is uploaded to online platforms
8	Forest monitoring systems	• Relies on ICT equipment which is relatively expensive	• Procure requisite equipment for the systems
9	Video conferencing	• Requires relatively expensive equipment • Affected by poor internet services and mobile network coverage • Requires skills and capacity building	• Promote training opportunities for ICT and video conferencing for youth • Upscale video conferencing equipment
10	Unmanned aerial vehicles (UAVs)	• Very costly equipment • A new development requiring legislation and policy direction	• Introduce tax waivers for agri–tech equipment • Develop policy and regulatory framework for unmanned aerial vehicles or promote awareness of the same if already in place

Sources: Authors compilation from stakeholder consultations and literature.

Stakeholders identified early warning systems M-CLIMES and PICSA, as being available in Malawi and useful. These systems are used in combination with mobile telephony and apps to disseminate information. For example, Malawi is using smartphone apps for weather alerts and reports using the Weather Chasers Malawi WhatsApp group (GIZ 2019)The WhatsApp group was established in January 2016 to improve communication of early warning weather information. In the aftermath, a WhatsApp group was created to send out weather information and request actual observations from members to verify forecasts and ultimately improve their reliability.

Falchetta et al. (2020) report a limited use of remote sensing and machine learning algorithms in Malawi.

There are also agricultural information management systems, eSOKO and 3 2 Airtel, for the delivery of agricultural extension services, which are vital for reducing the information gaps among smallholder farmers. At the consultation workshops in Malawi, stakeholders also highlighted the importance of last-mile digital infrastructure, including telecentres for smallholder farmers to obtain climate information.

Some of the key constraints for digital technology upscaling in Malawi are listed below:

a. Knowledge, awareness, and lack of digital skills are key barriers to using digital technologies to adapt to climate change.
b. Availability, affordability, and access to mobile phone subscriptions and the internet.
c. Access to finance to facilitate digital innovation.
d. Lack of funding for climate adaptation initiatives that involve the use of digital technologies.
e. Access to digital technologies for the rural poor, particularly women.
f. Poor network coverage particularly in rural areas.
g. Lack of electricity to recharge mobile phones or computers in rural areas (only 4.1% of the rural population have access to electricity). Studies show that mobile use in Malawi is negatively correlated to electricity access (Katengeza et al. 2011).
h. Lack of national policies or legal framework to support digital innovation expansion (UNCTAD 2020).
i. Malawi has no stand-alone policy and strategy on the digital economy and e-commerce development agenda (UNCTAD 2020). Developing a national digital innovation strategy is vital to building favourable policies and regulations to protect digital entrepreneurs and position funding toward digital innovations.
j. High cost of mobile phones (affordability is only 42, out of 100).
k. Gender gap in the digital sector, where fewer women are involved in digital solution management for the market, compared to men.
l. Malawians' lack of trust in online systems, low level of internet access, low technology adaptation by firms, lack of access to financing, and weak IT skills across the population (UNCTAD 2020).

m. Less than 14 percent of Malawians use the internet due to the high cost of access. The quality of internet services and last-mile connectivity is also quite low, discouraging investment in e-commerce (UNCTAD 2020).

n. According to the World Bank Malawi Economic Monitor (MEM)[29]Malawi is losing the potential for US$189 million in additional GDP and US$33 million in tax revenues per year from digital technology due to low levels of electricity access, high internet prices, unpredictable connectivity, the high cost of smart devices, and a lack of digital skills.

o. Available internet connectivity indexes consistently rank Malawi poorly on internet access, affordability, and inclusion[30]. For example, the Inclusive Internet Index, 2021[31] —assessing countries on availability, affordability, relevance, and readiness—ranks Malawi 114th of 120 countries. Ranking 114th globally and 24th among Sub-Saharan African countries, Malawi recorded its strongest improvement under Relevance (104/120). However, low digital literacy rates, poor infrastructure, and high smartphone and mobile internet costs present significant challenges for internet inclusivity in the country.

p. Not only poor connectivity, but Malawi also has one of the "lowest and slowest growth rates of the internet in the world[32]. The average fixed broadband upload speed in Malawi is 8.7 megabits per second (Mbps) and the average fixed broadband download speed is 8.5 Mbps, while mobile speeds average 11.6 Mbps for upload and 21.2 Mbps for download[33].

Mozambique

In Mozambique, the impact of the COVID-19 pandemic accelerated the adoption of online platforms and remote work systems[34]. The e-Government services currently being offered are limited to seven platforms that provide direct support for the delivery of relevant services The platforms operated by the central government are: i) the National System of Civil Registration (SINAREC), ii) Biometric Driving License and Motor Vehicle Registration Systems, iii) Biometric ID Card and Passport System, iv) Integrated System for Property Registration (SIRP),

[29] https://moderndiplomacy.eu/2021/06/27/affordable-ict-for-youth-women-and-rural-communities-in-malawi/
[30] https://dai-global-digital.com/dfid-and-dai-host-malawis-first-digital-development-forum.html
[31] https://theinclusiveinternet.eiu.com/explore/countries/performance

[32] https://freedomhouse.org/country/malawi/freedom-net/2021
[33] https://freedomhouse.org/country/malawi/freedom-net/2021#footnote8_5ua6n0b

[34] https://www.trade.gov/market-intelligence/mozambiques-digital-transformation

v) Electronic Licensing System (e-Bau), vi) Digital Declaration System, and vii) Digital Taxation System.

Several provincial government portals have also been developed. The major interventions are;

i) The State Financial Administration System (e-SISTAFE) was implemented to provide financial administration services through the internet using a single bank account for all government institutions' expenditures. This project also demonstrates that government transactions such as G2G (government-to-government), G2B (government-to-business), and G2C (government-to-citizen) can be done electronically more effectively and efficiently if all the security measures and mechanisms are taken.

ii) Mozambique e-Government Communication Infrastructure Project (MEGCIP) (2010 - 2014) was aimed at supporting government efforts to lower communication costs by using international capacity to extend the geographic reach of the broadband networks and contribute to improving the efficiency and transparency through e-Government applications. This project consisted of components on communication infrastructure, policy and regulation, e-Government applications, and institutional capacity building.

iii) Provincial Digital Resource Centers (CPRDs) were initiated in 2004 as the single-entry point for ICT deployment and activity in the provinces. The centers provided necessary capacity-building support for all sectors in the fields of computer maintenance, network administration, database design, and many other ICT services and development of local content.

iv) Multimedia Community Centers (MCC) program aims to provide the community with access to information using a wide range of Information Communication Technologies (ICTs) through a single point. This also serves to reduce the digital divide, reduce poverty by enabling people to solve development problems that the community faces and strengthen the community capacity.

A Virtual Farmers Market (VFM) was formed to integrate smallholder farmers into formal markets. The VFM provides market information, weather forecast information, and training, and integrates e-extension services focused on improved agricultural production and productivity. In December 2021, World Food Programme (WFP) broadcast 16 radio spots on good agricultural practice and supported linkages between 25 schools and 49 farmer associations (WFP 2021c).

In 2014, the Government of Mozambique and FAO agreed to pilot a system for targeted "smart subsidies" using e-vouchers to facilitate farmers' access to seeds, fertilizers, and other required inputs, and strengthen the distribution chain of agricultural inputs for increased output and productivity. The e-voucher scheme was successfully implemented in 13 districts of Mozambique, among approximately 23,000 beneficiaries. In 2016, over 16,700 farmers were willing to co-pay the subsidy, indicating the effectiveness of the system over the years[35].

The Water Productivity Open-access Portal (WaPOR) is FAO's water productivity database that uses remote sensing technology to monitor agricultural water productivity. This technology provides water data that can be used to calculate biomass and other indices to decide where to produce in near real-time. The methodology used to produce the different data components of WaPOR Version 2 at the 250 m (Level 1-continental level), 100 m (Level 2-country and river basin level), and 30 m (Level 3-irrigation scheme level) resolution. WaPOR is already being experimented with in the Xinavane and Lamego areas of Mozambique.

Community radios are being effectively used to reach farmers and farmer organizations in Mozambique to disseminate important information such as market prices and weather data, particularly to reach small farmers located in remote areas. For example, the International Fund for Agricultural Development (IFAD) supported Program for the Promotion of Rural Markets (PROMER) has used community radios to disseminate timely and reliable market information. Radio and television programs are very useful where there is no access to the Internet.

CropWatch is a cloud-based online tool to produce crop monitoring products at anytime and anywhere, including country-level crop conditions, arable land use, crop acreage, yield predictions, and prospects for the global food supply. It is also an affordable and effective way for developing countries and stakeholders to conduct crop assessments. A customized CropWatch cloud platform was developed for Mozambique in December 2017 and necessary training was provided for experts. The Ministry of Agriculture and Rural Development uses CropWatch mainly for crop production forecasts. The monthly agriculture bulletin generated during the rainy season using this tool informs policymaking at national and provincial-level agriculture departments.

The National Directorate for the Development of Subsistence Farming (DNDAF) in Mozambique is currently using remote sensing technology to monitor precipitation, seeding time, crop phase,

[35] https://www.ictworks.org/electronic-vouchers-agriculture-mozambique/

crop water satisfaction index, and production estimates. According to the stakeholder discussions, the accuracy of the information generated by the technology needs to be further improved. Mozambique is among the top 10 African countries by the proportion of individuals shopping online (World Bank Group 2019).

InfoSequia is a modular and flexible toolbox developed in Mozambique to provide Drought and Early Warning Systems (DEWS) to assess drought patterns and severity. The InfoSequia toolbox provides a comprehensive picture of the current drought status, mainly based on Earth observation (EO) data. InfoSequia-4CAST extends InfoSequia capabilities and is able to provide timely seasonal forecasts of drought impacts on crop yield and water supply. Seasonal outlooks are computed by a novel state-of-the-art machine learning technique (MLT)[36].

Another development was the implementation of "the Third Eye Project." The project formed a network of flying sensor operators to support farmers in Mozambique. The project used low-cost, high-resolution flying sensors to ensure that farmers received the necessary information to make fact-based decisions on appropriate agronomic practices, instead of relying on common-sense management. The drone cameras use a near-infrared wavelength to detect stressed conditions in the vegetation. Maps of the vegetation status are used in the field (with an app) to determine the causes of the stressed conditions: water shortage, nutrient shortage, pests or diseases, etc. This information is used by the technical staff and extension workers to provide relevant spatial information to assist their work in providing tailored information to local farmers. At the end of the growing season, the flying sensor images are compiled to report on the crop development, calculate the crop yield, and determine the magnitude of impacts. The flying sensor information guides the farmers toward the efficient use of scarce resources and maximizes yields at the same time. The progress reported during 2014–2017 comprised the training of 14 local flying sensor operators and the operation of 11 flying sensors, providing services to over 3,500 farmers, of whom 71 percent were female. Due to this intervention, water productivity has increased by 55 percent in the project area[37].

Several institutions in the country are using drones to map cultivated areas, crop status, water deficit, yield assessment, and impacts of climatic phenomena. However, the expansion of this

[36] https://www.futurewater.eu/projectcountry/mozambique/
[37] https://www.futurewater.eu/projects/third-eye/

technology throughout the country is challenging due to the high cost involved and the technical skills required.

The Integrated Climate Risk Management (ICRM) project implemented in Mozambique has deployed 30 in-field crop and climate monitoring sensors in Changara district (Tete Province) to improve access to real-time weather and crop productivity information by smallholder farmers and key local stakeholders of the ICRM project.[38]

A flood-hazard model created by WFP and partners in 2020, using aerial photography, has been reported to be effective in helping people prepare for climate shocks in Mozambique. The model provides early knowledge on areas to be affected by floods, providing enough time for the people to take flood preparedness measures to limit damages. Mozambique expects to use this information to establish no-build zones so that people do not live in flood-prone areas.[39]

Hollard Mozambique, an insurer working with farmers on bundled insurance, had to diversify its businesses during COVID-19 as part of its business continuity strategy. The company, in collaboration with Agritask, a leading global developer of a holistic agronomic operations platform, launched a new product using satellite technology covering crops and livestock in November 2021. As travel restrictions prevailed due to COVID-19, the introduction of an index-insurance product using satellite technology eased the rollout of the product since there is no on-site risk assessment and loss verification. The company is now investing in robust digital infrastructure, including digital enrolment, by working with several service and platform providers. Improved data collection and risk monitoring are expected to help innovate insurance offerings and increase client value.[40] Insured farms are registered and mapped onto the platform, offering real-time tracking of relevant parameters at each plot and at the portfolio level. The partnership included data capturing tens of thousands of smallholders initially, with the expectation of a ten-fold increase. The intervention is likely to strengthen preparedness and rehabilitation efforts, such as the generation of alerts for relevant farmers to take precautions.[41]

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[38] https://docs.wfp.org/api/documents/WFP-0000136096/download/

[39] https://medium.com/world-food-programme-insight/we-take-thousands-of-aerial-photos-and-run-them-through-a-big-computer-ff08eb096351

[40] https://www.indexinsuranceforum.org/news/giif-mozambique-advancing-agriculture-insurance-hollard-mozambique

[41] https://africanews.space/agritask-partners-hollard-mozambique-to-expand-its-digital-agricultural-insurance-platform-in-southern-africa/

The Sustainable Trade Initiative of Mozambique launched a digital microlearning toolkit for farmers in 2020 for capacity building in watershed management, animal husbandry, and good agricultural practices under the Mozambique Climate Resilience Program. The toolkit consists of a wireless hard drive, projector, white screen, and tablet and will be used by extension workers to supplement their farmer training. They can now access and screen tailor-made micro-learning videos on good agricultural practices, even in the most remote areas of Mozambique without access to the internet or electricity.[42]

The stakeholder workshops identified drones as important for mapping cultivated areas, crop status, water deficit, yield assessment, and impacts of climatic phenomena and noted the institutions implementing and promoting this technology, including the National Directorate for the Development of Subsistence Farming (DNDAF), the National Irrigation Institute (INIR), the National Disaster Management Institute and the Agricultura de Pequena Escala no Vale de Zambeze APSON Vale (the APSAN-Vale project demonstrates the best combinations of adoption strategies, tailor service delivery, and technological packages for these smallholder farmers). The Open Data Kits (ODK) applications used on tablets and smartphones to evaluate crops in the field were also reported as being implemented by the DNDAF and extension agents, while applications such as CropWatch, which simulate crop water requirements, remote sensing applications, Short Message Service (SMS) platforms, early warning systems, community radios and TVs, and WAPOR, which are used for monitoring of water productivity using remote sensing data (being experimented in Xinavane and Lamego), and the E-voucher System used to facilitate access to agricultural inputs, were all identified as very important and all need expansion.

It was also observed that weather-based index insurance (WBII) was important but had low coverage and was, in most cases, not available. There were challenges with mobile telephony as only a limited number of smallholder farmers (25%) have access to smartphones and, thus, to digital phone applications.

Some of these digital technologies being used for climate adaptation in Mozambique are summarized in Table 9:

Table 9: Top 10 digital tools for climate adaptation in Mozambique

[42] https://www.idhsustainabletrade.com/news/idh-launches-digital-microlearning-tool-for-climate-resilience-in-agriculture-in-mozambique/

No.	Technology	Constraints	Recommendations to resolve the constraint/s and to promote the technology
1	Drones	• High cost of equipment and limited availability • Lack of skills to use the technology	• Tax relief and subsidizing the price • Provide training and capacity building to the relevant actors
2	Software application	• Limited capacity on software development	• Human resources development with a special focus on the young computer professionals
3	Remote sensing	• Scarcity in skills for effective use • Limited access to high-resolution satellite images	• Train the agriculture actors on the use • Improve access to satellite images/skills to use open-source applications
4	SMS services	• Limited coverage of mobile phone services • Limited access to electricity	• Improve the coverage of mobile phone services, especially in rural areas • Expand access to electricity through using alternative sources of electricity such as solar power
5	Early Warning System	• Limited availability of real-time data • Weak mechanism of disseminating information • Limited preparedness/ institutional arrangements among farmers	• Establish data sharing mechanisms and build the capacity for the respective analysis • Establish a platform for sharing and disseminating information • Promote the formation of grassroots level climate change and disaster management committees
6	WAPOR	• Limited awareness and knowledge of the technology	• Training the agricultural actors on the use
7	Community Radios	• Limited coverage of the community radios • Limited resources for running community radios • Limited update of information	• Expand the coverage • Finance the functioning of the community radio • Train local radio staff on the production of high-quality radio programs and the allocation of sufficient financial resources.
8	Agro-climatic information	• Limited coverage of the agrometeorological station	• Expand the coverage of the agrometeorological stations

	dissemination platforms	• High cost of meteorological information is associated with limited dissemination	• Subsidize the price of meteorological information and improve information dissemination
9	Mobile Apps	• Limited knowledge of mobile application development • High cost of smartphones associated with poor digital literacy issues	• Train human resources and especially young computer professionals on mobile application development • Subsidize the price of smartphones and train agriculture actors on the use of smartphones in the context of mobile applications
10	Smart technologies integrated to network	• Limited knowledge of smart technologies development • Limited coverage of internet • High cost of internet	• Train human resources and especially young computer professionals on smart technology development • Expand access to internet, especially in rural areas • Subsidize the price of internet

Source: Authors compilation based on stakeholder workshop report.

The following points were identified as the key constraint limiting the use of digital technologies for climate adaptation in agriculture in Mozambique.

1. Limited knowledge and skills of agricultural stakeholders (i.e., technical staff and farmers) on the application of digital technologies.
2. Remote sensing images produced using the existing technologies are low resolution.
3. Lack of necessary supporting infrastructure and poor connectivity to adopt digital technologies, particularly fiber optic networks, have not reached the last mile.
4. Financial scarcity prevents the continuation of technological interventions in the pilot projects due to the high costs associated with the technologies for upscaling.
5. Failure to regularly update data on the platforms for effective decision-making.
6. Weak coordination between the government and collaborating partners in the implementation of digital technologies.
7. Weak technical capacity of extension workers in managing climate change issues.
8. Poor coverage of mobile telephony network infrastructure.
9. Insufficient weather station networks to provide good coverage of areas.

10. Limited supportive policies and strategies for the promotion and development of digital technologies.
11. Complexities associated with digital technologies limit their usage by wider groups due to a lack of literacy and digital know-how.

Namibia

The government has identified the major vulnerable sectors as water, agriculture, health, fisheries, tourism, and infrastructure. These sectors have already begun to set up institutional structures to respond to climate change, and the national climate change policy has been formulated. However, there is still more work to be done in advancing action on climate change adaptation to ensure that the most vulnerable groups are not severely affected by climate change (Table 10).

Table 10: Top 10 digital tools for climate adaptation in Namibia

Technology	Constraints per digital technology	Recommendation
Mobile and mobile apps	• Farmers cannot afford smartphones that allow them to access digital applications. • An unstable network, mainly in rural areas. • Cost of data too high	• Subsidize or reduce tax levels on smartphones to make them more affordable to smallholder farmers • Invest in additional telecommunication infrastructure such as base stations, optic fiber, and equipment servicing facilities. • Expand fixed network infrastructure to remote areas
Remote sensing	• Limited connectivity due to unavailability of network • Limited availability of computers, smartphones, and other gadgets to access these services through the internet service	• Improve the coarse resolution for remote sensing to enhance the accuracy of the results over small areas • Invest in the development of indices and satellites to reduce the inaccuracies caused by background noise, cloud cover, pixel mixing, and shadows in mountainous or built-up areas (mountains and clouds are often classified as water bodies due to their reflectance) • Research to be conducted on blending remote sensing methods

		with rain gauge estimates, climate models & precipitation models to reduce estimation variance
Community radios, television (TV)	• Unavailability of radio and TV signals in some areas. • Limited ownership of radios and TVs in rural areas	• Reduce import duties on radio and TV sets • Support the introduction of community halls where there are community TVs and radios
Sensors, buoy systems, pressure type equipment, ultrasonic and radar techniques	• Physical-based methods are costly, time-consuming, • Equipment cannot be installed in remote or mountainous areas	• Increase awareness campaigns and communication to inform on precision agriculture. • Subsidise farmers to increase the adoption rate of these technologies
GIS and GPS (Global Positioning System)	• Outdated and obsolete equipment which gives inaccurate results	• Invest in modern GIS and GPS equipment • Encourage private sector investment in the development of GIS and GPS infrastructure
Drones	• High cost of technology • Restrictive policies on the use of drones	• Support production of cheap /affordable drones at the country's innovations hubs • Lobby for policies that promote and support the use of drones for digital adaptation
E- markets/ E-commerce	• Limited or no access to e-markets due to unavailability of ICT gadgets such as computers and smartphones • Limited access to internet data	• Provide digital technology equipment including computers, smartphones, and printers • Revise internet data tariffs to be affordable as well as subsidise the cost of ICT data for selected smallholder farmers
Paleoclimatology & satellite data	• The low resolution of images used • Cost of the technology too high for smallholder farmers	• Invest in higher spatial and temporal resolution data and a 4G network • Encourage private sector investment in the development of satellite data

Namibian Livestock Identification and Traceability System (NamLITS)/Chips	• Costly to install • Based on wireless sensor networks or remote sensing devices, ineffective with unstable network • Not affordable for smallholder farmers	• Promote importation of the technology through subsidies and tax incentives • Provide innovative ways of funding the technology including subsidies, development financing, etc. • Provide awareness about the devices and how they work • Scaling of this technology to other regions

Source: Authors compilation based on stakeholder workshop reports.

Some of the constraints for using digital technologies in climate adaptation include the following:

- Farmers cannot afford smartphones that allow them to access digital applications.
- Limited/an unstable network, mainly in rural areas.
- Cost of data too high.
- Limited connectivity due to the unavailability of networks.
- Limited availability of computers, smartphones, and other gadgets to access these services. through the internet service.
- Unavailability of radio and TV signals in some areas.
- Limited ownership of radios and TVs in rural areas.
- Outdated and obsolete climate prediction equipment giving inaccurate results at times.
- Absence of enabling legislation for the usage of other technologies.

Tanzania

The government of Tanzania is investing in digital initiatives and currently, it uses e-office to operate various functions of government. There is also a desire to improve and increase access to digital agriculture extension services through mobile phones through systems known as M-Kilimo and Ugani Kiganjani, and considering that energy is important, there is a program to ensure rural communities are reached with cheap electricity and also the use of solar. Although the cost of mobile phones is still significant, mobile phones have become more affordable, as the government has reduced taxes on them. Internet penetration and use have been on the increase, especially in rural areas; and more companies are investing in development programs based on local interests and needs. There is also an important UK-AID-funded program called the Resilience Innovative

Academy. In this academy, students practice digital skills on climate change adaptation skills. Some digital technologies in use in Tanzania include the following (Table 11);

Table 11: Summary of digital services available to farmers in Tanzania

Mobile and online services	Digital solutions
Financial Services	Index-based agricultural insurance, artificial intelligence, other technologies, and Mobile banking
Data Management and Analysis	Farm Management Information
Information and Knowledge	Weather forecasts, information on fertilizers, and pesticides
E-Government	Online Fertilizer Recommendation Systems (OFRS)
Profiling Platform	Digital Profiling
Internet of things (IoT)	Sensors, fixed positions, and unmanned aerial vehicle satellites
Drones	Used to carry out household surveys

Source: Mushi et al. 2022.

There are several challenges associated with digital adaptation to climate change. They include:

i. Low digital literacy
ii. Poor internet connectivity especially in rural areas
iii. Lack of electricity
iv. Language barrier (especially where English is used)
v. Low literacy levels among rural communities
vi. Cost. While mobile technology has been spreading quickly, it has not done so equally, with lower uptake among women. Even when women own mobile devices, they are less likely to use them for sophisticated services such as mobile internet and mobile money. Research by the Global System for Mobile Communications (GSMA) highlights that women face many barriers to owning and using mobile phones, including cost, network quality, safety and harassment issues, and digital skills.

Zambia

Digital agriculture can increase connectivity between farmers and enhance resilience across the agricultural value chain through digital networks, allowing better access to high-quality real-time data that can be utilized in adapting to climate impacts. Yet, digital penetration is not universal in Zambia, and there are still access barriers for smallholder farmers, including the lack of access to electricity, digital illiteracy, and high broadband costs. Ensuring digital agricultural solutions are farmer-centered and provide equitable access across social groups is vital.

The introduction of weather index insurance into the Farmer Input Support Programme (FISP) as a platform for climate adaptation by the government of Zambia is a main adaptation technology. Pula is another digital innovation that addresses crop and livestock digital insurance. Pula advisors have been instrumental in weather index insurance, where they use satellite imagery to capture the extent of damage to crops and pay out the affected farmers. Through Pula, the insurance risks are removed via improved data and monitoring (https://www.pula-advisors.com/). Lima Links is developing an initiative to increase access to finance, market, climate, and advisory information by uploading farmer information onto the Unstructured Supplementary Service Data (USSD) platform. The Water Resource Management Authority (WARMA) has produced digital geological maps that show areas of high rainfall and areas with sufficient groundwater or other alternative water sources. However, access to digital geological maps is available for a fee.

There are also a few digital innovation and technology hubs in Zambia, such as BongoHive Consul, a consulting firm that builds technology platforms, products, and processes. BongoHive also offers tailored skills training to organizations. Jakaranda Hub aims to develop young people in information and communication technology (ICT) and entrepreneurship through innovation hubs. Anakazi Centre is an innovation hub used to mentor women in business development and foster equal participation of women and men in development issues (Digilogic 2022).

However, there are only a few digital applications in Zambia that are currently in use for climate adaptation in agriculture. The main ones include PLANt, a risk prediction tool that allows farmers to determine the level of risk associated with planting a given variety on a given date (crop failure risk). PLANt can also be used to plan planting operations with a service provider. Using a smartphone, the user can select a location, allowing PLANt to calculate in real-time when it is best to plant crops. PLANt uses real-time soil moisture and evapotranspiration data, past climate (temperature and rainfall), and weather forecast data (FAO 2022). Another application called Nexus Environmental Assessment Tool (NEAT+) is an innovative tool for environmental data gathering and risk assessment (UNEP 2019). In agriculture, plots vulnerable to deforestation and flood damage, for instance, can undergo modification to prevent further deforestation and reduce flood risks.

Table 12 lists the key digital technologies that stakeholders in Zambia identified as important for climate adaptation, and their constraints.

Table 12: Summary of key recommendations by constraint and technology for Zambia

S/N	Technology	Constraints	Recommendations to resolve the constraint and increase use of the technology
1	Weather-based index insurance (WBII)	• Farmers lack adequate awareness of climate adaptation options such as the WBII	• Raise awareness: farmers and key stakeholders need to be aware of all the available adaptation strategies to climate change and should be trained on how to implement them.
		• Weather forecasts are presented at the district level and are not area specific which may affect payouts. This may discourage farmer subscriptions to WBII.	• For decentralized weather information, Zambia Meteorological Department (ZMD) needs investments in additional weather stations to adequately cover the entire country. • Prompt payment of insurance claims to ensure farmer resilience.
2	E-extension platforms	• Limited telecommunications infrastructure in rural areas, e.g., network towers and thus limited network and internet. Remote areas may also not sit on the USSD platform preventing information dissemination via USSD messaging.	• Government to incentivize more investments in telecommunications infrastructure. This could be achieved by bringing more network providers onto the market. Where USSD code is available, it can be used as an alternative to internet-based platforms.
3	E-market information platforms	• Limited telecommunications infrastructure in rural areas, e.g., network towers and thus limited network and internet. • Remote areas may also sit on the USSD platform preventing information dissemination via USSD messaging	• In addition to updating telecommunications infrastructure, ensure digital technology is linked through the whole value chain and should include consumers

S/N	Technology	Constraints	Recommendations to resolve the constraint and increase use of the technology
4	Mobile telephony	• Limited number of smallholder farmers with access to smartphones and thus to digital phone applications.	• The private sector dealing with financial inclusion and weather adoption to invest in access to smartphones for farmers under their programs, e.g., for lead farmers.
		• Limited telecommunications infrastructure in rural areas, e.g., network towers and limited thus network and internet.	• Government to incentive investments in telecommunications. This can be either through engagement or by more network providers.
		• Low literacy rates- farmers may impair them in operating mobile phones.	• Farmer education is required as well as exposure to technology.
		• Women have low-cost phones (usually feature phones) compared to men among smallholder farmers.	• Technology developed should be sensitive to different users, their ability to access technology and the requirement of technology.
5	Radio and TVs	• High initial investment in solar solutions limits access to information shared through TVs.	• Create farmer information centers where farmers can meet on agreed days to receive information from solar TV/Radios and engage with presenters available.
		• When media is used, information may be altered due to the many number of media houses it passes through, as well as the lack of trained media personnel who understand the information shared.	• Ensure media personnel are trained in interpreting climate information and preferably that the information reaches farmers directly.
		• Radio programs on weather and adaptation are usually one-sided and thus lack a feedback mechanism to ensure farmers understand the advisory information provided.	• Radio programs of importance should be call-in programs where listeners are able to engage with presenters. • To counteract the possibility of network challenges, farmer centers should have solar powered TV with informed staff who can be engaged with
6	Rain stations (automated and manual)	• Technology is not easily accessible and not user-friendly to farmers. Even though available, farmers	• ZMD needs investments to equip it with automated weather stations properly

S/N	Technology	Constraints	Recommendations to resolve the constraint and increase use of the technology
		may not know how to interpret the information.	• Farmers can also be guided on how to read, interpret, and apply information from weather stations
7	Climate projection models	• Poor or late prediction of upcoming disasters makes it difficult for farmers to rely on information from forecasting agencies.	• Early warning systems need to be strengthened and coordinated to ensure investments are pooled together within the public sector and with the private sector
8	Digital geological maps	• Geological maps provided by WARMA have a cost implication which may make them unattractive to smallholder Farmers.	• Geological maps should be user-friendly and affordable for farmers and stakeholders to access. Awareness should also be raised about their existence and their use
9	Agro-metrological Bulletin	• Difficulty in reaching remote areas makes it hard for extension workers to disseminate available information to farmers. This creates a lag between when information is shared and when farmers eventually receive it.	• Climate messages need to be sent simultaneously to ensure all farmers receive them at the same time and within actionable time
		• Limited number of established information sharing frameworks.	• A framework for information dissemination needs to be established. This should link both the public and private sectors to ensure their grassroots network is utilized, e.g., rural civil service for the government and project extension staff for the private sector.

Source: Authors compilation from stakeholder consultative workshop held in Zimbabwe, April 2022.

The review of the top 10 digital technologies by three group stakeholders from the consultative workshop held in Lusaka on March 11, 2022, showed that the key intersecting technologies recommended by all groups were:

i. **Index-based weather insurance:** This was a top pick because it provides farmers with a means of resilience in case of crop failure brought on by dry spells, droughts, or floods. Premiums paid out can cushion farmers when they do not have sufficient funds to repurchase agricultural inputs.

ii. **E-extension platforms for timely and widespread access to information:** The E-extension seats with SMART Zambia and can be linked to the ZIAMIS for integrated information provision.

iii. **E-market information platforms** will enable market players to get the information required for better trading.

iv. **Smart gadgets** (e.g., phones, tablets, computers, etc.) open a wide range of possibilities, including access to weather information, such as ZMD's agro-meteorological bulletin, and digital applications, such as Aquacrop and AgriPay.

v. **Solar-powered radio and TVs** for information dissemination on climate risks and adaptation strategies: Community centres can host solar-powered devices and conduct group meetings during TV broadcasts and provide the opportunity for farmers to give feedback. Similarly, radios hold similar potential as they are widespread in rural communities.

Some of the identified cross-cutting challenges for the uptake of digital technologies for climate adaptation include the following:

i. **Poor mobile coverage in rural areas:** A higher percentage of the rural population lacks access to mobile networks, which is potentially one of the key weaknesses for digital adaptation against climate change, particularly among the rural population.

ii. **Poor access to electricity:** Most of Zambia's rural areas have no access to electricity, which has the potential to affect digital adaptation efforts negatively.

iii. **Poor road network in rural areas:** Infrastructure such as roads, is vital for investment in various sectors, including the digital subsector. However, in Zambia, especially in rural areas, roads are in a very poor state, and this negatively affects both private and public sector services essential for the development of the agricultural sector.

iv. **Fewer mobile service providers:** In Zambia, there are only three main mobile service providers, which is quite low compared to other countries in the region, such as South Africa, which has five mobile service providers. The low number of mobile service providers implies less competition, resulting in poor service delivery to the detriment of end-users.

v. **Linguistic fractionalization:** Despite having seven official vernacular languages, Zambia has at least 72 dialects, which presents a challenge for digital service providers to formulate products that accommodate all the local dialects. Ultimately, this has a negative impact on digital adaptation.

vi. **Fragmented extension services:** Extension services are key to the development of the agricultural sector. In Zambia, both the public and private sectors provide extension services; however, they are highly fragmented due to low coordination between the two sectors. This has the potential to affect digital adaptation to climate change negatively.

vii. **Gender gap in literacy:** Illiteracy levels among the rural population in Zambia are high, and more so among women. This implies that it is difficult for most of the population to interpret digital information that may be the key to its adaptation, which is a major impediment to digital adaptation.

Zimbabwe

Smallholder farmers are active participants in the digital technology space, with those negatively affected by climate change adopting technologies to help them cope with the situation. Farmers have shown that they can adopt some of the technologies well and become lead farmers. Mostly, these are farmers who are well-resourced and can afford to purchase equipment and, in some cases, data for connectivity. These lead farmers are instrumental in allowing other farmers who do not trust the technologies to evidence the benefits of adopting such tools. However, the concept of “lead farmers” can also be problematic as there are no readily available accountability frameworks that may ensure they act as desired. The positive role of lead farmers in technology adoption is well covered in the literature. Farmers find it easier and perhaps more convenient to learn from fellow farmers on matters of technology adoption and roll-out than to learn from pre-packaged extension messages that often omit other key context-specific information for the success of the technology. Nevertheless, for such lead farmers to be effective in scaling technology adoption, they must be selected such that they are representative of the local farming community in terms of gender, economic status, culture, etc. Many of the default lead farmers turn out to be retired civil servants with better capital access, better education, and better market access. They do not fit as lead farmers who can spur technology adoption among the small-scale, land constrained, and often semi-illiterate farmers. To spur technology adoption through lead farmers, they must share similar characteristics or have risen from those characteristics owing to the adoption of the technologies in question.

During the rollout of the Pfumvudza concept [43] (conservation agriculture technique), the government used demonstration plots for farmers to learn and uptake the method at their farms. Although labour-intensive, this has been very successful. Pfumvudza is a concept of conservation agriculture (CA) that is designed to meet food security for an average household of six members over a period of one year. The CA practice includes mulching, rainwater management, the use of organic and bio-fertilizers, and the planting of traditional grains instead of maize on Pfumvudza plots in the drier and marginal areas. The government, through the Department of Research and Specialist Services (DR&SS) and in partnership with various stakeholders such as academia and NGOs, has been involved in research to find solutions to climate change challenges faced by farmers. Farmers access weather information to aid in the process of choosing crops and planting dates so that the crop does not suffer moisture stress during the mid-season. A number of programs and projects by the government, private sector, and development partners are implementing activities to promote the adoption and use of digital tools in climate change adaptation.

The Zimbabwe Resilience Building Fund (ZRBF) program is promoting the use of digital weather stations in districts where it is implemented, including Kariba, in the Zambezi basin. It is also promoting e-extension through a mobile app, an e-marketing app, and a financial app through Kurima Mari. The ZRBF program also promotes the use of digital technologies in boreholes to monitor the abstraction of groundwater to avoid over-abstraction. The FAO, under the Livelihoods and Food Security Programme (LFSP), piloted and funded the Kurima Mari app, which is used for group savings and lending by a group of smallholder farmers. The App requires investment in connectivity and data by members. Also, the policy environment should encourage investment in expanding network coverage to other areas to enable wider use. Under the AMALIMA[44] project, the United States Agency for International Development (USAID) promoted a number of mobile applications for early warning systems, crop focusing, and vegetation mapping, among others. The major challenges in adopting and expanding mobile applications were infrastructure, technical skills, connectivity challenges, and the availability of requisite gadgets.

A private sector company, the Financial Securities Exchange (FINSEC), operates the Warehouse Receipt System and Commodity Exchange Platforms. These platforms are run and operated

[43] https://lfspzwcom.files.wordpress.com/2021/08/pfumvudza.pdf

[44] AMALIMA draws its name from the Ndebele word for the social contract by which family comes together to help each other engage in productive activities such as land cultivation, livestock tending and asset building; https://www.cnfa.org/program/amalima/

through a mobile application that is available to farmers, input suppliers, traders, and consumers. Econet, a mobile cell phone company, is promoting 'Eco Farmer,' a mobile platform providing extension messages for farmers' use. It is an interactive platform where farmers can ask questions and receive responses in return. The major challenges for farmers to utilize this platform, however, are connectivity to the internet and access to data.

The Dairy Farmers Association of Zimbabwe members have access to a mobile app to assist dairy farmers in accessing inputs, finance, extension, and marketing services. However, some farmers are sceptical about the use of technology as they fear losing industry secrets that give them a competitive edge, while others cannot use the application because they do not possess smartphones.

In Zimbabwe), the ICT sector has been experiencing a number of challenges. Some of the listed challenges are;

- **Inadequate communications infrastructure:** Broadband coverage is mainly concentrated in affluent urban areas, which is widening the urban-rural digital divide against the principles of equitable access.
- **Inadequate commercial electricity:** The national power grid does not cover the whole country, and the supply is erratic. A significant population is dependent on expensive alternative power sources. The electricity shortage has had adverse effects on the development and use of ICT.
- **ICT skills shortage:** The shortage of ICT skilled manpower is hampering the rollout of ICT programs. This is affecting digital literacy which drives uptake and usage of ICT services.
- **Low digital literacy level:** The education curriculum does not include ICT; therefore, the level of digital literacy at the grassroots level is very low and insufficient to stimulate service uptake and usage, particularly in rural areas.
- The high cost of data and bandwidth has made data beyond the reach of many Zimbabweans.

Digital technology for climate change adoption requires fundamental infrastructure and a conducive policy environment to be in place in order to increase uptake and use. Key infrastructure such as base stations, reliable energy sources, digital weather forecasting equipment, including human capacity at the weather forecast station, investment in farmers' education, collaboration between the government and the private sectors, such as credit providers, banks, insurance providers, network providers, and a conducive policy environment are needed to support the adaptation of digital technologies. Table 13 summarizes key digital technologies and constraints to adaptation in Zimbabwe and Table 14 lists the top five recommended technologies

Table 13: Key digital technologies and constraints to adaptation in Zimbabwe

Technology	Constraints	Recommendations
Early Warning Systems	• Access to modern gadgets (smartphones, computers, cameras) and software	• Facilitate access to digital technology gadgets
Mobile and fixed telephones	• Farmers cannot afford smartphones that allow them to access digital applications.	• Subsidize or reduce tax levels on smartphones to make them more affordable to smallholder farmers
	• Non-availability of telecommunication infrastructure.	• Invest in additional telecommunication infrastructure such as base stations, fiber optic, and equipment servicing facilities. • Expand fixed network infrastructure to remote areas
	• Cost of data too high	• Promote infrastructure sharing to lower the operational costs hence reducing the costs of voice calls and data
Websites, blogs, and social media	• Limited connectivity due to unavailability of network	• Invest in expanding coverage in the Zambezi River Basin
	• Limited availability of computers, smartphones, and other gadgets to access these services through the internet service	• Reduce or remove taxes on the importation of computers and smartphones into the country • Promote local production of computers and ICT accessories
Drone	• High cost of technology	• Support the production of cheap /affordable drones at the country's innovation hubs
	• Restrictive policies on the use of drones	• Lobby for policies that promote and support the use of drones for digital adaptation.
E-mobility	• Limited availability of the technology	• Promote importation of the technology through subsidies and tax incentives
	• Cost of the technology too high for smallholder farmers	• Provide innovative ways of funding the technology including subsidies, development financing, etc.
Community radio,	• Unavailability of radio and TV signals in some areas.	• Invest in improving radio and TV signal transmission infrastructure

Television (TV)	• Limited ownership of Smartphones, computers, TVs, radios, and TVs in rural areas.	• Reduce import duties on radio and TV sets • Support introduction of community halls where there are community TVs and radios • Incentivise private sector investment in the production of TVs and Radios in the country
Insurance Weather indexed insurance	• Limited adoption of weather-indexed insurance by farmers due to a lack of information on the importance of insuring crops and livestock.	• Increase awareness campaigns and communication to inform farmers of the importance of weather insurance and its importance to agriculture • Incentivise insurance firms to develop innovative weather insurance products to promote adoption • Provide incentives to insurers to invest in rural weather-indexed insurance systems
GIS and GPS	• Outdated and obsolete equipment which gives inaccurate results	• Invest in modern GIS and GPS equipment.
	•	• Encourage private sector investment in the development of GIS and GPS infrastructure.
E- markets /E-commerce	• Limited or no access to e-markets due to unavailability of ICT gadgets such as computers and smartphones	• Provide digital technology equipment including computers, smartphones, and printers
	• Limited access to internet data	• Revise internet data tariffs to be affordable as well as subsidize the cost of ICT data for selected smallholder farmers.
Video Streaming	• High cost of internet connectivity (requires high bandwidth)	• Invest in ICT infrastructures such as base stations and fiber optic cables to lower the cost of data
Automated Teller Machines (ATMs) , banking and Finance	• Limited access to ATMs as they are located mainly in growth points, towns, and city centres	• Invest in decentralising banking services, have ATMs at local centres
	• Most ATMs are non-functional due to intermittent internet connectivity	• Invest in internet connectivity infrastructure Invest in alternative sources of energy such as solar so that ATMs are continuously powered
Robotics	• Non-availability of suitable technology in smallholder areas	• Invest in R&D in robotics technology and have a strategy for deployment in smallholder farming areas
Self-scanning machines and printers	• Access to the technology is limited	• Invest in community information kiosks where these services are available

Source: Authors compilation from stakeholder consultative workshop held in Zimbabwe, April 2022.

Table 14: Top 5 recommended technologies

Focus of Technology	Technology	Where to invest in
Information dissemination	Early Warning Systems	Equipment, Capacity strengthening
Specialised information provision	Global Positioning Systems (GPS)	Equipment, Capacity strengthening
Provision of weather-related information	Automated Weather stations	Digital weather equipment
Transactions, information dissemination	Mobile platforms	Mobile platform infrastructure
Extension services provision, Market information	e-Government, e-Learning, e-Extension, and e-Commerce	Mobile platform infrastructure, base stations

Source: Authors compilation from stakeholder consultative workshop held in Zimbabwe (April 2022).

Climate adaptation through digital technology in Zimbabwe still faces serious challenges:

Digital infrastructure is one of Zimbabwe's relative strengths. However, regulatory roadblocks and macroeconomic conditions hamper its growth. Zimbabwe's international connectivity infrastructure is relatively well-developed, with optical fiber connecting major cities and urban areas. However large gaps remain in rural areas, resulting in inequalities in access to information and different adaptive capacities between the well-served and those who are not. Aging infrastructure and insufficient resourcing, combined with overall macroeconomic distress, electricity, and connectivity issues, are some of the major bottlenecks.

The mid-Zambezi basin communities are being severely impacted by climate hazards such as droughts, floods, high temperatures, and erratic rainfall patterns. Therefore, digital climate adaptation technologies offer an opportunity to attain food security. However, many cannot afford such technologies. Therefore, there is a need for awareness campaigns along with strategies that enable farmers to access the technologies and improved ICT infrastructure that are currently insufficient. Capacity development is required for key organizations such as the Civil Protection Unit (CPU), with suitable equipment for improved data generation and reporting. There is also a need for digital skill development programs to ensure a successful transformation process.

The availability of affordable smartphones is providing women the opportunity to own phones and receive equal access to information to enhance their preparedness. Strategies need to be put in place to complement smartphones and provide access to a wide range of digital tools, including computers, GPS equipment, and tablets. Through scaling the adoption of digital tools, many opportunities can be derived apart from delivering information, data collection can also be done, and this makes it faster and cheaper. To encourage adoption there is a need for all stakeholders to be involved. The Government can promote local production of some of the ICT equipment.

Through the country's goal to achieve an upper middle-class economy by 2030, digitalization is a key component in the achievement of this goal. Zimbabwe needs to make regulatory improvements as well as investments in four interconnected areas across all pillars: policy and regulatory framework, resource management and coordination, governance, and capacity building. Much work remains to be done both on fixing the macroeconomic fundamentals and yet these also create an opportunity for leapfrogging and incentive for further innovation, just as the case of digital financial services illustrates[45]. The lack of digital literacy needs to be addressed at the academic level through the inclusion of ICT in the curriculum complemented by professional digital training that can be offered in schools and within companies through on-the-job training programs.

Constraints towards adoption of digital technologies in climate change adaptation

The major challenges limiting the adoption of digital technologies in climate change adaptation in agriculture in Zimbabwe that emerged from the consultation workshop include the following:

i. Capacity challenges – Low capacity of smallholder farmers to generate and process data and effectively use the information required to strengthen them to maximize benefits from the use of the technologies. Also, there are capacity challenges in terms of skills to install and operate digital adaptation technologies.

ii. Unavailability and Immature technologies – The agriculture sector has a number of digital technologies under pilot, but smallholder farmers are hesitant to adopt and use them. In addition, some of the suitable technologies, applications, software systems, and platforms for data-driven agriculture and precision farming are just emerging and not readily available in the country. Some of the technologies require high computer literacy skills which most smallholder farmers do not have e.g., artificial intelligence.

iii. Access barriers and lack of information on available technologies—Most farmers are excluded from some technologies because they lack information about them and their benefits.

[45] https://www.worldbank.org/en/country/zimbabwe/publication/digital-transformation-

iv. Data challenges—Digital technologies rely on data to provide the required output. There is limited capacity to obtain climate data at the local level, hence challenges in using the technologies. There is a lack of partnerships between different stakeholders and ensuring coordination, accurate and advanced climate modelling, and forecasting capacities.

v. The requirement for high levels of climate literacy is also another challenge for digital adaptation. Some farmers are not comfortable using digital technologies as they look complicated.

vi. Poor coordination- In general, there is poor coordination among stakeholders involved in digital technologies for climate change adaptation. This results in duplication and waste of resources. The sharing of telecommunication infrastructure will result in reduced costs to the end users. Poor coordination also results in unnecessary competition between players which in some cases does not benefit the final consumer. Licensing authorities should better coordinate well to have investments spread across all areas i.e., urban and rural.

vii. Policy inconsistencies -Policy inconsistencies at times cause investors to have challenges in investing in the digital sector. The National Cyber Security Policy and Strategy, which was put in place in 2020 and the act has some sections that are not in sync with earlier policy positions. For instance, there is a conflict with regard to the interpretation of cyber security and national security, where the latter allows the government to incept private communication in the name of national security infringing on the right to privacy (MISA Zimbabwe 2021). This has resulted in some investors reconsidering investment options. Also, State companies are perceived to enjoy preferential treatment from the Government in terms of taxes and other incentives. The state controls data and call charges, which are creating viability challenges for some of the companies in the sector, hence acting as a barrier to further investments in the area.

Summary of technologies and challenges

a. There are several challenges associated with digital technology applications for climate change adaptation in agriculture. Some of these challenges are listed below: Lack of electricity to recharge mobile phones or computers specifically in rural areas. Since the majority of the population is living in rural areas rural electrification is key. It is important to invest in alternative energy sources such as solar power or other alternative energy sources.

b. Network coverage in rural areas is constrained by a lack of infrastructures such as roads and telecommunication towers.
c. Lack of national policies or legal framework to support digital technology in the Zambezi River Basin countries.
d. The gender gap in the digital sector exists, where fewer women than men are involved in digital solution management for the market. Women, particularly in rural areas, are less likely to own mobile phones, on the other hand, they are the ones who are more engaged in agricultural activities.
e. Constraints like local languages not being catered for SMS messaging limit information to target groups.
f. Lack of digital skills for agricultural climate change adaptation using digital technologies, and lack of human capacity to process remote sensing data and generate useful information that can be used for climate change adaptation. Furthermore, digital skills in applying Machine learning algorithms are often lacking in all Zambezi River Basin countries.

6. Digital adaptation readiness

The previous chapter focused on summarizing the digital tools that are frequently mentioned as being used in adaptation efforts in the eight riparian countries of the Zambezi River Basin. It is noted that while countries are making efforts to leverage digital technologies, in most cases, these technologies only reach a small fraction of those who need them. In some cases, their performance is not optimal owing to the limitations in skills by users and archaic or insufficient equipment. Clearly, stakeholders need to make additional efforts to entrench digital technologies in climate adaptation. Given the initiatives by the African Development Bank and the Global Centre on Adaptation as well as the ZAMCOM, in which they purport to invest in more digital technologies for climate adaptation, the question about the readiness of these countries for further digital adaptation upscaling comes to the fore. This chapter, therefore, revisits each of the eight countries to understand the levels of infrastructure that support digital upscaling, skills, ICT programs, and an enabling environment. One of the purposes of this analysis is to understand if the countries are ready for the upscaling of digital adaptation. Therefore, parts of this chapter present some initiatives for digital adaptation in the Zambezi countries, whereas other parts also present a summary of the level of progress in crucial factors that foster digitalization and an analysis of key enablers. Table 15 presents the status of digital access, use, and affordability in the Zambezi River Basin countries.

Table 15: Digital access, use, and affordability in the Zambezi River Basin

INDICATOR	Angola	Botswana	Malawi	Mozambique	Namibia	Tanzania	Zambia	Zimbabwe
Population covered by a mobile-cellular network (%)	90	>95	86	85	>95	95	86.9	93.0
Mobile-cellular subscriptions per 100 inhabitants	45	162.6	47.8	49	102.105	85.75	103.918	88.8
Active mobile broadband subscriptions per 100 inhabitants	3.7	67.3	16.6	17	90	9.80	51.1	51.7
Individuals owning a mobile phone (%)	78.6			31.4		88	83.4	89.6

Male mobile phone ownership as a percentage of total male population (%)	77.6			56			86.5	
Female mobile phone ownership as a percentage of total female population (%)	79.8			26	54		80.8	
Individuals using the Internet, total (%)	36	64	15.50	17	40.5	20	19.0	25.1
Female internet users as a percentage of the total female population (%)				17	20		12.0	30.0
Male Internet users as a percentage of the total male population (%)				27			17.3	28.9
Households with Internet access at home (%)		63.5	10.5	2		23	49.7	50.1
Households with a computer at home (%)	9.2	14.75	5.19	7.33	16.53	3.8	8.1	14.2
Individuals with basic ICT skills (%)			40				51.9	3.9
Affordability, out of 100	56th (39.83)	13th (71.1)	54th (42.27)	51st (45.17)	53rd (43.51)	38th (55.55)	48th (48.54)	58th (39.34)
Price per 1.5 GB (US$)	4.65	5.68	6.70	2.86	8.45	6.17	2.82	11.22
Mobile cellular basket as a percentage of GNI per capita (%)	3.1	1.1	22.1	19.9	2	4.5	5.62	13.4
Mobile broadband basket as a percentage of	3.2	1.1	20	8	2.5	6.8	3.7	23.5

GNI per capita (%)								
E-Government Development Index * rank out of 193 countries	159th (0.38)	115th (0.53)	165th (0.35)	163rd (0.36)	104th (0.57)	152nd (0.42)	148th (0.42)	126th (0.50)
E-Participation Index*rank out of 193 countries	122nd (0.45)	137th (0.37)	129th (0.42)	103rd (0.52)	112nd (0.5)	98th (0.56)	158th (0.31)	122nd (0.45)
Network Readiness Index*rank out of 134 countries	126th (25.99)	102nd (38.03)	119th (29.00)	125rd (26.55)	109th (35.66)	107th (35.83)	112th (33.93)	122nd (28.74)

Sources: Authors from World Bank 2021 and ITU 2022a (on mobile ownership) and other sources.

In the Zambezi River Basin, countries rank differently regarding access, use, and affordability of mobile telephony, ICT, and Internet. They are also at different stages of embracing E-government. In general, Botswana, Namibia, and Tanzania rank high in the region in terms of e-government, e-participation, and network readiness indicators. At the same time, Angola, Mozambique, and Malawi have lower scores and rank lowest in the region (Table 15). The affordability of internet as measured by the cost of data and the cost of internet bundles as a share of income per capita also confirms the heterogeneity across countries. While Angola ranks low on E-government measures, it is among the top three (including Botswana and Namibia) countries where internet is affordable. However, mobile internet is also more expensive in Malawi, Mozambique, and Zimbabwe.

The available data On ICT skills and internet penetration in homes shows that huge populations of the Zambezi countries have limited access to internet and computers. Malawi, Tanzania, Mozambique, Zambia, and Angola have the lowest proportions of households with computers (below 10% of the population). In contrast, Botswana, Namibia, and Zimbabwe have comparatively higher proportions of the population using internet. Mobile infrastructure, as proxied by mobile cellular coverage, is high in Namibia and Botswana, where the populations covered by mobile cellular networks are close to 100 percent. Still, mobile broad penetration is very low across all the Zambezi countries. For example, less than 10 percent of people in Angola and Tanzania have active mobile broadband subscriptions.

So, there are significant challenges in access, use, and availability of infrastructure throughout the region. There is a gender gap in favor of men regarding access to internet and mobile phone ownership in some countries, and the overall E-Governance and E-Participation rates are among the lowest countries in the world. While these results show the need for intervention, it is also important to note that these challenges are heterogeneous, and similarly, the approaches for intervention need to emphasize different aspects of these challenges. In the following sections, these indicators are discussed alongside others for each Zambezi River Basin country.

Closing the gender gap in technology adoption requires a nuanced approach

The issue of technology gaps between men and women is complex in that it is governed by many factors, which may fall in the categories of finance, culture, awareness, skills, and needs as may be dictated by the sector in which the women work. These issues are similar with respect to the youth's access to and use of technology. It is important to differentiate technology ownership and use, as these may be influenced by factors that may not always be the same. The use of phones, for example, even among women with access to mobile internet, may be influenced by cultural factors in cases where being on social media may be looked at with stigma. These sentiments were echoed in consultation meetings in Zimbabwe, Zambia, and Malawi. In these cases, men in control of household resources may also shun supporting women's internet use. Thus, besides addressing issues of ownership of mobile phones, skills for use, and financial access, a focus on awareness and cultural change communication may be useful to free women from institutions that trap them in perpetual helplessness.

The typology of women in each context that accounts for their income group, location, and education is thus important for identifying the right interventions that seek to increase and upscale the use of digital technologies in climate adaptation. So, besides addressing issues of ownership of mobile phones, skills for use, and financial access, a focus on awareness creation and cultural change communication may be useful to free up women from cultural institutions that may prevent them from using mobile technology for certain profitable activities otherwise viewed negatively by society (for example presence on social media). It is also important to recognize the cross-country differences in the importance of the gender gap, as well as the importance of recognizing the differences among women themselves in terms of location (urban vs rural), income categories (poor, ultra-poor, well-off) as well as education (literate vs illiterate). Smart mobile phones can impact the poor and literate women, whereas ordinary mobile phones with voice abilities may hold a better chance of positively increasing adoption among the illiterate poor.

Table 16 provides an example of interaction/intersectionality of three factors that shape the plight of women and the youth in a particular setting, and the implications such interactions may have on the type and nature of technology that may be recommended.

Table 16: Possible interventions to increase technology adoption among women/youth depending on their circumstances

Information delivery methods /Mobile phone targeting	
Nuances/intersectionality	**Interventions**
Ultra-Poor, Literate Urban Farmer	Low-cost smartphones/internet, TVs, radios bundled with social safety nets, low-cost credit
Poor Literate Urban Farmer	Low-cost smartphones/ internet, TVs, radios, or TVs and radio programs
Rich Literate Urban Farmer	Smartphones, TVs, radios,
Ultra-poor Illiterate Urban Farmer	Low-cost mobile phones with voice abilities, local language-based radio and TV programs, and social safety nets bundled with low-cost credit.
Poor Urban Illiterate Farmer	Low-cost mobile phones with voice abilities, local language-based radio and TV programs, and social safety nets bundled with low-cost credit.
Rich, Illiterate Urban farmer	Mobile phones with voice abilities, local language-based radio and TV programs, social safety nets bundled with low-cost credit
Ultra-Poor Literate Rural Farmer	Low-cost smartphones/internet, TVs, radios bundled with social safety nets, low-cost credit, cultural change communication/training programs
Poor Literate Rural Farmer	Low-cost smartphones/ internet, TVs, programs and radio programs, cultural change communication/training programs
Rich Literate Rural Farmer	Smartphones, TVs, radios, cultural change communication/training programs

Ultra-poor Illiterate Rural Farmer	Low-cost mobile phones with voice abilities, local language-based radio and TV programs, social safety nets bundled with low-cost credit, cultural change communication/training programs
Poor Illiterate Rural Farmer	Low-cost mobile phones with voice abilities, local language-based radio and TV programs, social safety nets bundled with low-cost credit, cultural change communication/training programs
Rich, Illiterate Rural farmer	Mobile phones with voice abilities, local language-based radio and TV programs, social safety nets bundled with low-cost credit, cultural change communication/training programs

Source: Authors compilation.

Some small-scale farmer's business owners, be they women or youth, may find themselves in a situation where several factors negate their ability to take advantage of technology in climate adaptation. Many factors may influence technology adoption within a particular setting aside from the economy-wide, or community-wide factors. Where a particular female or youthful small-scale farmer or business owner is of a certain income group (ultra-poor, poor, and rich), lives in either an urban or rural setting, and is either illiterate or literate, then at least 12 unique farmer/youth groups can be identified as in Table 16. On the extremes, some farmers will be rich, literate peri-urban farmers who may simply need awareness creation to adopt technology. In contrast, others will be ultra-poor, illiterate rural farmers who may need help with everything from financing to skills development to cultural change communication. All these and even more complicated nuances exist in each of the 8 Zambezi riparian countries. Beyond these factors, many other factors, including landlessness and family dynamics, are also at play. It is important to take these into account in intervention design and roll-out. Along the value chain of business (production, processing, distribution, retailing, and use) or across subsectors (crops, livestock, fisheries, forestry), the adoption of appropriate technologies by women farmers and the youth face similar individual-specific challenges. However, the importance of each of these factors may vary from one sector, one point of the value chain, to another.

The role of social safety nets, adaptive capacities, and assets in digital adaptation

Many of the stakeholders with whom the research teams interacted indicated that the costs of data and mobile phones were a deterrent to ownership and use. The importance of costs implies that income sources, including agricultural and off-farm income, are critical for resilience building. This may not be overemphasized particularly because a resilient household that can better adapt to climate change should have better access to assets, better adaptive capacity, better access to social safety nets, and better access to public services[46]. The adaptive capacity of the farmers measures a household's ability to adapt to changes and shocks in its environment. Factors including education of household members, diversity of income sources (including non-agricultural incomes), and labor access increase the adaptive capacity of a household. On the other hand, social safety nets available to the farmer measure a household's access to formal and informal transfers that provide social protection in times of need, for example, remittances from urban centres and abroad, as well as access to credit from informal and formal markets. Productive and non-productive household assets are also important for technology adoption and climate adaptation. Productive assets (such as land and livestock) enable households to produce tradable and consumable goods, while non-productive assets (such as appliances, house quality, etc.) determine the household's well-being.

The design of adaptation interventions needs to consider capitalizing on these elements of the pillars of climate adaptation to be successful. For example, a household with productive assets, or other sources of income rather than agriculture can re-finance agriculture by selling assets in a bad agricultural year, while social safety nets and formal and informal transfers, including remittances, can provide the needed capital for technology adaptation. Where feasible, programs should seek to strengthen smallholder farmers' access to such assets, adaptive capacities, and social safety nets.

The general policy and regulatory frameworks need to be improved to advantage technology adoption in climate adaptation.

A better regulatory environment is critical for the adoption of technology and for climate adaptation in general. While all the eight Zambezi River Basin countries reported having policies and strategies for climate change adaptation, only Malawi, Mozambique, and, to some extent, Zambia reported having policies/strategies on digitization or having drafted one (e.g., Zambia). There is also no regulatory framework for cyber-security in the Zambezi region or in the SADC region, and neither is there an overarching framework or guideline for regulating investments in technology or mobile banking. Although there is a SADC climate services center in Gaborone, its operation is not optimal and often suffers from resource constraints. These weaknesses in the

[46] FAO. Www.FAO.org

regulatory environment (absence of policies and laws that cut across the region) make it hard to prevent cybercrimes, as well as for the general regulation of investments in technology across the countries. Such weaknesses depress both the supply of technology and the demand thereof. At the SADC level, it is important t to coordinate these matters more through the promulgation of an overarching framework for investments in technology, as well as for fighting cybercrime.

Angola

As highlighted previously, Angola's readiness indicators confirm the importance of examining various factors to understand the key challenges of digital technology access. For example, Angola ranks comparatively higher in the Zambezi region on the costs of mobile data, with prices per 1.5GB data bundles averaging under US$5 and mobile cellular basket costs of under 3.5 percent of Gross National Income (GNI) per capita compared to data costs of US$6.7, US$8.45 and US$11.22 for Malawi, Namibia, and Zimbabwe respectively (Table 15). The shares of mobile cellular baskets to GNI are higher in Malawi (22.1%), Mozambique (19.9%), and Zimbabwe (13.4%). On the other hand, the performance of E-government indicators, which are also important for digital technology upscaling, is low. Angola ranks number 159, number 126, and number 122 in the world on E-government, network readiness, and E-participation indicators, respectively. It also occupies the lowest rank compared to many Zambezi River Basin countries (Table 15).

Although mobile network coverage is reported to reach 90 percent of the population, only 45 percent and 3.7 percent of Angolans have mobile cellular subscriptions and active mobile broadband subscriptions, respectively. The total number of people using internet is under 36 percent of the population, while mobile ownership stands at 78 percent, and women are reported to own more phones as a share of the total female population. Some reports in the literature suggest that women own non-smart phones with limited use for purposes of receiving climate information. Only 9.2 percent of the households in Angola have a computer which means that many of the households will struggle to take advantage of some of the digital applications necessary for climate adaptation if they require computers (Table 15). From this information, it appears that Angola is ready to upscale the use of digital technology because data costs are low, and the wider coverage of mobile networks offers further opportunities for entrepreneurs and investors.

Botswana

Like Namibia, Botswana is the richest of all the Zambezi riparian countries when viewed from the perspective of income per capita. Botswana's GDP per capita qualifies it for the status of an upper-middle-income country with a GDP per capita of over US$6,500. Botswana has three mobile network providers: Mascom Wireless, Orange Botswana, and BTC mobile (beMobile)[47]. Mascom Wireless, a private Botswanan mobile company led by Portugal Telecom, is the country's market leader. It has the best 3G coverage and in 2014 its 3G covered 70 percent of the population. In 2015, Mascom started with 4G/LTE in Gaborone. Orange Botswana is the second operator in the country, with a 27 percent market share. It has a lower coverage, but they were the first to start with 4G/LTE on 1800 MHz to be available in Gaborone and some other towns in 2015. BTC Mobile (rebranded from beMobile) is the brand name of the state-owned Botswana Telecommunications Corporation (BTC) that combines the operations of fixed-line operator BTCL and wireless operator beMobile. It's the third operator with a 16 percent market share. 4G/LTE started in 2016 in Gaborone and claims the best 4G coverage right now.

The population covered by mobile cellular networks in Botswana surpasses 97 percent, and when multiple subscriptions are accounted for, mobile subscriptions per hundred people surpass 160 in Botswana. However, broadband subscriptions per 100 people in Botswana stand only at 67 percent, and general usage of internet in the total population stands at 64 percent, implying that an overwhelming 36 percent of Botswana do not use internet. The proportion of households with a computer at home in Botswana is 15 percent, which is second to Namibia in the Zambezi River Basin (Table 15).

Internet affordability in Botswana stands at 71.1 (13th in the world) out of 100 and is the highest among the Zambezi riparian countries. As a share of GNI per capita, the cost of a mobile cellular basket is only 1.1 percent in Botswana compared to an overwhelming 22.1 percent in Malawi and 13.4 percent in Zimbabwe. Botswana currently ranks second in Africa in internet affordability[48]. Three years ago, the country's broadband was incredibly expensive, ranking Botswana among the highest on the African continent (BOCRA, 2020). Botswana Fibre Networks (BoFiNet), a state-owned enterprise, is mandated to provide Botswana with the necessary primary infrastructure for

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[47] https://prepaid-data-sim-card.fandom.com/wiki/Botswana#Basics

[48] https://www.sundaystandard.info/a-look-into-botswanas-internet-performance-and-cost/#:~:text=In%20Botswana%2C%20broadband%20is%20embraced,a%20total%20of%20around%203.5%25

broadband connectivity, nationally and internationally (BOCRA, 2020)BoFiNet plays a crucial role in delivering the backbone infrastructure for national broadband. Its national fiber is 10,600 km countrywide, connecting cities, major towns, villages, and selected strategic locations. According to the Botswana Communications Regulatory Authority (BOCRA), broadband prices were reduced by up to 46 percent between 2019 and 2020.

Mobile broadband subscriptions have increased by 16.3 percent (284,812) from 1,752,547 in March 2019 to 2,037,359 in March 2020 (BOCRA, 2020). This significant increase in uptake of mobile broadband is attributable to several reasons, including ownership of more than one Subscriber Identity Module (SIM)-card to enjoy different benefits offered by different service providers; better affordability due to recent price reductions; reduced movement and extreme social distancing during COVID-19, leading to extensive use of electronic platforms to access self-service for utilities and internet use to apply for movement permits. As Botswana moves towards a digital economy, the number of subscriptions is expected to grow, with service providers introducing more affordable products and services to the market.

Mobile broadband coverage in Botswana is growing fast. The extensive network coverage is supported by 1,670 3G base stations and 1,333 4G/LTE base stations that are located to serve subscribers in frequently travelled parts of the country. There has been an increase in the number of base stations for both 3G and 4G. The increase in 2019 and 2020 were 7 percent and 40 percent, respectively. The increase in base stations also shows commitment by public telecommunication operators to achieve universal service through mobile broadband networks (BOCRA, 2020)Although Botswana's ranking is low on network readiness, E-participation, and E-government compared to other countries in the world, it ranks first among the Zambezi countries on network readiness and second on E-government.

It is, therefore, clear that Botswana has sufficient mobile-cellular network coverage to expand digital technologies for climate adaptation. Furthermore, considering that mobile broadband has expanded significantly, along with a long history of using a drought forecasting model, two important building blocks for upscaling are already in place. Also, the existence of digital applications for marketing (mAgri), Blockchain, IoT for ranching and cattle asset tracking, Modisar for farm record keeping, and chameleon and wetting front detectors (WFD) for management of soil-water and nutrients in an irrigation field, all indicate a good starting point.

Therefore, Botswana's internet infrastructure, the prevalence of digital applications and initiatives, cost, and government systems make the country ready for digital upscaling.

Malawi

When viewed from the perspective of income per capita, Malawi and Mozambique are the poorest countries in the Zambezi River Basin. It is therefore not surprising that the proportion of the population covered by a mobile cellular network is only 86 percent in Malawi while other countries in other countries of the basin approach 90 percent in the other countries of the basin, Mobile subscriptions per 100 inhabitants stand at just 47.8 percent, while mobile broadband subscriptions per 100 inhabitants is as low as 16.6 percent, much lower than Botswana, Namibia, Zimbabwe, and Zambia, which stand above 50 percent (Table 15). Overall, only 15.5 percent of individuals in Malawi use the internet, while just 5.2 percent are reported to have a computer at home.

The affordability of internet access in Malawi is a major problem. Out of 100, Malawi ranked 54th in internet affordability, making it among the top three most expensive countries in the Zambezi River Basin, next to Zimbabwe and Angola. Part of the low ranking in affordability of the internet is due to Malawi's low income per capita, making the share of spending on mobile phones and services a significant portion of that low per capita income. The share of the mobile cellular basket in Gross National Income (GNI) per capita stood at 22 percent in 2021, significantly above Botswana (1.1%), Angola (3.1%), Namibia (2%), and Zimbabwe (13.4%). Malawi's performance on E-government indicators is poor, often ranking above 119 on network readiness, 129 on E-extension, and 165 on E-government (Table 15). Malawi requires significant infrastructure investments and the skills to speed up the uptake of digital technology for climate adaptation.

In general, Malawi is at the infant stage of digital transformation. It was ranked 167 out of 176 countries in the ICT Development Index (IDI)[49] in 2017. The digital sector is faced with many challenges, including inadequate ICT infrastructure, high investment costs, inequitable access to internet services across social and economic groups, a lack of ICT and e-services awareness, and a lack of digital skills and competencies (Ernst & Young Private Limited, 2021). About 60 percent of the population in Malawi lacks the basic competence for operating computers and accessing

[49] https://www.itu.int/net4/ITU-D/idi/2017/index.html

the internet on mobile devices, which poses a major challenge for digitalization and access (Ernst & Young Private Limited, 2021). Mobile penetration remains low in Malawi. Furthermore, the price of 1 GB of mobile data in Malawi is significantly higher compared with other African countries[50].

The Ministry of ICT in Malawi was established in 2016 and comprised two technical departments, namely Information and E-Government, with the mandate of providing policy direction and guidance in the production and dissemination of public information and coordinating and managing ICT development and services[51]. Malawi's first technology and innovation hub, called mHub,[52] is located in Lilongwe. Over the last five years, the hub has facilitated over US$1 million in financing for emerging entrepreneurs, created more than 950 jobs, and trained over 40,000 youth with business and technology skills. Ecobank[53] became the first bank in Malawi to launch a mobile app called 'Ecobank Mobile Banking App' to support wallet-to-bank transactions. To harness the benefits enabled by ICT and digital technologies, the government of Malawi initiated the Digital Malawi program, managed by the Public Private Partnership Commission (PPPC), in partnership with the World Bank Group to support a comprehensive, long-term investment in Malawi's digital transformation[54]. The main objective of the Digital Malawi program is to build digital capacity and improve digital innovation in the country by supporting digital technology or innovation hubs and entrepreneurs to scale up their innovation and services.

Malawi has a dedicated humanitarian drone corridor, which has created the foundation for a number of drone-based businesses that are experimenting with everything from transporting blood samples to mapping out geospatial agriculture and climate data[55].

The African Development Fund (ADF) financial digitalization initiative and the government of Malawi signed a grant agreement for US$14.2 million in December 2021 to undertake infrastructure upgrades and create a more efficient and transparent digital payment system[56]. The

[50] https://www.dw.com/en/why-mobile-internet-is-so-expensive-in-some-african-nations/a-55483976

[51] http://www.ist-africa.org/home/default.asp?page=doc-by-id&docid=6995
[52] https://mhubmw.com/
[53] https://businesschief.eu/company-reports/ecobank-embraces-digital-transformation-malawi-through-new-technology-initiatives
[54] https://unesdoc.unesco.org/ark:/48223/pf0000228807
[55] https://dai-global-digital.com/dfid-and-dai-host-malawis-first-digital-development-forum.html
[56] https://www.afdb.org/en/news-and-events/press-releases/malawi-african-development-fund-signs-142-million-grant-agreement-financial-digitalization-initiative-49073

Malawi Innovation Challenge Fund project[57] sought to develop a universal service fund (USF) framework to extend ICT connectivity to unconnected and underserved rural and remote communities. It aims to provide technical and financial assistance to promote innovative, pro-poor, and inclusive business models.

Malawi is taking a significant step in the integration of ICT in the education sector to digitalized teaching and education across the country[58]. Notable efforts in this regard include providing computers and tablets to schools and training teachers in using ICT with the support of development partners. However, effective integration of ICT in schools is hindered by a lack of access to electricity, computers, tablets, and other devices, supportive ICT infrastructure, and secure storage for digital devices.

Thus, Malawi is adequately prepared to scale up digital technology for climate adaptation.

Mozambique

The mobile infrastructure in Mozambique is weak but comparable to other Zambezi countries (Table 15). The mobile cellular network penetration of the population is 85 percent, with about 49 subscriptions per 100 people. However, active broadband subscriptions are significantly low at 17 percent. There is a wide gender gap in favour of men in terms of both mobile phone ownership (56% for men versus 26% for women) and internet usage (27% for men versus 17% for women). This gender gap likely undermines the ability of women to adopt mobile and internet-based technologies and increases gender inequality. Again, households with internet access at home stand at just 2 percent, the lowest in the Zambezi River Basin countries. Computer ownership is 7.3 percent and falls behind the region's leaders, such as Namibia (16.5%) and Botswana (14.75%), among others. Although the cost of 1.5 GB of data is US$2.86, much lower than most Zambezi countries—except Zambia, the country ranks low in terms of the mobile cellular basket as a share of Gross National Income (GNI) per capita. Mozambique also ranks low on E-government and network readiness, both worldwide and when compared to the region.

It is, however, useful to note that, in general, Mozambique's digital transformation is accelerating with the increasing use of mobile technology and the internet. The number of mobile connections

57 https://my.southsouth-galaxy.org/en/solutions/detail/malawi-innovation-challenge-fund
58 https://www.ilo.org/wcmsp5/groups/public/---ed_dialogue/---sector/documents/publication/wcms_783666.pdf

in January 2022 amounted to 17.1 million, or 52.5 percent of the total population. This is an increase of 1.2 million connections (+7.7%) compared to 2021. The total number of active social media users in Mozambique was 3.05 million in January 2022, or 9.3 percent of the total population. Total internet users were 7.5 million in January 2022, or 23.1 percent of the total population. GSMA Intelligence's statistics indicate that mobile connections in Mozambique were equivalent to 52.5 percent of the total population by January 2022. Broadband penetration remains low, however, at 17.5 percent in 2017 and is lower than the average for the Southern Africa region (29.1%) and Sub-Saharan Africa (SSA) (19.9%) (ITU 2022a).

Internet access is limited to 14 percent of males and 7 percent of females in the population aged between 15 and 65, indicating a 50 percent gender disparity in internet use. However, the urban-rural gap in internet use is even bigger than the gender disparity at 85 percent. A quarter of mobile phone users have smartphones, and the majority (70%) use basic phones without the facility to connect to the internet (Gillwald et al. 2019).

Mozambique was ranked 123 in the World Economic Forum's (WEF) Network Readiness Index (NRI) for 2016, which measures countries' propensity to exploit the opportunities offered by ICT. It was ranked 150th in the ITU's ICT Development Index (IDI) for 2017, based on 11 different sub-indicators covering ICT access, ICT usage, and digital skills. These international rankings highlight the relatively poor global positioning of Mozambique, which is also classified in the second half among SSA countries (World Bank 2019a).

The country has relatively well-developed international connectivity. It is currently connected to two subsea cables. Facebook has announced plans to invest in 2 Africa (a mobile company) to procure cable systems in the north of the country between 2023 and early 2024. However, a major variation exists in the connectivity between urban and rural areas. Maputo is the largest and best-connected city, although the present challenges in infrastructure, market maturity, and affordability deter connectivity throughout the country. The limited metro and access network is mostly wireless, providing last-mile access. The government aims to tackle this discrepancy by establishing digital villages via an infrastructure project to improve connectivity and ICT access in rural areas.

The government operates Maluana Park and four other data centers in the country as part of its E-governance strategy. Maluana Park is set to centralize and host Mozambique's public administration computing systems. Amazon Web Services (AWS), Heroku, and Microsoft Azure are among many international companies that offer cloud services to Mozambique, although they do not operate their own in-country data centers.

Mozambique has taken several steps to create the enabling environment necessary for the development of a dynamic digital economy. The positive regulatory measures have fostered healthy competition in the telecom market and mobile broadband penetration, leading to rapid growth in the sector in recent years. Mozambique has the lowest mobile internet cost in sub-Saharan Africa (US$1.97 per gigabyte), and the penetration of mobile phones among most of the population is enabling significant opportunities for the provision of multimodal service delivery (hotlines, mobile financial services, SMS, etc.). According to the World Bank (2020), about 40.3 percent of registered firms in Mozambique operate via their own website, close to 10 points above the SSA average. The 2018 United Nations Business-to-Consumer (B2C) e-Commerce Index placed Mozambique among the top ten African countries by the proportion of individuals shopping online, with 15 percent of those aged 15 and above making online purchases. Improvements in foundational digital transformation elements have great potential for the Mozambican economy to harness digital data and new technologies, generate new content, link individuals with markets and government services, and address the challenges the country is facing in public service delivery and job creation (World Bank 2020a).

The Financial Sector Development Strategy 2013–22 of the government of Mozambique foresees new digital payment systems, the expansion of digital banking, and new financial infrastructure that relies on digital technologies, such as a collateral registry and credit information systems (World Bank 2019b).

The government has taken initiatives to expand ICT services through the Universal Access Service Fund (USAF) since 2007. Efforts have been made to use technologies to support public service delivery. However, as reported by the World Bank (2019a), most systems created in the country are backend digital solutions that enable in-person service delivery, rather than digital services. Mozambique is among the top 10 African countries in terms of the proportion of individuals who shop online.

Mozambique is preparing to develop a secure and resilient critical information infrastructure (CII) utilizing a US$150 million grant from the World Bank. The project supports the Digital

Governance and Economy project to improve digital public services and digital business opportunities[59]. The project has components to establish two data centers in northern Mozambique (Mocuba and Nacala cities), improve infrastructure for the e-government network, and develop multimedia community centers and digital villages.

Namibia

Namibia and Botswana are ranked significantly high in terms of income per capita in the Zambezi and are categorized as upper-middle income countries with GDPs per capita surpassing US$4,000. Not surprisingly, the proportion of the population with internet coverage in Namibia is one of the highest (above 90%). At the same time, mobile cellular subscriptions per hundred inhabitants surpass 100 when multiple subscriptions per individual are counted. However, individuals using the internet make up only 40.5 percent of the population, and female internet users, as a proportion of the total number of women, stand at 20 percent (Table 15). This implies that further efforts are needed to ensure more people, especially women, have internet access. Although the proportion of households with a computer at home is low (16.5%), it is the highest among the Zambezi riparian countries. Namibia's internet affordability is ranked 38th in the world, which means it ranks only second to Botswana in the Zambezi region, which ranks 13th in the world. At just under 2 percent, mobile cellular costs as a share of GNI per capita are one of the lowest in the region. Although Namibia's world ranking on e-government is low (104th out of 193 countries), it leads in the Zambezi riparian countries. Namibia is also among the top three highest-ranking countries in the Zambezi in the areas of e-participation and network readiness (Table 15). Therefore, although Namibia ranks low compared to many other countries on these indicators, it is more ready for digital upscaling compared to the other Zambezi countries, at least on the basis of these parameters.

Some initiatives in Namibia also count as opportunities that make it ready for further upscaling of digital technology. Climate change has made food systems more resilient to future shocks such as floods, droughts, and disease than would have been the case. Namibia experienced increased flooding around 2009, 2010, and 2011, which prompted Namibia to set up "Namibia Flood Sensor Web" in 2009 with the help of external funders. The project's main aim was to integrate remote sensing into a flood monitoring and early warning decision support system (Mandl et al. 2012).

[59] https://www.trade.gov/market-intelligence/mozambiques-digital-transformation

This project was implemented with the help of Namibian Hydrological Services, which was at the forefront of formulating a reliable decision support system. The decision support system uses key satellite and ground sensor data and assimilates the information to provide meaningful awareness of floods and early warning. While this initiative has weaknesses due to its data demands, it provides an opportunity to upscale digital tools in climate adaptation.

Namibia also developed a national climate change strategy and action plan for the period 2013–2020, focusing on sustainable energy, low-carbon development, and transportation. More emphasis is placed on adaptation, prioritizing four key critical themes, i.e., food security and sustainable biological resources; sustainable water resources base; human health and wellbeing; and infrastructure development (GoN 2021). The national climate change policy is already in place, and sectors including water, agriculture, health, fisheries, tourism, and infrastructure have already begun to set up institutional structures to respond to climate change. Such legislation, the cost structures, the available infrastructure, and the past and current initiatives in Namibia create a suitable backdrop to start upscaling efforts.

Tanzania

Tanzania is a vast, low-income country with a huge population. The proportion of the population with mobile cellular networks is more than 93 percent, with 85.5 subscriptions to mobile cellular services per 100 inhabitants. Individuals owning mobile phones account for 88 percent, but only 20 percent use the internet, and 3.8 percent of households have computers (Table 15). Tanzania is ranked high in the cost of data (listed 38th in the world), behind Botswana (13th in the world), inferring that data bundles are cheaper in Tanzania. Tanzania also ranks number one in the Zambezi on the e-extension index and second on the network readiness index. These indicators suggest that Tanzania is ready to upscale digital technology.

Zambia

As a low-middle-income country, Zambia's mobile subscriptions per 100 inhabitants are among the highest in the Zambezi River Basin (Table 15). But at 86.9 percent, the reach of mobile cellular networks in the population lags behind Angola, Botswana, Namibia, and Zimbabwe. Zambia has the 4th highest number (51.1%) of active mobile broadband subscriptions per 100 inhabitants in Zambezi, but there is a gender gap in mobile phone ownership in favour of men (86.5%) against women (80.8%). Individuals using the internet as a share of the total population are just 19 percent. Therefore, although there is significant infrastructure for upscaling internet use, more effort is needed to increase the number of internet users, especially in rural areas. There is also a gender gap in terms of internet usage, with only 12 percent of women using the internet as compared to 17.3 percent of men. Households with a computer at home make up only 8.1 percent, but 51.9 percent of individuals possess basic ICT skills.

The affordability of the internet is a challenge in Zambia, but at US$2.82 per 1.5 GB of data, data costs are lower than in Malawi ($6.7) and Zimbabwe ($11.22). Zambia also ranks low in the world in terms of e-government, e-extension, and network readiness. In addition to the series of government programs highlighted previously, several digital initiatives exist in Zambia.

The Zambia Meteorology Department (ZMD) is responsible for weather forecasting in Zambia. The ZMD has only 41 manual and 107 digital weather forecast stations throughout the country, catering to 117 districts (Below and Nalwimba, 2021;). Weather forecast information is mainly broadcast through extension officers, radio, television, and social media (e.g., Facebook). The main challenges in weather forecasting and distribution include inadequate weather forecasting stations and equipment for location-specific weather forecasting, the absence of local languages in sharing weather information that targets rural farmers, and a limited number of trained broadcasters for interpreting weather forecast information, especially on radio stations (Below and Nalwimba, 2021). The biggest impact of inadequate weather stations is that communities, especially smallholder farmers that depend on rainfed agriculture, are not sufficiently served. Farmers rely on weather forecasts from a wider coverage area (e.g., at the district level) and are therefore ill-advised on when and what to plant. This is amplified by the inadequacy of trained broadcasters of weather forecast information, leading to misinformed farmers who are unable to plan for the farming season. Improving timely access to accurate, intelligible, and useable climate information and early warning systems for small-scale farmers has the potential to significantly improve lives and build resilience in Zambia, supporting the global effort to achieve the Sustainable Development Goals (UNDP 2020). Therefore, it is recommended that investments in digital weather forecasting equipment be fast-tracked to serve communities across the country. Increased training of broadcasters at radio stations is also recommended to ensure that accurate information is delivered to the intended audience.

Again, in view of the common hazards and vulnerabilities in the country, such as floods, droughts, epidemics, environmental degradation, human and animal conflicts, food insecurity, animal and plant diseases and pests, and road and water accidents in Zambia, the government is making efforts to create a permanent response mechanism to deal with these threats. The Disaster Management and Mitigation Unit (DMMU), within the office of the vice president, is tasked with managing disasters. The disaster risk management program entails building capacities for disaster preparedness, response, prevention, disaster mitigation, rehabilitation, recovery and restoration, coordination, disaster risk management information, and communication, monitoring and evaluation, research and assessment, administration, logistical and management support services, and resilience to climate change.

Zambia has experienced a boom in financial payment platforms which include Real Pay, Airtel Mobile Money, MTN Mobile Money, Bayport, Touch4Pay, Zamtel Kwacha, Broadpay Zambia, Zoona, Xapit (Zanaco), Shoprite Money Transfer, Swiftcash, Kazang (Spargis), FNB e-wallet, Cash send (Absa), Payment card (e-voucher), Speed pay, Stanbic IM Voucher, among others (ZICTA, 2018). According to Silimina (2020), the number of mobile money service users grew to over 8.6 million in 2020, compared to 4.85 million in 2019.

The government has provided a sufficient legal framework for regulating how companies in the business of developing digital technologies ought to operate. In addition, the institutional framework is in place to facilitate digital companies. The Zambia Information and Communications Technology Authority (ZICTA) is the main government institution responsible for the regulation of operators within the digital space in Zambia. In addition, laws enacted include the Postal Services Act No. 22 of 2009, the Electronic Communications and Transactions Act No. 21, and the Information and Communications Technologies (ICT) Act No. 15 of 2009, which regulate ICT, postal, and courier services in Zambia.

Several digital services and applications are currently being used by smallholder farmers across the country. The focus is mostly on access to market information as well as extension services related to potential pest and disease attacks and corresponding control measures. Examples of digital service providers in Zambia include Lima Links, SMART Zambia, and MoA, among others.

It is important also to note that there is a need to expand the Zambian ICT space further to enable more companies to operate and provide a wider range of services. This can be achieved through a conducive and enabling regulatory environment provided by the government. Further, there is a need to improve access to electricity, broadband network coverage, SIM registry procedures, and adult literacy, especially in rural areas. This will enable Zambia to tap the full potential of digital adaptation for smallholder farmers. Such improvements will likely lead to increased mobile phone uptake and greater demand for digital adaptation solutions among farmers. In addition, both the public and private sectors need to invest in digital infrastructure as well as awareness raising among farmers. This can be coupled with women's inclusion and support an enhanced climate change adaptation and mitigation pathway.

Zimbabwe

Mobile cellular coverage in Zimbabwe is 93 percent of the population, while mobile cellular subscriptions are 88.8 percent and phone ownership is 90 percent (Table 15). Therefore, Zimbabwe has sufficient mobile infrastructure for upscaling digital technologies. However, there seems to be a bias towards women in terms of the proportions of women using the internet to the total female population, compared to that of males. The stakeholder consultations carried out in Zimbabwe revealed that women were more likely to own non-smartphones than men. Mobile data is expensive in Zimbabwe and only comes second to Malawi in terms of the mobile cellular basket as a share of Gross National Income (GNI) per capita. However, with a score of 0.5 and a world ranking of 126, Zimbabwe performs better on e-government in the Zambezi region (Table 15).

Zimbabwe is leading the revolution on the African continent in using mobile money. The country boasts 7.67 million subscribers with mobile wallets, mostly adults, where the population is 14.5 million (7 million adults), reflecting the pervasiveness of mobile money adoption[60]. The country has a well-developed payment system, with 96 percent of all transactions happening via digital means and only 4 percent being cash-based. However, there is still no interoperability among mobile money operators, and the cost of transactions is high. Internet banking usage in rural communities is relatively low due to limited internet coverage. The level of mobile penetration in

[60] Government of Zimbabwe, POTRAZ “Abridged Postal and Telecommunications Services Report,” 1st quarter 2020

Zimbabwe presents an opportunity for the informal sector to leverage technology to actively participate in the food supply chain.

Zimbabwe has been slow to embrace satellite-based systems for its agricultural sector. However, the benefits of using the technology are understood, as it helps farmers adapt to the impacts of climate change. In 2019, a project was launched to create information using high-resolution satellite data in collaboration between the Chinese Academy of Sciences and the University of Zimbabwe. Climate and crop information collected through satellite was sent to farmers' mobile phones by the consortium Turning Matabeleland Green (TMG). It was reported that satellite-based real-time messages sent to farmers' mobile phones were more accurate than traditional weather station forecasts. The TMG uses a new database that enables faster access to information for even the most remotely located smallholders[61]. Ngwenya and Marambanyika (2021) reported that 69.8 percent of academia and research institutions, 14 percent of government agencies, and 16.3 percent of international development partners had used remotely sensed data in wetlands assessment and monitoring from 1980 to 2019. Satellite images in wetland management in Zimbabwe are used to detect land use and land cover changes (42.1%), vegetation health monitoring (21.1%), water quantity monitoring (5.3%), water quality monitoring (13.2%), and wetland mapping (18.4%). The main challenges stakeholders face in effectively utilizing earth observation data are the high cost of high-resolution images, limited expertise, and inadequate equipment and software.

Small-scale farmers require market information such as current prices, market trend forecasts, and sales timing. The pandemic has increased the demand for online services worldwide, including in Zimbabwe. Paper-based systems are costly, labour-intensive, and slow. There is an increase in the application of specialized mobile services that can fulfil specific agricultural functions.

Again, to address the climate challenge, the Zimbabwe Farmers' Union (ZFU) has teamed up with Econet Wireless Zimbabwe, a privately owned mobile company, to provide bundled climate-smart agriculture products and services to farmers. The bundles consist of weather-based insurance, real-time and location-based weather information, and agronomic advisories that are sent to farmers' mobile devices to help farmers enhance their climate resilience (Kuipa and

[61] Marko Phiri, 11, February 2020. Satellite technology is transforming the lives of Zimbabwe's remote farmers. https://www.weforum.org/agenda/2020/02/satellite-data-farming-advice-remote-zimbabwe

Mozhendi 2019). The insurance cost is US$1.12 per month, which is deducted from farmers' mobile money wallets (EcoCash). The program's learning indicated a need for further extension support for farmers when they receive weather information and advisories on their mobile phones. To resolve this issue, the project has subscribed 300 extension workers living in the 100 target villages, paying a monthly subscription fee on their behalf. This ensures that extension staff receive the same tips as those sent to the farmers, enabling them to provide additional input to farmer groups at the monthly farmers' meeting.

Econet Zimbabwe, a Zimbabwean mobile company, has developed the Ecofarmer mobile application. The subscribers receive a package of mobile phone-delivered agri-services, including microinsurance for farmers to insure inputs and crops against poor weather, such as drought or excessive rainfall. Eco-Farmer has partnered with the Zimbabwe Farmers' Union (ZFU) to develop Eco-Farmer's Diala-Mudhumeni (Extension Officer) service[62]. Farmers can call for timely farming information and advice for free using this service. It is delivered in a language of their choice and covers livestock, daily weather data from a weather station linked to the farmer's field, farming, and market tips, daily rainfall advice, weekly best farming prices, weekly crop data, monthly market pricing requests, crop information, credit rating, advertisements, and marketing and financial linkages. Currently, three helpdesks are operating under the service for field and horticultural crops, tobacco, and livestock. The helpdesks can host marketing and technical personnel from agricultural input suppliers, produce buyers, and the service industry to advise farmers for a small fee. Dial-a-Madhumeni service is considered a win-win solution for both the farmers and participating organizations, where farmers obtain free services, and organizations are able to promote their products and services via free advertorial SMSs to Econet customers.

Timely access to essential farming equipment and services is a challenge, especially for smallholder farmers in Africa, causing a bottleneck in improving their productivity, yields, and value-added capabilities. There is a mismatch between the supply of a limited number of private and public production and processing (hiring) services. The demand is great for those who own equipment, while the level of utilization is very low. The AgriShare mobile application addresses these economic inefficiencies by providing a paid model that empowers those with and without

[62] https://www.ecofarmer.co.zw/dial-a-mudhumeni

assets. AgriShare is a platform that links farmers without assets with commercial or private hiring services for production, processing, and transporting to promote the effective utilization of community farming assets. It provides an overview of the equipment available around your location and beyond with the GPS location and indicates the prices of the available services to help customers make an informed and transparent decision on which offer to take. It has the potential to improve market prices for rental services through increased competition. Private-sector companies with modern and advanced equipment can reach more customers through the platform. The AgriShare platform also provides the opportunity for rental service providers to advertise their services and acquire sufficient clientele for a profitable business.

As of February 2021, the Zimbabwe Agricultural Knowledge and Innovation Services (ZAKIS) has been installing Zimbabwe Agricultural Growth Programm (ZAGP) applications on tablets for more than 5,000 extension staff as part of their collaboration in support of digitization and enabled extension services. About 5,000 extension staff are being targeted to receive the apps that cut across the Agricultural Extension Services (Agritex), including the In-Service training app, Kurima Mari (earning money through farming) app, the AgriShare app, ZimAgrihub, the Kurima Mari Beef app, and the Kurima Mari Poultry app. The e-extension strategy is built on five extension pillars: digital applications, SMS, social media, podcasts, and video. Zim-AgriHub is a virtual agricultural center of excellence that aims to complement agricultural training and research institutions.

Another success story is Kurima Mari weather, market, and price-tracking app that allows farmers to sell their products more profitably and acquire professional skills through video tutorials and podcasts. The app targets farmers, extension services, and agricultural and rural development office staff. It was very useful during the lockdown, as it enabled information sharing without requiring physical meetings and training.

The Transforming Zimbabwe's Animal Health and Food Safety Systems for the Future (SAFE) project, funded by the ZAGP, has developed an information management system to provide value chain actors with up-to-date information on disease outbreaks, market regulations, prices, supply and demand, weather, and financial matters. This data enhances disease surveillance and reporting as well as serves as the basis for a comprehensive livestock identification and traceability system.

A pilot version of the Kurima Mari Beef app was launched under the ZAGP[63] funded by the Beef Enterprise Strengthening and Transformation (BEST) project. Nearly 300 beef farmers have so far registered, and the project is targeting at least 20,000 users across 10 districts[64]. The app interconnects all farmers within the beef value chain locally, regionally, and globally. It covers various topics, including marketing costs, marketing channels, and selling tips. Farmer chat rooms provide an avenue to connect small and commercial farmers in real-time to share ideas, establish partnerships, and create networks[65].

The Kurima Mari Poultry app[66] reached roughly 10,000 poultry farmers in 2021. It included a feature to track the weight of chickens so farmers could receive early warning of potential problems via food conversion ratios. Training has been provided to 100 lead farmers and extension officers to train others on how to use the app. The poultry app not only educates farmers on farming practices and procedures through videos, podcasts, and manuals, but it also offers a digital marketplace where products can be bought and sold online[67].

The Ministry of Land, Agriculture, Fisheries, Water, and Rural Resettlement launched a farmer-focused digital knowledge resources platform in 2021 to promote the use of ICT in the farming sector with financial support from the European Union. The platform consisted of Zim Agrihub, Zim Agric extension, the In-Service training app, and a lead farmer training program[68].

The In-Service training app is designed to equip and empower the frontline extension workers throughout Zimbabwe with the latest and most up-to-date information on field crop production, horticulture production, livestock production, agribusiness, marketing, and cross-cutting issues such as gender and nutrition. The platform provides new or refresher extensionist knowledge to enhance the capacity to train farmers in the country effectively[69]. The app allows extension officers to capacitate themselves remotely, wherever they are based. The app is also open to smallholders, providing courses to sharpen their agricultural knowledge on selected value chains

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[63] http://www.zagp.org.zw/projects/view/beef
[64] https://www.welthungerhilfe.org/our-work//zimbabwe-digital-skills-to-revolutionise
[65] https://www.herald.co.zw/mobile-app-to-assist-beef-farmers/
[66] http://www.zagp.org.zw/projects/view/poultry
[67] https://dai-global-developments.com/articles/zimbabwe-agriculture-project-finds-ways-to-engagehttps://dai-global-developments.com/articles/zimbabwe-agriculture-project-finds-ways-to-engage-smallholder-farmers-despite-covid-19smallholder-farmers-despite-covid-19
[68] https://www.chronicle.co.zw/just-in-govt-launches-farmer-focused-digital-extension-app/
[69] http://zagp.org.zw/News/Details/42

to improve the production, productivity, and profitability of their farming enterprises. These courses are offered at a nominal fee.

Rural Wash Information Management System SMS Notification Response (RWIMS.SNR) is a mobile-to-web-based system undertaken by the government of Zimbabwe in partnership with UNICEF (United Nations International Children Emergency Fund). The RWIMS captures and stores water supply, sanitation, and hygiene (WASH) data in near real-time, providing quick access to the most recent national data on WASH infrastructure at all levels of governance. On the other hand, the RWIMS.SNR also integrates data from RapidPro (SMS messages) with geo-referenced data of facilities and villages in RWIMS. The SMS-based RWIMS interface enables communities to report changes in infrastructure functionality by texting messages directly to government functionaries. Information technology has improved the delivery of water and sanitation services and enabled real-time monitoring of WASH services for improved repair responses.[70]

In this context, the government of Zimbabwe launched the Smart Zimbabwe Master Plan 2030 in 2020, to guide all sectors, including agriculture, to improve productivity and competitiveness. The master plan provides forward-thinking guidelines to develop, deploy, and manage ICT across all sectors. According to the plan, the Internet of Things and drone technologies will be central to the future of agriculture [71].

The government, in its Strategic National Development 1 (NDS1) of 2020, has identified e-agriculture as a key factor in boosting agriculture and the national economy. The NDS1 aims to deliver internet to the village level by 2030 by extending the existing fiber optic backbone. The government's strategy is to increase internet access to 75 percent and the mobile penetration rate to 100 percent by 2025 (Mbiza 2021).

In a separate development, the government has adopted a policy to encourage infrastructure sharing to increase efficiency in the use of national resources and reduce duplication. It is now in the process of establishing a national data center to centralize information storage, management,

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[70] https://www.unicef.org/zimbabwe/stories/digital-dividend-information-technology-improves-deliveryhttps://www.unicef.org/zimbabwe/stories/digital-dividend-information-technology-improves-delivery-water-and-sanitation-serviceswater-and-sanitation-services
[71] https://www.herald.co.zw/ict-masterplan-to-guide-industrialisation/

and protection and to take advantage of cloud computing. Zimbabwe is also developing a national strategy and blueprint for the planning, design, and implementation of e-government infrastructure and services. Both digital government platforms and digital entrepreneurship are still emerging in Zimbabwe, but both have the potential to grow. The government of Zimbabwe currently offers the following e-services: Zimbabwe is, therefore, ready for upscaling digital technologies.

- The central government website connects and links citizens to a variety of e-services.
- Online reporting tool for gender-based violence
- E-registration for cooperatives
- Online application for technical studies
- Online application for secondary boarding school placements
- Mobile toll payments: pre-payment for tollgates via mobile money
- Vehicle licensing system for payment of road-user fees,
- E-payments for commercial and operator licenses
- E-learner driver's license testing
- E-licensing for import and export
- Automated customs processes for importation and exportation
- E-services for tax and revenue management
- Online payment for temporary import licenses
- Issuing e-visas
- Facilitate deed searching and company name searching
- Online recruitment tool for nurses
- Online liquor licensing system

The Digital Adaptation Readiness Index and its implications

To summarize the information presented thus far, an index was developed to track the readiness for digital upscaling in the Zambezi River Basin. The index has seven pillars identified from the theory of adoption as presented in Chapter 2: adopter characteristics, technology characteristics, business environment, policy, and regulatory environment, e-extension, essential infrastructure, prior digital penetration, and relevance of agriculture. Each of these pillars has indicators as follows (Table 17):

Table 17: Pillars and Indicators of Digital Adaptation Readiness

Pillars	Indicators	Measure	Effect of increase on readiness
	Adult male literacy	%	+
Adopter level	Youth literacy	%	+
	The gender gap in literacy	%	-
	Agricultural land per total	%	+
	Income per capita	US$	+
	Alternative income	3; more; 2 less; 1 negligible	-/+
Technology Characteristics	Cost of complementary technology	Affordability (internet, mobile bundles) %	+
Business environment	Cost of borrowing	Lending interest rate %	-
	Ease of doing business	index	+
	Openness to trade	Trade % of GDP	+
	Macroeconomic stability	Inflation %	+
Policy and regulatory environment	Public administration rating	1 Lowest 6 Highest	+
	Property rights and rule-based governance	1 Lowest 6 Highest	+
	Fiscal policy rating	1 Lowest 6 Highest	+
	Availability of digitization policy/strategy and laws	0, Absent, 1 In Progress, 2 Good Progress, 3 Yes	+
	Availability of climate adaptation plans/strategy	0 No; 1 Yes	+
E-extension	e-government	1 is poor; 100 is good	+
	e-participation	1 is poor; 100 is good	+
	Network readiness	1 is poor; 100 is good	+
Essential supportive infrastructure	Rural people with electricity	% of rural	+
	Mobile network coverage	% of population	+
Prior digital penetration	Mobile subscribers per 100	Individuals with subscriptions %	+
	Internet penetration per 100	Individuals using internet %	+
	Computers at home	Households with	+

Relevance of agriculture	Relevance of agriculture (e.g., share of agriculture to total GDP)	%	+/-
	Share of pop in primary agriculture	%	+
	Share of women population in primary agriculture	%	+

Source: Authors compilation.

Methodology for computing the baseline Digital Adaptation Readiness Index (DARI)

Normalization and weighting of indicators

Raw data and sub-indicators used to calculate composite indices and indicators were normalized for comparability (Nardo et al. 2005; Saisana and Tarantola 2002). Using the min-max normalization method, the individual indicators were re-scaled from 0 to 100, with 0 being the lowest (worst) performance and 100 the highest (best) possible score. The min-max normalization method is also widely used in other composite indicators such as the Gender Development Index, the Human Development Index (UNDP 2016), and the SDG Index (Sachs et al. 2016).

Explicit weighting (equal weighting, expert weighting), and statistical weighting (regression analysis, factor analysis) were some of the methods used in the development of composite indices and indicators (Nardo et al. 2005). Weighting impacts of the outcome of the composite indicator as well as the ranking of country performance and, therefore, requires important considerations. This report applies equal weighting, similar to previous research in other fields (Sachs et al. 2016; Schmidt-Traub et al. 2017).

The various indicators are then normalized to values between 0 and 100 to develop the Digital Adaptation Readiness Indicator. The normalization was implemented using the Min-Max principles in which the transformed value, for example, takes the form of Equation 1:

…………………………………………………(1)

This applies to values for indicators where more is good for digital upscaling. For indicators such as the costs of technology, more is bad. These indicators were transformed so that high values scored less, and the formula used is represented in Equation 2:

…………………………………………………(2)

Calculation of the Digital Adaptation Readiness Index

The composite indicator DARI for each country c is usually a simple linear weighted function of a total of normalised sub-indicators with weights can be calculated using Equation 3.

……………………………………………………(3)

Where is as defined in (1) or (2) as the case may be, and represents the value of the indicator i for the country c at the time t, represents the weight for the indicator i.

The calculation of the agriculture-related DARI for the Zambezi is based on the arithmetic mean aggregation method. This method has been widely applied in the calculation of composite indices such as the United Nations Human Development Index (UNDP 2016), Gender Development Index (UNDP 2016), baseline African Green Growth Index, Global Innovation Index (Cornell University et al. 2016), SDG indicators and dashboards for countries (Sachs et al. 2016; Schmidt-Traub et al. 2017). Other functional forms generally used for aggregation in calculating composite indices are the geometric average and the Leontief production function (Sachs et al. 2016). The arithmetic mean method is widely used compared to the other methods for its ease of application and communication. Therefore, the composite index was generated by averaging with the arithmetic mean, assuming equal weighting across indicators. Figure 5 shows the calculated overall composite index of digital adaptation readiness in the Zambezi River Basin countries.

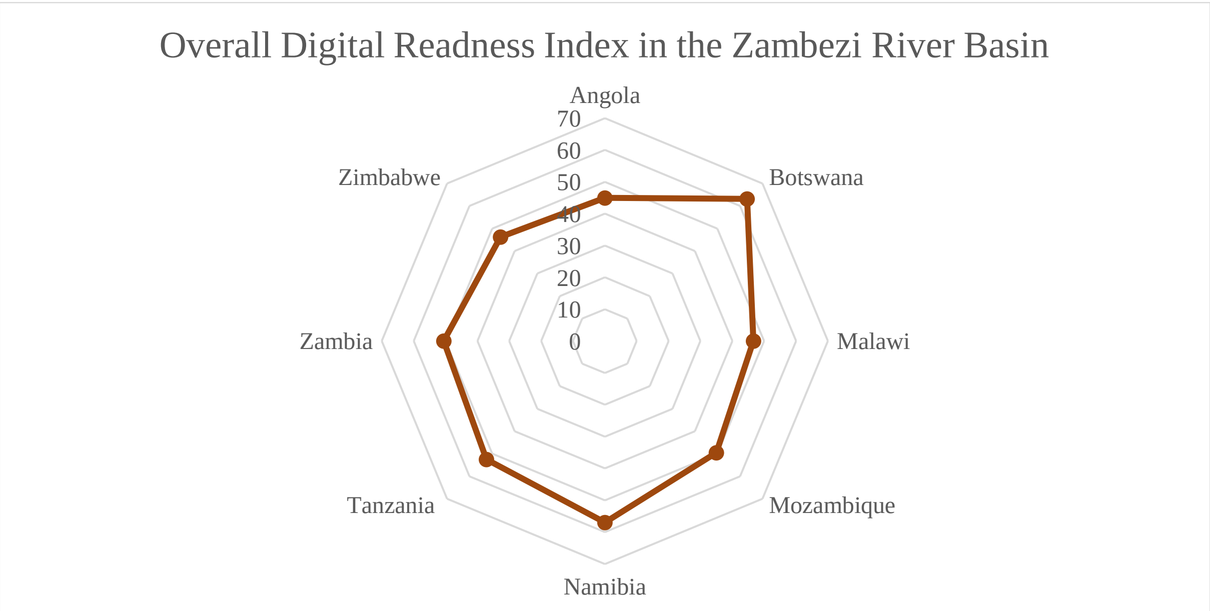

Figure 5: Overall digital adaptation readiness in the Zambezi River Basin countries

Source: Authors compilation with data cited from various sources.

It is clear from Figure 5 that in the constructed index of adaptation readiness, Botswana ranks highest, followed by Namibia and Tanzania. Angola is the least prepared for adaptation, followed by Zimbabwe, Malawi, and Mozambique. The implication is that the factors contributing to this outcome should be understood for each country to design appropriate interventions. Figure 6 presents the relative scores for each of the eight areas a country must improve to perform better on the readiness index.

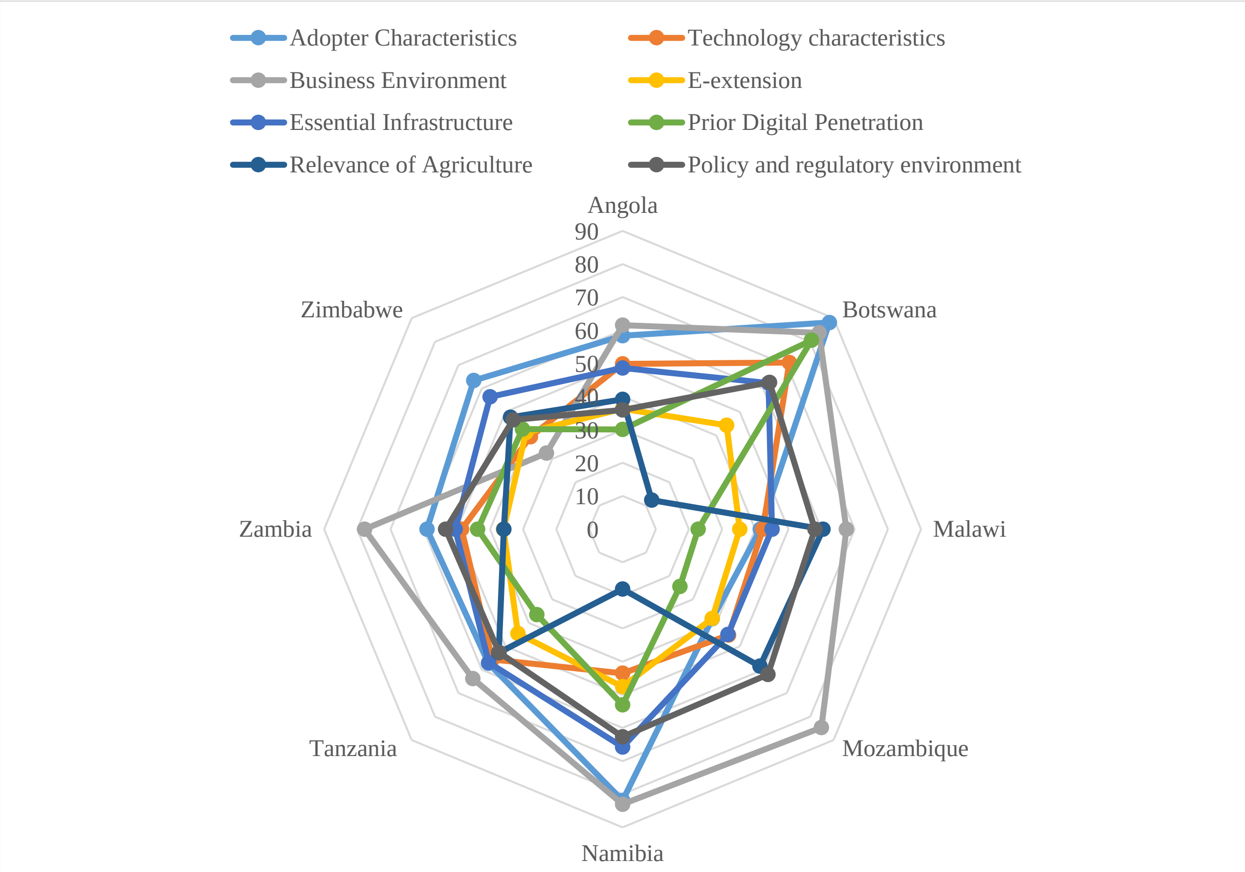

Figure 6: Major factors contributing to overall digital adaptation readiness in the Zambezi River Basin countries

Source: Authors compilation with data cited from various sources.

Figure 6 indicates that, in relative terms, Botswana ranks highest in readiness for digital adaptation. The factors that count in Botswana's favour include a good business environment, a good policy and regulatory environment, high prior digital penetration, better infrastructure, and a low cost of complementary technology. It is also clear that Botswana needs to improve on e-extension, and the low relevance of agriculture also threatens the likelihood that players may attach importance to digital technology in agriculture. On the other hand, Malawi has the lowest index. The factors that pull down Malawi's score on digital adaptation readiness include poor current digital penetration, a low ranking in e-extension, poor scores on essential complementary infrastructure, and low adopter characteristics. Figure 7 discusses these factors for each country.

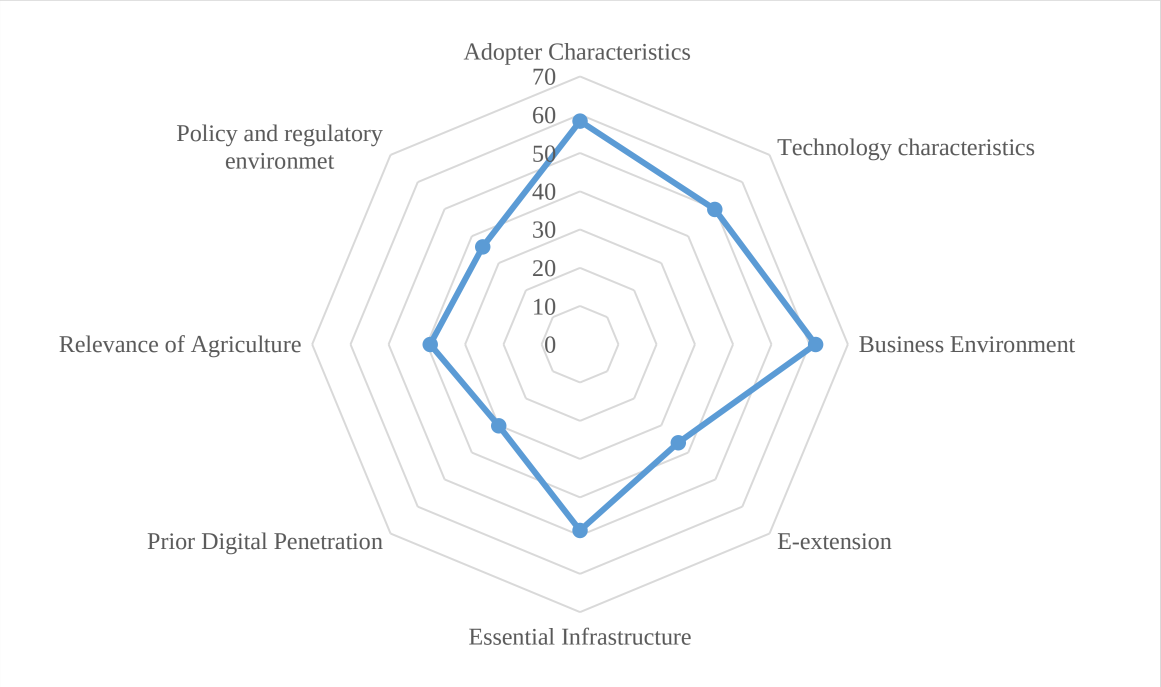

Figure 7: Factors contributing to digital adaptation readiness – Angola

Source: Authors compilation with data cited from various sources.

Angola is among the top three least-ready countries on the overall index of digital adaptation to climate change. In comparing the performance across the eight pillars to measure digital readiness in Angola, it is clear that the business environment, policy, and regulatory environment, adopter characteristics, and essential infrastructure contribute more to the overall index; however, prior digital penetration (mobile internet signal coverage, subscriptions, computer possession at home), e-extension (e-government, e-participation, and network readiness), and agriculture relevance are low (Figure 7). The business environment is also not at the same level as many of the other countries, though given that inflation is high (17.1%) and lending rates stand at 19.3 percent, it is only the third highest after Zimbabwe and Malawi.

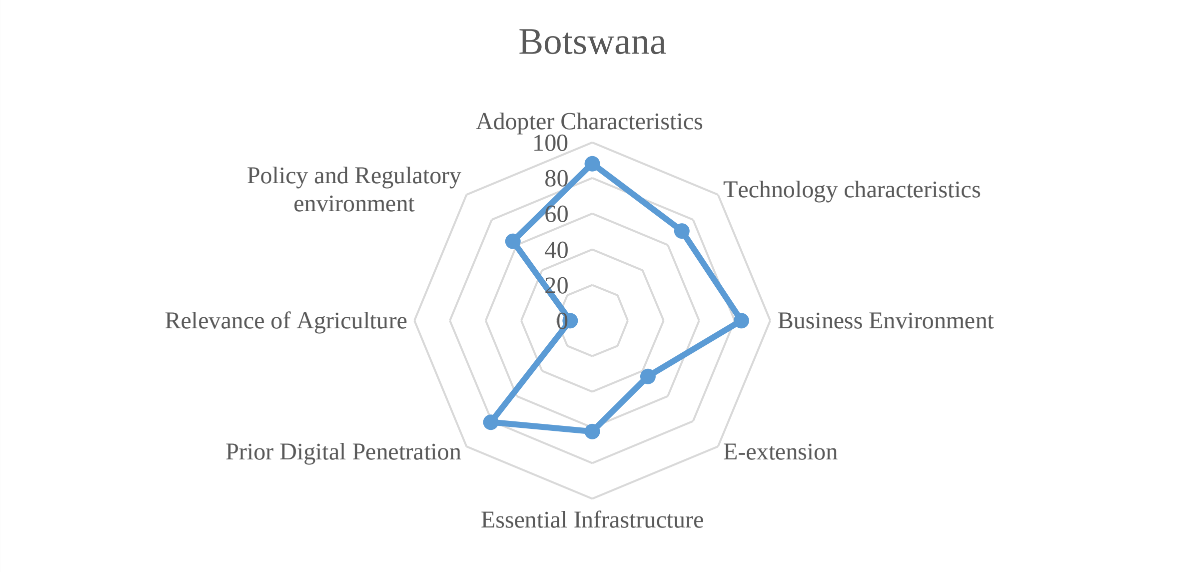

Figure 8: Factors contributing to digital adaptation readiness – Botswana

Source: Authors compilation with data cited from various sources.

Strong areas in Botswana, as depicted in Figure 8, including all pillars except the relevance of agriculture and e-extension. The literature discussed previously supports the strengths in adopter characteristics (education, income per capita, share of agricultural land, gender equality in education), prior digital penetration, and business environment. Botswana is among the most economically successful countries in Africa.

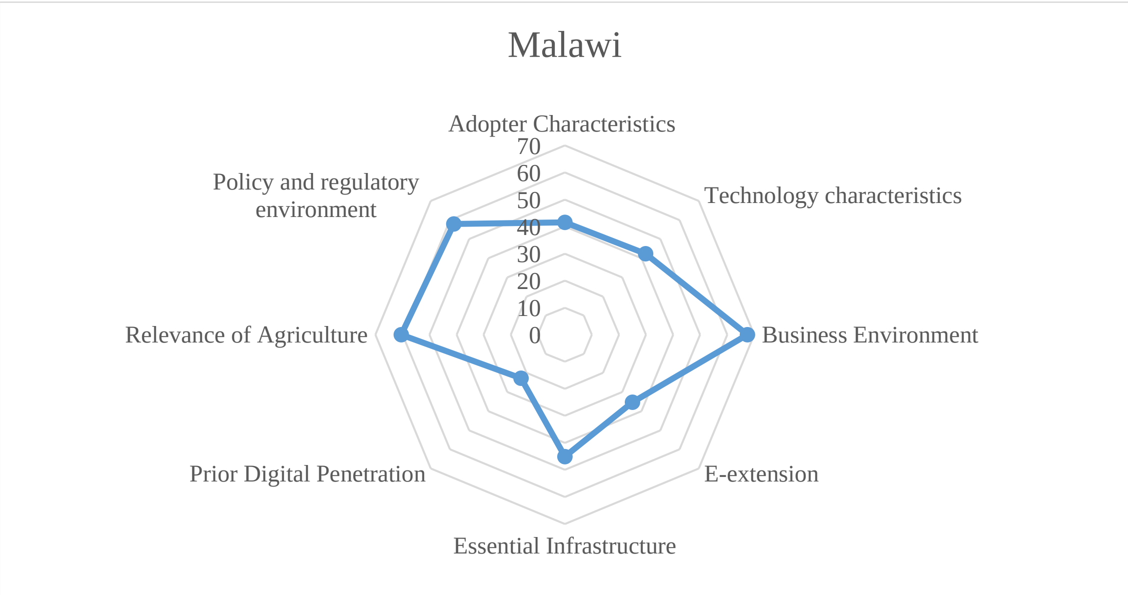

Figure 9: Factors contributing to digital adaptation readiness – Malawi

Source: Authors compilation with data cited from various sources.

Overall, Malawi ranks third from the bottom in terms of preparedness and readiness for digital upscaling. The most important factors contributing to readiness in Malawi include the business environment and the relevance of agriculture (Figure 9). Malawi scores poorly on prior digital penetration, the cost of complementary technology, adopter characteristics, and e-extension. These areas are critical and need investments to spur rapid and effective adoption of digital technology for climate adaptation.

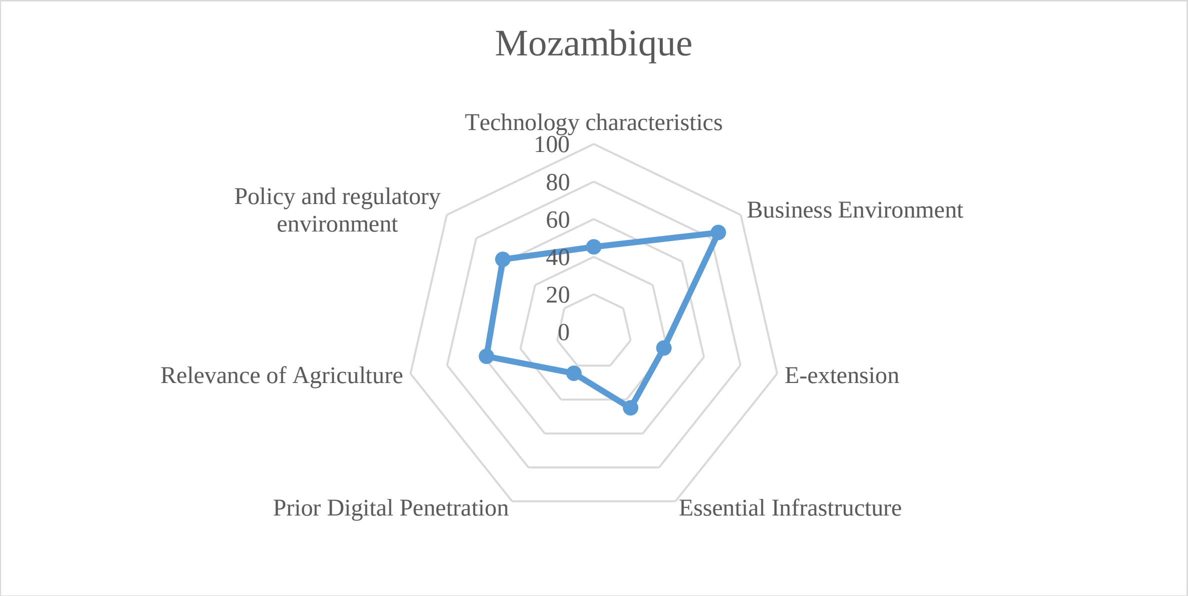

Figure 10: Factors contributing to digital adaptation readiness – Mozambique

Source: Authors compilation with data cited from various sources.

Mozambique is among the top four countries that are least ready for digital adaptation. When the digital readiness pillars are compared for Mozambique alone, it is clear that the business environment and the relevance of agriculture are contributing significantly to the overall readiness (Figure 10). It is important to note that Mozambique's inflation rate stands at just below 3.5 percent, the country is open to trade, and doing business is easy. However, prior digital penetration remains low, and human capital skills are among the region’s lowest.

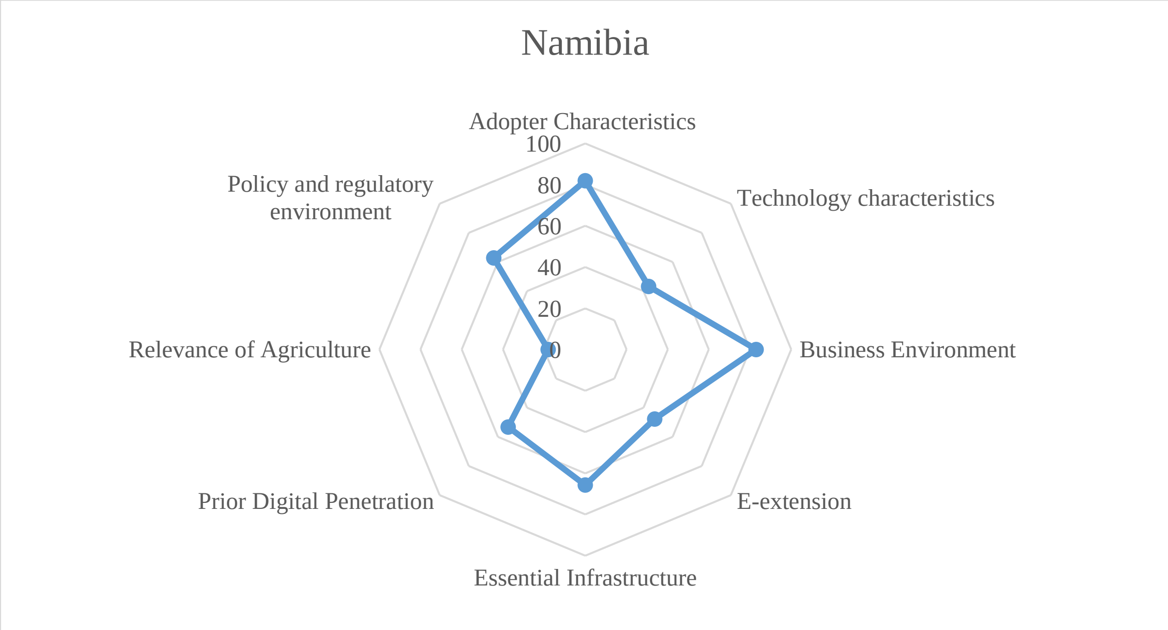

Figure 11: Factors contributing to digital adaptation readiness – Namibia

Source: Authors compilation with data cited from various sources.

Namibia ranks second on the digital adaptation readiness index. This is explained by the adopter characteristics, which are among the highest: the business environment is better than in most other countries; essential infrastructure is relatively available, and there is considerable prior digital penetration (Figure 11). However, the cost of essential complementary technology (mobile bundles) is high in Namibia. The e-extension ranking is low, and the relevance of agriculture to the overall economy and jobs remains lowest in Zambezi.

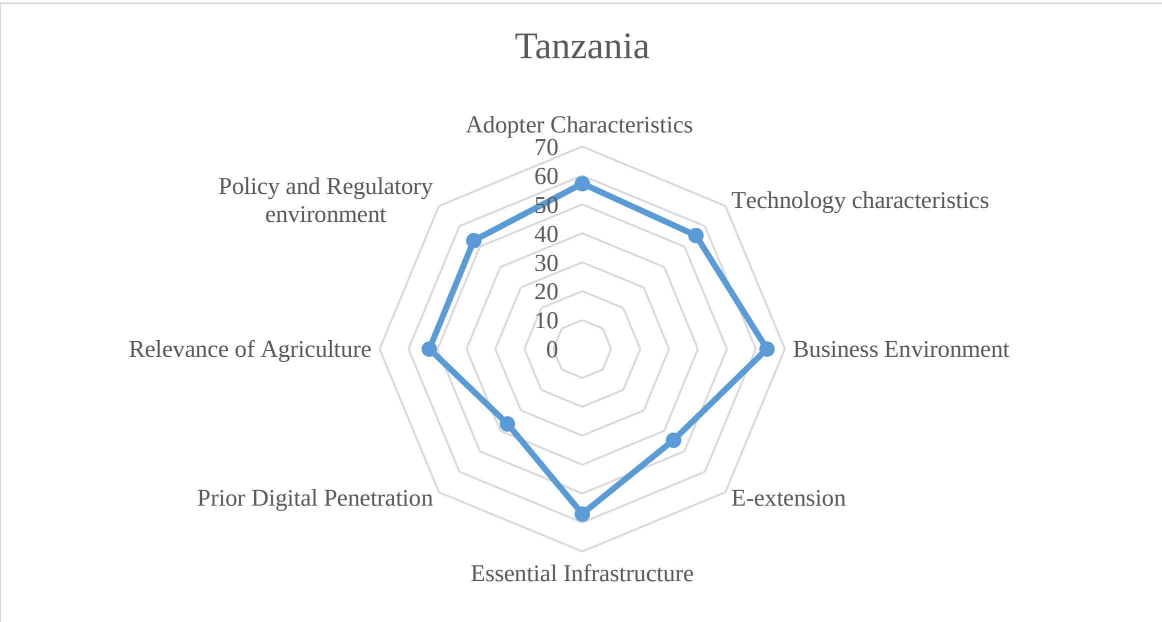

Figure 12: Factors contributing to digital adaptation readiness – Tanzania

Source: Authors compilation with data cited from various sources.

Tanzania ranks as the third-most ready country for digital adaptation in the Zambezi region. It has the essential infrastructure, the adopter characteristics are favorable, and the business environment is also good compared to Tanzania's own performance in the other seven pillars defining the overall index. However, low prior digital penetration and poor scores on e-extension contribute less to the overall index (Figure 12). Therefore, Tanzania would need to strengthen e-extension services (e-government, e-extension, and network readiness) as well as access to computing equipment and internet usage in general.

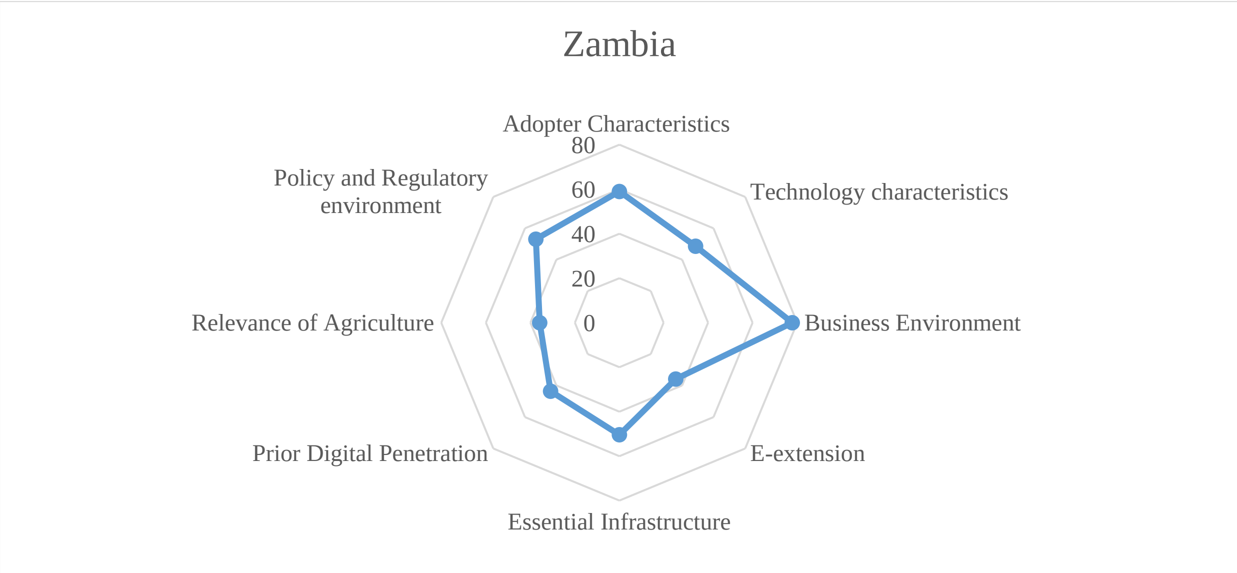

Figure 13: Factors contributing to digital adaptation readiness – Zambia

Source: Authors compilation with data cited from various sources.

A low-middle-income country, Zambia ranks as the 4th readiest country. While the low share of agriculture in GDP, poor prior digital penetration, and low e-extension scores pull the index downward, Zambia scores better on the business environment, adopter characteristics, and availability of essential infrastructure (Figure 13). Thus, areas requiring urgent investments include e-government, e-extension, and digital infrastructure to improve network and access.

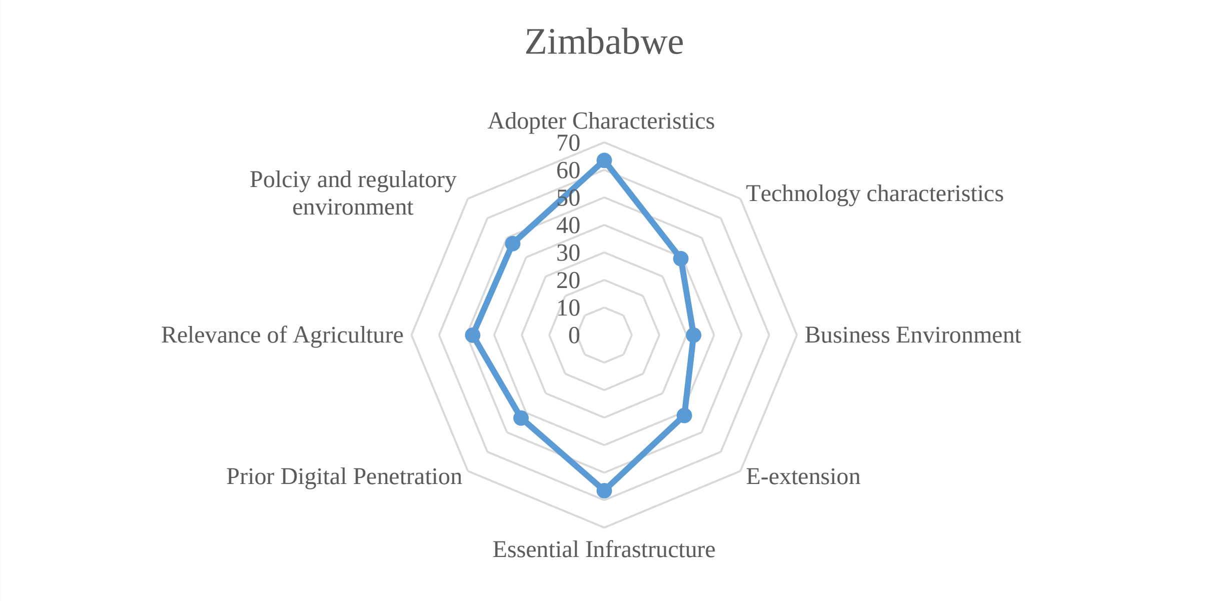

Figure 14: Factors contributing to digital adaptation readiness – Zimbabwe

Source: Authors compilation with data cited from various sources.

Finally, Zimbabwe's strengths are its fairly educated population (adopter characteristics), essential infrastructure availability, and high agriculture relevance to the economy (Figure 14). However, Zimbabwe needs to put an even greater focus on improving the business, policy, and regulatory environment (high inflation, high lending rates, no digitization policy), e-extension, reducing the costs of internet bundles, and improving the ownership of internet-receiving gadgets in rural areas.

Figure 15 confirms the importance and relevance of most pillars in explaining digital adaptation readiness. Many of the pillars correlate positively with the overall index of readiness for digital adaptation to climate change. Only agricultural relevance appears to suggest that those countries that depend less on agriculture have higher readiness levels. This also makes sense because the country's dependence on agriculture wanes with economic transformation and, hence, the availability of many factors that define the other six pillars.

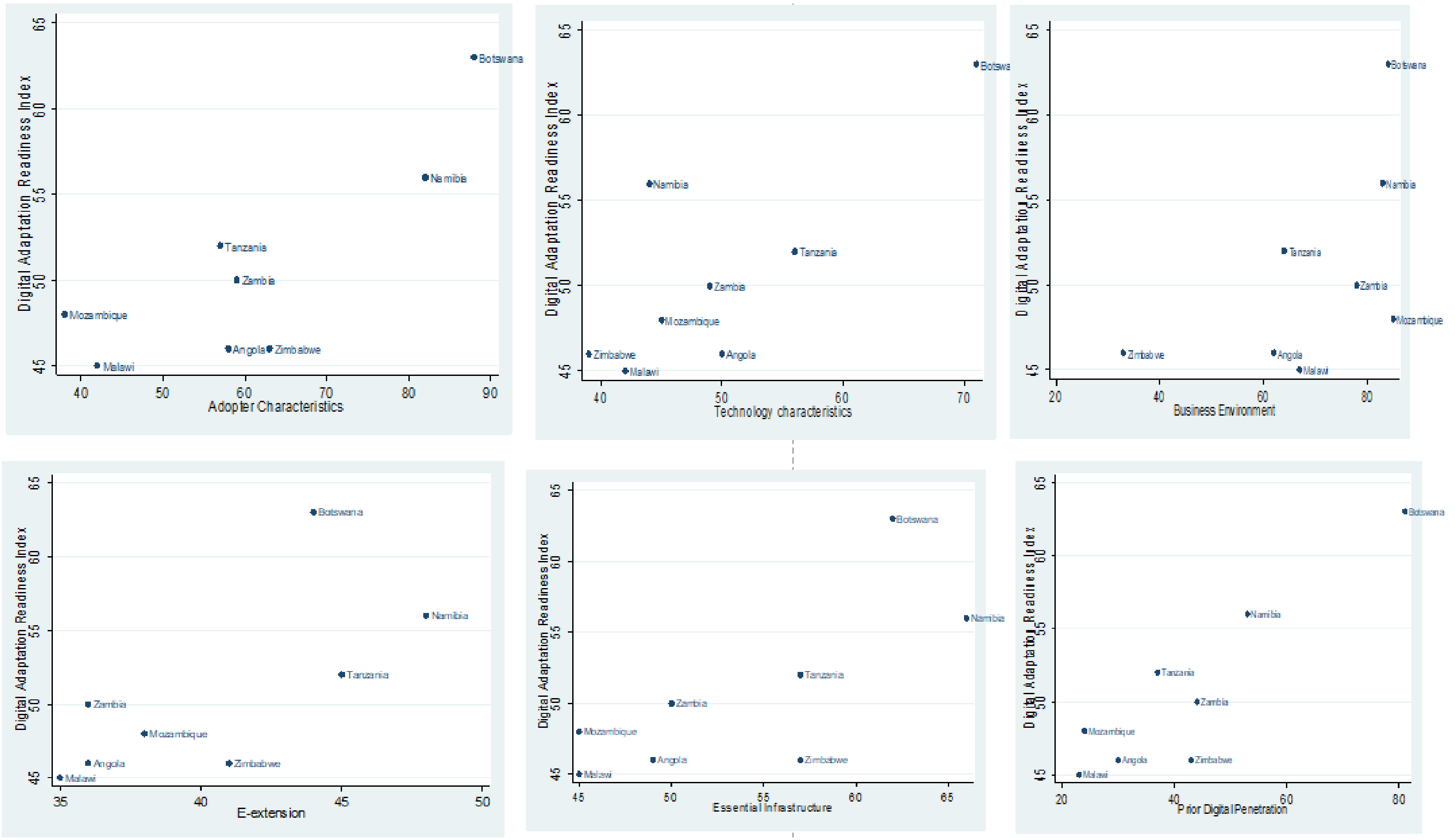

Figure 15: Correlations between pillars and the Digital Adaptation Index

Source: Authors compilation with data cited from various sources.

7. A summary of strengths, weaknesses, opportunities, and threats for digital adaptation in the Zambezi River Basin countries

Key messages

a. Initiatives for digital adaptation are available in the Zambezi riparian countries but are not sufficient.

b. Improvements in rural electricity, broadband network coverage, SIM registry procedures, skills development programs, and the policy environment will be necessary to tap the full potential of digital adaptation for smallholder farmers. Such improvements will likely lead to increased mobile phone uptake and greater demand for digital adaptation solutions among farmers and small-scale businesses.

c. Improvements in gender and inclusion are needed to reduce the gap in mobile phone ownership and use. This will increase the demand for digital technology by women and reduce the gap between men and women farmers.

d. Investments are needed in e-government to improve the efficiency of information flow within government and beyond government to farmers and small-scale businesses.

e. Investment is also needed in building ICT skills, remote sensing, and extension within the sphere of climate change adaptation and beyond.

The following section presents key country-level insights into the strengths, weaknesses, opportunities, and threats relevant to digital adaptation. These analyses highlight promising intervention and investment opportunities in infrastructure, policy, capacity building, and digital agriculture services.

Angola

Strengths

a. Compared to other Zambezi River Basin countries, Angola has a high Gross Domestic Product (GDP) per capita of over US$3,000, indicating a good market for businesses that focus on various services, including the provision of digital technology. By contrast, the GDPs per capita for Malawi, Mozambique, Tanzania, Zimbabwe, and

Zambia are low and stand at US$394, US$574, US$1,029, US$1,273, and US$1,307, respectively.

b. Mobile data costs are also relatively lower in Angola, and the country has the third lowest rates for internet (behind Botswana and Namibia) when expressed as a share of income per capita. This implies that upscaling digital technologies would be relatively easy, keeping other factors constant.

c. Angola has the region's fifth highest rate of rural electrification (16.2%), behind Botswana, Namibia, Tanzania, and Zimbabwe. This is important as digital technology upscaling relies on electricity availability.

d. The population covered by a mobile cellular network is also high (90%) a precondition for digital technology upscaling.

e. Angola has recently seen the launch of mobile money services, including the app Multicaixa Express, which was launched in 2019. After associating one or more debit cards in the app, the user can execute online payments, purchases, and transfers.

Weaknesses

a. Angola’s population growth rate is one of the highest (3.2%) and undermines progress in poverty eradication. Capital formation is undermined by consumption, which in turn threatens the country's ability to leverage technology for adaptation as priorities tilt toward short-term consumption goals.

b. Although mobile networks reach 90 percent of the population, it is erratic in rural areas and needs upgrading. Although the country tried to launch its own satellite, AngoSAT1, in 2017, it was lost in space, pushing the country backward in this area.

c. There is a high prevalence of malnourishment in Angola, and it ranks 1st in the Zambezi on the proportion of undernourished children. This implies that efforts toward strengthening digital technology may be seen as secondary, and public resources may concentrate on fighting such health ills.

d. The country also ranks lowest on the second E-government index in the Zambezi (after Malawi) and ranks lowest on network readiness measures. All these imply that upscaling digital technologies may be less smooth.

e. Since one challenge mentioned for accessing digital information is that information comes in languages unknown to users, Angola's considerable linguistic fractionalization (more than ten local languages spoken) pauses a problem for extension.

f. There is a wide gender gap in adult literacy, with male adult literacy rates being far higher (80%) than women's (53%). This dictates further gender gaps in digital technology usage.

Opportunities

a. The share of the population in rural areas has reduced to 33 percent, implying that there is less congestion in rural areas, thereby leading to more land availability for profitable capital-intensive farming.

b. There is good potential for using remote sensing data and real-time data for decision-making, especially once the satellite that is reported to be under development for Angola launches successfully.

c. Gender-inclusive design of digital adaptation services can help address the existing gender gap in adult literacy by creating solutions that specifically target women farmers, even if they are less educated.

d. The strong penetration of mobile banking and mobile networks is an opportunity for many companies in Angola to enable better access to modern farm inputs.

Threats

a. Angola is historically oil-dependent, and agriculture's contribution to GDP is below 10 percent. The limited government emphasis on agricultural development may also imply that the government may under-prioritize investments in climate adaptation digital technologies for agriculture.

b. Civil society in Angola has yet to grow, and domestic organizations face important obstacles to promoting change within the agriculture sector.

c. As is the case in all the Zambezi River Basin countries, the booming cybercrime industry has the potential to undermine trust in digital solutions.

d. The government’s over-reliance on crude oil sales to fund operations, coupled with price volatility, puts infrastructure investments and the sustainability of government-led digital agriculture initiatives at risk.

Botswana

Strengths

a. Compared to other Zambezi River Basin countries, the environment for private-sector engagement and entrepreneurship and the ease of doing business is good. Botswana (66 out of 100), Zambia (67), and Namibia (61) rank high on this indicator, implying that establishing digital technology businesses would be relatively easy.

b. Mobile data costs in Botswana are relatively cheap, and the country ranks number one (with the lowest ratio) in terms of the share of the mobile cellular basket in income per capita.

c. Botswana’s population growth is low (2.1% per annum), and this gives Botswana a better chance for economic growth.

d. Computer science teaching and human skills development in Botswana are relatively better than in many African countries and Zambezi, which is important for scaling digital technologies.

e. Generally, there is a high literacy rate in Botswana for both the youth (97%), males (86%), and females (87%), which would make the adoption of and extension through digital technology relatively easier.

f. Although Botswana's economy has stagnated following COVID-19, its incomes per capita are the highest in the Zambezi. Unlike many low-income countries, Botswana is considered an upper middle-income country. The high incomes favour the diffusion of technology.

g. Botswana has a good mobile network coverage, reaching more than 90 percent of the population.

h. Mobile money services available in Botswana include Smega by BTC, Orange Money by Orange Botswana, and Myzaka by Mascom. Mobile network operators have partnered with banks and fintech companies to provide these services, which can be extended to the non-banking population.

i. Botswana has fair electricity coverage in the rural areas (27%) compared to many of the Zambezi countries.

Weaknesses

a. Botswana's economic mainstay is its mineral resources, although Botswana also has a strong standing as a key livestock producer and exporter in the region. As agriculture contributes under 2.5 percent to the total GDP, efforts for climate adaptation through digital technology and focusing on agriculture may receive low emphasis.

b. Due to the country's arid and semi-arid nature, Botswana produces low levels of agricultural commodities and relies more on imports.

c. c. Botswana’s ranking on e-participation is the second lowest in the Zambezi region, implying low effectiveness of online services. These services are needed to propel interaction and information exchange between government and individuals and engage citizens in policy and decision-making.

d. Although Botswana performs well on computer possession at home (14.75% of households), this figure is still low, and many households need to acquire computers to take advantage of the many digital technologies available.

Opportunities

a. The low but wealthy population is an opportunity for digital technology upscaling for climate adaptation.

b. The scarcity of rainfall coupled with volatility in global supply chains due to wars, diseases, and weather-related events could indicate that precision agriculture has a chance for consideration. Therefore, the Chameleon sensors being piloted for efficient water use could be upscaled.

c. c. There is also high potential for using remote sensing data and real-time data for decision-making. The current government's efforts to launch a space program and its own satellite are a step toward this opportunity.

d. There is a strong penetration of mobile banking and mobile networks in Botswana. These may make it easier for digital technology to be scaled up.

e. Since droughts and riverine floods are major hazards to farmers, the government constantly produces early warning information, and encouraging farmers to invest in information-receiving technologies may be easier.

Threats

a. The smaller share of agriculture in the total GDP may reduce the government's emphasis on agricultural development, potentially raising concerns about the long-term sustainability of investments and interventions.

b. As digitization takes shape, cybercrime can potentially undermine trust in digital solutions, and more should be done in this area to protect internet users.

Malawi

Strengths

a. Of the Zambezi countries, Malawi's economy has a higher share of agriculture (23% of the GDP), implying that digital technologies for climate adaptation in agriculture are encouraged.

b. Cellular phone network coverage is about 86% of the population, providing the requisite infrastructure for upscaling digital technologies.

c. Although mobile subscriptions are low (47 per 100 inhabitants), they are increasing over time.

d. Mobile money services are available. There are two mobile phone operators (MPO) that operate mobile money transfer services. These are Airtel Malawi and Telekom Networks in Malawi (TNM), which offer the services Airtel Money and Mpamba, respectively.

e. Malawi boasts the presence of many international organizations working in collaboration with the government, including the World Bank, UN, AfDB, CGIAR, etc., which offers opportunities for collaboration in the delivery of digital technologies for climate adaptation.

f. Malawi has the highest share (80%) of women working in the agriculture sector and engaged in primary agriculture production in the Zambezi River Basin countries. Targeting investments in that area offers real possibilities for positively impacting women's livelihoods.

Weaknesses

a. Malawi has low literacy levels (69.8% for men and 55.2% for women) compared to the other Zambezi countries such as Botswana (above 86% for both men and women), Namibia (above 91% for both men and women), Zimbabwe, and Zambia (above 83% for both men and women).

b. While the other countries are making efforts to launch their own satellites, Malawi has no such plan yet.

c. Due to low literacy levels, there is a lack of basic ICT skills in Malawi, especially in rural areas.

d. Malawi's GDP per capita is the lowest in the Zambezi River Basin countries, and the persisting high population growth undermines its future prospects.

e. There is also considerable gender inequality in Malawi, emanating from cultural and historical factors. Gender gaps in education, especially, lead to technology adoption that tilts against women.

f. Compared to other Zambezi River Basin countries, the environment for private-sector engagement and entrepreneurship and the ease of doing business are yet to improve. The country ranks low in the Zambezi region on this indicator.

g. One key challenge that undermines the diffusion of digital technology in rural areas is mobile data costs. The country tops the list of the most expensive countries in Zambezi to access the internet. A mobile cellular basket, as a share of income per capita, stands at an overwhelming 22 percent, compared with Botswana (under 1.1%), Namibia (2%), and Angola (3.1%). To speed up the adaptation of digital technology, Malawi must address data costs.

h. Only 4.1 percent of the rural people in Malawi have access to electricity coverage, which means many of the technologies that rely on power cannot be adopted or widely used.

i. There is a poor mobile network in rural areas, making it hard to access SMS and the internet.

j. Malawi has few good roads in rural areas, although this is changing.

k. Cereal productivity remains below 2 tons per hectare while processing is in its infancy, leading to negative trade balances.

l. A high population growth rate of about 2.7 percent, one of the highest in the Zambezi, undermines real economic growth.

Opportunities

a. Although population growth is high, the huge rural population offers an opportunity for businesses and the upscaling of digital technologies.

b. Frequent dry spells, floods, and droughts could indicate that precision agriculture has a chance, and investments in more early warning systems may be welcome. Thus, there is potential for using remote sensing data and real-time data for decision-making.

c. Gender-inclusive design of digital adaptation services can help address the existing gender gap in mobile phone and internet usage by creating solutions that specifically target women farmers.

d. The strong penetration of mobile banking and mobile networks could enable better access to modern farm inputs. The agriculture input program being used for input distribution can be a vehicle for upscaling digital technologies.

e. The weather-based crop insurance programs offer opportunities for increased data demand.

Threats

a. The booming cybercrime industry has the potential to undermine trust in digital solutions.

b. The heavy reliance on donor support for the budget undermines the sustainability of government-led investments in climate adaptation.

Mozambique

Strengths

a. Agriculture contributes about 25 percent of the GDP in Mozambique, and the country has a huge chunk of the population (70.2%), deriving a living from primary agricultural production. This implies that efforts to improve the agriculture sector's ability to adapt to climate change will likely be favoured.

b. Despite the low income per capita, Mozambique boasts lower mobile data costs (US$2.86 per 1.5 GB of data) compared to US$11.22 in Zimbabwe, US$8.45 in Namibia, and US$6.7 in Malawi.

c. Mozambique has mobile money services, including M-Pesa, that allow people to transfer, deposit, and withdraw money, pay bills; and purchase airtime and electricity (vouchers). There is also the mKesh service by Carteira Movel, controlled by the main mobile phone operator in Mozambique.

d. International organizations are active in Mozambique and collaborate with the government, which offers possibilities for collaboration in the delivery of these digital technologies.

Weaknesses

a. Mozambique's ease of doing business is rather low compared to other Zambezi River Basin countries, although the environment for private-sector engagement and entrepreneurship is improving.

b. Mozambique also ranks substantially low on e-government indicators, implying that information diffusion from sources to users takes longer.

c. Although computer science teaching and human skills in universities have taken shape, the rural population lacks basic ICT skills.

d. Adult literacy rates are low in Mozambique, and there is a larger gender gap in literacy in favour of men, as the adult male literacy rate stands at 72.6 percent compared to women (just below 50%).

e. Economic growth rates for Mozambique (2.4% in 2021) are below those required to uplift the masses from poverty (at least 6%). The country is generally poor with a GDP per capita of under US$575, which is only better than that of Malawi.

f. Network coverage is poor in rural areas, undermining efforts toward the adoption of digital technologies.

g. Mozambique does own a satellite, and there are no significant known efforts to acquire one.

h. Only 4.9 percent of rural households have access to electricity, which is a challenge for the adoption of digital technologies that often require energy to be powered.

i. There is a wide gender gap in mobile phone ownership, with women registering mobile phone ownership as a percentage of the total at just 26 percent compared to 56 percent for men.

j. There is also a huge gender gap in actual usage of the internet, with female internet users as a percentage of total females standing at just 17 percent compared to that of men, which stands at 27 percent.

k. Mozambique's cereal productivity has remained below 2 tons per ha, which leads to imports of some agricultural commodities.

l. Although Mozambique has Portuguese as a lingua franca in urban centers, rural people speak local languages. Such linguistic fractionalization is often not catered for in information dissemination.

Opportunities

a. The huge rural population (63%) provides a potential market for the expansion of digital technology for climate adaptation.

b. The frequent floods in some parts of Mozambique, which also claim lives, can mean drought and early warning systems can be funded or popularized without debate.

c. c. There is also huge potential for using remote sensing data and real-time data for decision-making, especially in the context of much-needed weather-indexed crop insurance.

d. Gender-inclusive design of digital adaptation services can help address the existing gender gap in mobile phone and internet usage by creating solutions that specifically target women farmers.

Threats

a. The booming cybercrime industry has the potential to undermine trust in digital solutions.

b. The heavy reliance of the government budget on donor support risks infrastructure investments and the sustainability of government-led digital agriculture initiatives.

c. The emerging conflicts in Cabo Delgado can destabilize climate adaptation efforts as more efforts and attention are channelled to the war.

Namibia

Strengths

a. Compared to other Zambezi countries, the environment for private-sector engagement and entrepreneurship and the ease of doing business are good. Namibia (61 out of 100), Zambia (67), and Botswana (66) rank high on this indicator, implying that establishing digital technology businesses would be relatively easy.

b. Mobile data costs in Namibia are relatively cheap, and the country ranks number two (second lowest ratio) in terms of the share of the mobile cellular basket in income per capita.

c. Namibia's population growth is low (1.8% per annum), and this provides Namibia with a better chance of achieving real economic growth.

d. Computer science teaching and human skills development are relatively better than in many countries in Africa and the Zambezi, which is an important factor for upscaling digital technologies.

e. There is also a high literacy rate in general for both youth (95%), male (91.6%), and female (91.4%), which would make the adoption of extension through digital technology relatively easier.

f. Although Namibia's economy has stagnated following COVID-19, its income per capita is the second highest in the Zambezi. Unlike many low-income countries, Namibia is considered an upper middle-income country. The high income favours the diffusion of technology.

g. Namibia has good mobile network coverage, reaching over 90 percent of the population.

h. Mobile money services available in Namibia include MTC Money (MobiPay), which enables customers to buy airtime, pay for MTC services, make pre-payments for contract customers, pay for electricity, and use their phones as a digital wallet to pay for goods and services, withdraw and deposit cash, transfer money, and settle bills.

i. Namibia has good electricity coverage in rural areas (34.47%) compared to other Zambezi countries, and it ranks at the top.

Weaknesses

a. Namibia's main economic stay is mineral resources, although Namibia has also strengthened its standing as a key livestock producer and exporter. As agriculture contributes under 10 percent to the total GDP, efforts for climate adaptation through digital technology and focusing on agriculture may receive low emphasis.

b. Owing to the arid and semi-arid nature of the country, Namibia produces low levels of agricultural commodities and relies more on imports.

c. Although Namibia performs well on computer possession at home (16.53% of households own computers at home), this figure is still low, and many households need to acquire computers to take advantage of many available digital technologies.

Opportunities

a. The low but wealthy population is an opportunity for upscaling digital technology for climate adaptation.

b. The scarcity of rainfall and volatility in global supply chains due to wars, diseases, and other weather-related events can mean precision agriculture may be considered.

c. There is also huge potential for using remote sensing data and real-time data for decision-making.

d. Mobile banking and mobile networks are highly prevalent in Namibia, which may facilitate scaling digital technology.

e. Since droughts and riverine floods are major hazards for farmers, and the government constantly produces drought and flood-related early warning information, encouraging farmers to invest in information-receiving technologies may be easier.

Threats

a. It is possible that the smaller share of agriculture in the total GDP may reduce the government's emphasis on agricultural development, potentially raising concerns about the long-term sustainability of such investments and interventions.

b. As digitization takes shape, cybercrime has the potential to undermine trust in digital solutions, and more should be done in this area to protect users of the internet.

Tanzania

Strengths

a. Among the Zambezi River Basin countries, Tanzania has a higher share of agricultural GDP (26.6%), implying that digital technologies for adaptation in agriculture would be welcome.

b. Network coverage for mobile phones applies to about 95 percent of the population, providing the requisite infrastructure for upscaling digital technologies.

c. Mobile subscriptions are high (86 per 100 inhabitants) and increasing over time.

d. Mobile money services are available. Six mobile operators offer mobile money services in Tanzania: Vodacom with M-Pesa (39%), Tigo with Tigo Pesa (30%), Airtel with Airtel Money (20%), Halotel with Halopesa (7%), TTCL (3%), and Zantel with Ezy Pesa (1%). Together, they provide the necessary preconditions and the opportunity to introduce digital technology to the non-banking population.

e. Tanzania boasts the presence of many international organizations working in collaboration with the government, including the World Bank, UN, AfDB, CGIAR, etc., which presents opportunities for collaboration in the delivery of digital technologies for climate adaptation.

f. Tanzania has a significant share (67%) of women working in the agriculture sector and engaged in primary agriculture production. Targeting investments in that area offers real possibilities for positively impacting women's livelihoods.

g. Tanzania’s performance on e-participation is commendable and is the highest among Zambezi River Basin countries, implying that the drive towards digitization and information sharing is already present in Tanzania.

h. Tanzania’s economic growth has averaged above 6 percent and is the highest in the Zambezi River Basin countries.

i. Almost 19 percent of Tanzania’s rural population has access to electricity, which, although low, is higher compared to other Zambezi countries.

Weaknesses

a. Nevertheless, Tanzania has a low per capita income.

b. Tanzania does not possess a satellite of its own, although this is characteristic of most Zambezi countries.

c. Although literacy levels have improved in Tanzania, there is considerable gender inequality in adult education among women. These gender gaps in education lead to technology adoption disadvantaging women.

d. Compared to other Zambezi River Basin countries, the environment for private-sector engagement and entrepreneurship and the ease of doing business are yet to improve. The country ranks low in the Zambezi on this indicator, with a score of 54 in 2019 (the best score is 100).

e. Cereal productivity remains below 2 tons per hectare while processing is in its infancy, leading to negative trade balances.

f. The population growth rate is about 2.9 percent, one of the highest in Zambezi, and this could undermine future real economic growth.

Opportunities

a. Although population growth is high, the huge rural population (58.1%) is an opportunity for business and upscaling digital technologies.

b. Gender-inclusive design of digital adaptation services can help address the existing gender gap in mobile phone and internet usage by creating solutions that specifically target women farmers.

c. Strong mobile banking and mobile network penetration could enable better access to modern farm inputs.

d. The government planned weather-based crop insurance programs would result in increased data demand.

Threats

a. The booming cybercrime industry has the potential to undermine trust in digital solutions.

b. The national budget's heavy reliance on donor support (20%) undermines the sustainability of government-led investments in climate adaptation.

Zambia

Strengths

a. As a low-middle-income country, Zambia's ranking (67 out of 100 in 2019) on the ease of doing business index is good relative to the scores of the rest of the Zambezi region. This implies that businesses, including those in digital technology, can easily be established.

b. Mobile data costs are also among the lowest in Zambezi, with 1.5 GB of data costing just under US$2.82, compared to an overwhelming US$11.22 in Zimbabwe, US$8.45 in Namibia, and US$6.7 in Malawi.

c. Adult and youth literacy levels are significantly high in Zambia (over 83%), although there are some disparities in terms of age and gender.

d. Zambia is considered a low-middle-income country and, therefore, a growing market for digital technology, especially because Zambia's mobile network infrastructure reaches over 86 percent of the population.

e. Mobile money services are also significantly present in Zambia. Airtel, MTN, or Zamtel customers who subscribe to these services can move money to or receive money from other subscribers who have digital money accounts on the same platform using secure text messages.

f. International organizations work closely in collaboration with the government in Zambia.

g. There is significant penetration of electricity among the rural population (14%), compared to Malawi (4%) and Mozambique (4.9%).

Weaknesses

a. There is a significant and growing gender gap in mobile phone ownership between men and women, largely favoring men. Only 12 percent of the total number of women use the internet, compared to 17.3 percent of men. These gender disparities can lead to biased adoption of digital technology for climate adaptation. This implies that most of the population would find it difficult to interpret digital information, which may be the key to its adaptation. This poses a key impediment to digital climate change adaptation and mitigation.

b. Zambia's cereal productivity remains below the SADC target of 2 tons per hectare, leading to unnecessary food imports and putting pressure on foreign exchange and the balance of payments.

c. <u>Poor mobile networks in rural areas:</u> A higher percentage of the rural population does not have access to mobile networks, which is potentially one of the key weaknesses for digital adaptation against climate change, particularly among the rural population.

d. <u>Poor electricity coverage:</u> Most of Zambia's rural areas have no access to electricity, which could negatively affect efforts aimed at digital adaptation.

e. <u>Poor road network in rural areas:</u> Road infrastructure is vital for investment in various sectors, including the digital subsector. However, in Zambia, especially in rural areas, roads are in very poor condition, which negatively affects the provision of various services that are essential for the development of the agriculture sector by both the private and public sectors.

f. <u>Fewer mobile service providers:</u> In Zambia, there are only three main mobile service providers, which is quite low compared to other regional countries, such as South Africa, which has five mobile service providers. The low number of mobile service providers implies less competition among themselves, resulting in poor service delivery to the detriment of end-users.

g. <u>Linguistic fractionalization:</u> Despite having seven official vernacular languages, Zambia has at least 72 dialects, creating a challenge for digital service providers to develop products that accommodate all the local dialects. Ultimately, this has a negative impact on adopting digital technologies for climate change adaptation and mitigation.

h. Fragmented extension services: Extension services are key to developing the agriculture sector. In Zambia, both the public and private sectors provide extension services; however, they are highly fragmented due to low coordination between the two sectors. This has the potential to affect digital adoption negatively.

Opportunities

a. Zambia's economy benefits from huge copper deposits, which could potentially obscure the importance of agriculture for economic development and livelihood reliance in the face of climate change.

b. The significant rural population (56%), coupled with the vibrant mineral sector, means that Zambia has a potentially larger market for digital technology businesses to establish.

c. There is potential for the use of remote-sensing data and real-time data for decision-making, especially in Kariba dam operations.

d. Gender-inclusive design of digital adaptation services can help address the existing gender gap in mobile phone and internet usage by creating solutions that specifically target women farmers.

e. Over the past decade, Zambia has been experiencing droughts throughout the production season, which has contributed to low production levels. However, this in turn creates a great opportunity for the introduction of advanced irrigation approaches, such as precision irrigation, and could potentially help farmers adapt to consistent droughts.

f. Use of remote-sensing data and real-time data for decision-making: Zambia has continued to invest in equipment within various ministries, which could be utilized to generate remote-sensing data and inform decision-making for enhanced effectiveness and impact.

Threats

a. Limited government emphasis on agricultural development in favour of the mineral sector potentially raises concerns about the long-term sustainability of agricultural investments and interventions.

b. The booming cybercrime industry has the potential to undermine trust in digital solutions.

c. The government's heavy reliance on donors for budgetary support puts infrastructure investments and the sustainability of government-led digital agriculture initiatives at risk.

Zimbabwe

Strengths

a. Adult and youth literacy levels are very high in Zimbabwe (over 88%), and there are very small disparities in terms of age and gender.

b. Zimbabwe's mobile network infrastructure reaches over 93 percent of the population, implying that this precondition for the diffusion of digital technology is favourable.

c. There is also a significant presence of mobile money services in Zimbabwe. Platforms such as Ecocash, Onemoney, and Telecash are run by the three mobile network operators (MNOs), Econet, NetOne, and Telecel, and not by conventional banks. Customers who subscribe to these services can move money to or receive money from other subscribers who have digital money accounts on the same platform using secure text messages.

d. There is a significant penetration of electricity in the rural population (20%), compared to countries such as Malawi (4%) and Mozambique (4.9%).

Weaknesses

a. Mobile data costs are also among the highest in Zambezi, with 1.5 GB of data costing US$11.22 in Zimbabwe, compared to US$42.82 in Zambia, US$8.45 in Namibia, and US$6.7 in Malawi. The high cost of data and bandwidth has made data beyond the reach of many Zimbabweans.

b. As a low-income country, Zimbabwe's ranking on ease of doing business (54 out of 100 in 2019) is relatively low compared to the rest of the Zambezi. This implies that businesses, including those in digital technology, may not be easily set up.

c. Although 20% of rural Zimbabweans have access to electricity, most rural areas have no access to electricity. There is inadequate commercial electricity, the national power grid does not cover the entire country, and the supply is erratic. As a result, a significant portion of the population is dependent on expensive alternative power sources. The electricity shortage has adversely affected the development and use of ICT.

d. Roads in rural areas are in a very poor state, affecting both the private and public sectors negatively, and the provision of various services is essential for the development of the agriculture sector.

e. <u>ICT skills:</u> The shortage of ICT-skilled manpower is hampering the roll-out of ICT programs. This shortage has a knock-on effect on digital literacy, which drives the uptake and usage of ICT services.

f. <u>Low digital literacy level:</u> The education curriculum does not include ICT; therefore, the level of digital literacy at the grassroots level is very low and insufficient to stimulate service uptake and usage, especially in rural areas.

Opportunities

a. The significant rural population (68%) coupled with the vibrant mineral sector means that Zimbabwe has a potentially larger market for businesses in digital technology to set up.

b. There is potential for using remote-sensing and real-time data for decision-making, especially in Kariba dam operations.

c. Over the past decade, the country has been experiencing erratic rainfall throughout the production season, contributing to low production levels. However, this inturn creates a great opportunity for the introduction of advanced irrigation approaches, such as precision irrigation, and could potentially help farmers adapt to consistent droughts.

d. Zimbabwe has continued to invest in equipment within various ministries that could be utilized to generate remote sensing data and inform decision-making for enhanced effectiveness and impact.

Threats

a. Limited government emphasis on agricultural development in favour of the mineral sector potentially raises concerns about the long-term sustainability of agricultural investments and interventions.

b. The booming cybercrime industry has the potential to undermine trust in digital solutions.

8. Main findings and key implications for intervention

Although there are significant variations across countries, these findings apply to varying degrees across the Zambezi River Basin.

a. Droughts, dry spells, rising temperatures, floods, and changing seasons are becoming more frequent, and the future will be characterized by an increase in these climate risks across the Zambezi River Basin countries. The levels of significance for each of these risks vary by country. Floods, for example, are more frequent and deadly in Mozambique, Malawi, and Zimbabwe, while dry spells, rising temperatures, and droughts are more frequent in Namibia and Botswana.
b. In all the Zambezi riparian countries, significant efforts, including adaptation initiatives and legislative reforms, are underway in an attempt to build basin resilience to climate change.
c. Climate adaptation through digital technology is not prevalent, but in each Zambezi country, some developments could be considered steps towards using digital technology for better climate adaptation.
d. The most common digital adaptation technologies vary in popularity and extent of usage from country to country, but weather-indexed crop insurance, introduced in Zambia and Malawi, is drawing attention in Tanzania and Angola as well. The use of the Internet of Things (IoT) to improve farm management is emerging in Botswana, Namibia, and Angola through specific initiatives, sometimes sponsored by external agencies.
e. Digital technologies are also being used across various stages of the value chain (production, processing, and marketing), and where this is the case, an improvement in efficiency has resulted.
f. The most frequently mentioned digital technologies used or potentially used for climate adaptation include radios, satellite televisions, mobile phones, drones, computers, mobile applications, and data-enabled insurance services.

Constraints

The major constraints that undermine the adoption and use of digital technologies across the Zambezi River Basin countries are related to availability, access, affordability, and skills for utilization, as follows:

a. Many countries have low ICT skills, which inturn undermines the adoption and utilization of digital technology.
b. Energy is important for the operationalization of digital technology, but rural areas generally lack electricity in almost 80 percent of the Zambezi River Basin countries.
c. Mobile infrastructure needs strengthening, as the current state of the infrastructure leaves out significant portions of the rural population. Network signals are often poor in rural areas.
d. There is also a high cost of data across the basin in general, with some countries, such as Malawi and Zimbabwe, experiencing the highest data costs compared to the rest.
e. Poor or weak early warning systems often undermine information generation which calls for significant investments in automatic weather stations and other enabling equipment.
f. Information sharing and coordination mechanisms are weak across the Zambezi countries, although many of the issues of interest are transboundary in nature.
g. There is limited fixed broadband infrastructure and penetration, limited LTE (Long Term Evolution) coverage outside urban areas, limited competition, and limited infrastructure sharing.
h. Macroeconomic conditions (especially inflation and a lack of foreign exchange) also undermine the growth prospects for the use of digital technology in adaptation.
i. Some digital tools are simply unavailable or costly, such as sensors, drones, and satellites.
j. There is a lack of access to digital technologies for the rural poor, particularly women.
k. The absence of national policies or legal frameworks to support digital innovation expansion[72]. Malawi has no stand-alone policy or strategy on the digital economy and e-commerce development agenda[73]. Developing a national digital innovation strategy is vital for building favourable policies and regulations to protect digital entrepreneurs and positioning funding toward digital innovations.
l. There is a gender gap in the digital sector, where fewer women than men are involved in digital solution management for the market.

[72] https://annualreport.uncdf.org/article/7342/industry-players-identify-barriers-to-innovation-in-malawi
[73] https://unctad.org/news/tanzania-malawi-prepare-reap-benefits-digital-economy

Opportunities space

a. The large population in the Zambezi is an opportunity for digital technology upscaling for climate adaptation.

b. The scarcity of rainfall coupled with volatility in global supply chains due to wars, diseases, and other weather-related events could mean that precision agriculture could be considered, and Chameleon sensors being piloted for efficient water use can be upscaled.

c. c. Remote sensing and real-time data have huge potential for decision-making. The current government's efforts to launch a space program and establish its own satellite are a positive step.

d. Mobile banking and mobile networks are strongly penetrating in the Zambezi River Basin countries. These may make it easier for digital technology to be scaled up.

e. Since droughts and riverine floods are major hazards to farmers, and as the government is constantly producing drought early warning information, it may be easier to encourage farmers to invest in information-receiving technologies.

f. Mobile phone-based information dissemination services for smallholders can have a positive impact.

g. Another opportunity for investment lies in building regional hubs for cross-country learning and promoting youth entrepreneurship based on the experiences of more digitally advanced countries.

h. The fast-developing ICT infrastructure is providing an opportunity for youth in most Zambezi River Basin countries.

i. Partnering with private-sector stakeholders would provide an opportunity to extend information and services to farmers and close the last-mile gap in extension service.

j. Scaling digital solutions among the Zambezi River Basin countries is a promising way forward to use the region’s heterogeneity of digital development and convert it into an opportunity for some countries.

k. Another key opportunity lies in the promotion and use of open standards, open data, open source, and open innovation processes.

l. Public-private collaborations, supporting the design of new tools and services, providing evidence of digital technologies used by smallholders, and observing any unintended consequences, especially for smallholders on the edge of the digital divide.

Recommendations

a. Network coverage in rural areas is constrained by the lack of infrastructure, including roads and electricity. In most rural areas, there is no electricity access for charging mobile phones or computers; therefore, it is important to invest in alternative energy sources such as solar power.
b. It is also important to expand telecommunication infrastructure, such as towers for internet and mobile network coverage.
c. Enhancing digital skills through education programs in schools and public institutions (e.g., increasing human capacity to generate and use data).
d. Engage and incentivize the private sector to reduce the cost of internet and mobile phone services.
e. Constraints such as local languages not being catered to in SMS messaging significantly limit information. Therefore, information dissemination using local languages is critical.
f. Women in rural areas are less likely to own mobile phones. However, they are the ones who are more engaged in agricultural activities. The gender gap in mobile phone ownership is wider in rural areas; therefore, expanding access to mobile phones and the use of mobile phones to more women will contribute to the expansion of digital technologies in climate change adaptation.
g. Lowering or removing sector-specific taxation for ICT
h. Strengthening competence for digital skills and entrepreneurship through investment in infrastructure and coordination between the government, academia, and private sector.[74]

[74] https://www.worldbank.org/en/country/malawi/publication/leveraging-malawi-s-existing-digital-infrastructure-to-boost-economic-growth

i. According to the Malawi Economic Monitor (MEM)[75] the pathways that help the government improve the enabling environment for the digital economy include rolling out digital financial services to rural areas by developing broadband and financial infrastructure and increasing the affordability of smart devices and services. In addition, new public-private partnerships can help drive digital transformation.
j. Removal of all excise duties on feature- and entry-level smartphones is important.
k. Reviewing of universal service levies and funds that are not meeting objectives.
l. Reviewing the negative impact of premium secondary taxes on the cost of services and direct existing taxes to free public Wi-Fi to offer complimentary access to price-sensitive users.
m. Leveraging private investments for servicing public sector connectivity in under-served areas by creating incentives through smart procurement and offering anchor tenancies based on aggregating public sector demand can reduce significant capital expenditure by the government.
n. Providing incentives for infrastructure sharing and wholesale regulation of facilities and bandwidth to reduce the input costs for service providers and private networks. However, this requires a fair and competitive environment.
o. Opening up government data to the public in a manipulable format could spur its use in the development of apps for commercial and public service purposes.
p. Stimulating local content development by allocating the necessary budget to support the development of apps and local content, particularly in local languages.

The findings from stakeholder consultation and literature reviews, as well as analysis of secondary data, show that addressing the various constraints and weaknesses while capitalizing on strengths at the country-specific and regional level would be extremely useful in driving technology adoption for climate adaptation and mitigation in the Zambezi River Basin. Annex 1 summarizes the interventions that may be considered in each country to resolve some of the constraints that undermine digital adoption and upscaling for climate adaptation. In general, these range from those seeking to improve infrastructure that supports digital technology (e.g., electricity, towers, weather stations, software for remote sensing, mobile phones, computers, etc.), to the regulatory and policy environment (e.g., e-government, institutions), the ease of

[75] https://moderndiplomacy.eu/2021/06/27/affordable-ict-for-youth-women-and-rural-communities-in-malawi/

doing business, as well enhancing adopter attributes (e.g., skills development, use of cooperatives), and technology characteristics (e.g., costs, affordability, accessibility, user-friendliness for all genders, profitability). The details are given in Annex1.

9. Conclusion

While this study has not exhausted all the issues that undermine climate adaptation in the Zambezi region, it provides key insights into the nature of climate risks facing Zambezi River Basin countries, the adaptation efforts that are underway, and the constraints that challenge the upscaling of digital tools for climate adaptation. The set of interventions proposed at the end of this report is not exhaustive. Still, it is considered relevant and perhaps more important for the respective countries, given the nature of the challenges they face, and the threats, strengths, opportunities, and weaknesses observed. The research approach taken, in which both stakeholder consultations and secondary data analysis are key elements, confers advantages that none of the methods used alone would provide. While the research results are useful for the purposes outlined herein, future research should consider adding a further layer to the approach herein by adding more in-depth studies in rural areas sampled purposefully to track various heterogeneities within in-country locations and cultures, which of course would cost more time and resources for a diverse region such as the Zambezi River Basin with its eight riparian countries.

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Annex 1: Interventions

Based on the findings of the feasibility assessment, context-specific interventions have been identified to leverage different digital and data-enabled climate-smart agriculture technology interventions to accelerate climate adaptation in the region. They include:

Angola

Interventions areas	Knowledge and analytics	Investment in middleware infrastructure	Capacity building
Development of digital climate services	• Strengthen national adaptation plans by mainstreaming digital technology.	• Develop a national integrated database management system for the collection, analysis and dissemination of climate data to avoid confusion in messaging. • Finalize the development and launch of the Angola satellite, which is in progress.	• Provide training and capacity building for national early warning systems to improve coordination and knowledge sharing on disaster preparedness and implement other management practices. • Provide training to the Angola Meteorological Department to facilitate precise climate and weather predictions for Angola.
Facilitating access to advisory services and markets through digitalization	• Develop climate science communication mechanisms that use all local languages in Angola and integrate these in mobile applications for climate information dissemination. Currently, some of the languages are not covered, and there are more than 10.	• Create farmer information centers equipped with solar TV and radio access in all districts to ease access to information. • Promote business models that target rural women farmers with low-cost smartphones.	• Train media personnel, especially women farmers, on the interpretation of climate and weather information from weather stations. This can reduce the effect of gender disparities in education in Angola.
Promotion of climate-smart innovations and technologies	• Undertake a feasibility study on the uses, policies and regulatory issues of digital agriculture with a focus on climate adaptation and resilience for food and nutrition security in the region.	• Increase the number of functional automatic weather stations in Angola • Invest in e-government as the current rankings are lowest in the Zambezi region	• Train staff in the national meteorology departments on reporting and aggregation of weather and climate data and predictions. • National training of trainers on specific climate-smart solutions and technologies using the AAAP adaptation toolkit.
Promote natural resources management		• Introduce chameleon sensors in irrigation management	

Botswana

Interventions areas	Knowledge and analytics	Investment in middleware infrastructure	Capacity building
Development of digital climate services	• Strengthen national adaptation plans by mainstreaming digital technology.	• Improve early-warning systems for better coordination and emergency and response planning. • Develop and invest in water accounting and aquifer mapping tools for efficient water use.	• Provide training to the Botswana Meteorological Department to enable it to provide precise climate and weather predictions. • Strengthen coordination between stakeholders to ensure coordinated efforts to fighting climate change.
Facilitating access to advisory services and markets through digitalization	• Increase water and climate data availability, access, and documentation to increase awareness.	• Promote business models that target rural women farmers with low-cost smartphones.	• Train the youth and women farmers on the importance of technology for adaptation.
Promotion of climate-smart innovations and technologies	• Study mainstreaming digital technologies to drive adaptation and resilience capabilities.	• Increase the number of functional automatic weather stations in Botswana. • Increase the internet penetration rate by reducing taxation on service providers.	
Promote natural resources management		• Invest in wetting-front detector (WFD) tools and Chameleon soil water sensors to maximize water use efficiency and reduce the loss of nutrients.	• Provide training on the use of remote sensing data to monitor aquifer water availability and use.

Malawi

Interventions areas	Knowledge and analytics	Investment in middleware infrastructure	Capacity building
Development of digital climate services	• Strengthen national adaptation plans by mainstreaming digital technology. • Promote the expansion of innovative digital tools.	• Improve early-warning systems for better coordination and emergency and response planning. • Develop and invest in water accounting and aquifer mapping tools for efficient water use.	• Enhance digital skills and analytical capacity in the development and implementation of early warning systems. • Tailor knowledge on climate risk management for smallholder farmers. • Strengthen coordination between stakeholders to ensure coordinated efforts to build resilience against climate change. • Strengthen extension services to improve information flow to farmers and bridge the gap between early warning and the last mile through effective communication means.
Facilitating access to advisory services and markets through digitalization	• Increase water and climate data availability, access, and documentation to intensify awareness.	• Promote business models that target rural women farmers with low-cost smartphones. • Expand telecommunications infrastructure, e.g., mobile towers.	• Train the youth and women farmers on the importance of technology for adaptation.
Promotion of climate-smart innovations and technologies	• Possible study on the effects of AI on people's wellbeing as a step towards increasing its use.	• Increase the number of functional automatic weather stations in Malawi. • Increasing the internet penetration rate by reducing taxation on service providers.	• Promote digital learning and knowledge sharing among farmers and other stakeholders. • Develop a data sharing platform and ensure information exchange.

Promote natural resources management	• Adoption of drought- and flood-tolerant crop varieties.	• Invest in wetting-front detector (WFD) tools and Chameleon soil water sensors to maximize water use efficiency and reduce the loss of nutrients.	• Provide training to farmers on the use of internet of things (IoT) devices. • Provide training on the use of remote sensing data to monitor water availability and use.

Mozambique

Interventions areas	Knowledge and analytics	Investment in middleware infrastructure	Capacity building
Development of digital climate services	• Strengthen national adaptation plans by mainstreaming digital technology.	• Develop a national integrated database management system for the collection, analysis, and dissemination of climate data to avoid confusion in messaging. • Support the development of a coordinated and holistic approach to digital economy development rather than fragmented interventions.	• Provide training to the Mozambique Meteorological Department to enable it to provide precise climate and weather predictions. • Develop a digital technology platform that offers information to farmers on the tools available for climate adaptation.
Facilitating access to advisory services and markets through digitalization	• Develop climate science communication mechanisms in Mozambique that use all major local languages and integrate these into mobile applications for climate information dissemination.	• Develop business models in which rural women farmers are targeted for low-cost smartphones through cooperatives. • Strengthen early warning systems for disaster preparedness and other management practices. • Enhance user skills through e-schools and e-literacy programs, develop content in local languages, and support the development of apps.	• Train media personnel and farmers on interpreting climate and weather information from weather stations and improving their digital literacy. • Remove duties and taxes on imports of digital technology. • Develop capacities for the local production of these technologies to make them more accessible.

Promotion of climate-smart innovations and technologies	• Increase the availability and access of climate data.	• Increase the number of functional automatic weather stations in Mozambique. • Develop digital maps that summarize recommended farm inputs and markets depending on location, soil types, rainfall patterns, and seasons. • Invest in radio and TV signal coverage.	• Train staff in the national meteorology departments on the reporting and aggregation of weather and climate data and predictions. • National training of trainers on specific climate-smart solutions and technologies using the AAAP adaptation toolkit.
Promote natural resources management	• Promote awareness among farmers on the importance of technology use in farming and climate adaptation. For example, the use of irrigation sensors to conserve water.	• Equip universities with remote sensing and AI software for teaching. • Introduce Chameleon sensors to maximize water-use efficiency. • Assist stakeholders to use freely available high-resolution Sentinel data and benefit from cloud computing.	• Provide training on the use of remote sensing data to monitor production, deforestation, and water availability.

Namibia

Interventions areas	Knowledge and analytics	Investment in middleware infrastructure	Capacity building
Development of digital climate services	• Strengthen national adaptation plans by mainstreaming digital technology.	• Improve early-warning systems for better coordination and emergency and response planning. • Introduce weather-index-based crop insurance to make smallholder farmers more resilient.	• Provide training to the Namibia Meteorological Department to enable it to provide precise climate and weather predictions. • Cover local languages when climate information is packaged for transmission.

Facilitating access to advisory services and markets through digitalization	• Increase water and climate data availability, access, and documentation to increase awareness.	• Establish a farmer e-registration platform to connect farmers in the basin region to other agriculture value chain actors, such as agro-input suppliers, aggregators, financial service providers, etc. • Expand e-extension services to reach many farmers efficiently.	• Develop farmers' hubs where information on good agronomic practices, markets, etc. is centrally accessed by farmers.
Promotion of climate-smart innovations and technologies	• Undertake a feasibility study on the uses, policies, and regulatory issues of digital agriculture with a focus on climate adaptation and resilience for food and nutrition security in the region.	• Increase the use of data-enabled precision methods of farming and production to conserve inputs, e.g., drones in combination with field sensors to determine areas of problems and where to intervene.	• Develop human capacity in aquifer mapping for efficient groundwater utilization. • Deliver national training of trainers on specific climate-smart solutions and technologies using the AAAP adaptation toolkit.
Promote natural resources management		• Invest in wetting-front detector (WFD) tools and Chameleon soil water sensors to maximize water use efficiency and reduce the loss of nutrients in irrigation systems.	• Provide training on the use of remote sensing data to monitor aquifer water availability and use.

Tanzania

Interventions areas	Knowledge and analytics	Investment in middleware infrastructure	Capacity building
Development of digital climate services	• Strengthen national adaptation plans by mainstreaming digital technology.	• Invest in crop insurance and make it easier to adopt by combining it with input support or other climate adaptation programs. • Build the capacity (procuring modern equipment) of the meteorology department for	• Provide training to the Tanzania Meteorological Department to enable it to provide precise climate, and weather predictions across all the Zambezi River Basin countries.

		better climate and weather prediction in Tanzania.	• Develop a digital technology platform that offers information to farmers on which tools are available for climate adaptation.
Facilitating access to advisory services and markets through digitalization	• Develop climate science communication mechanisms in Tanzania that use all local languages and integrate these into mobile applications for climate information dissemination. Currently, some languages not covered. Although Swahili is the lingua franca and English is becoming more widely used, rural areas show considerable linguistic fractionalization.	• Promote business models that target rural women farmers with low-cost smartphones. • Expand telecommunications infrastructure, e.g., mobile towers. • Invest in e-extension systems to increase efficiency. • Develop a digital platform that addresses smallholder farmers' challenges through the complete farming cycle, bringing together the stakeholders at the national level, in order to achieve sustainable agriculture goals and support the adoption of cutting-edge digital technology.	• Train media personnel and farmers on interpreting climate and weather information from weather stations and improving their digital literacy.
Promotion of climate-smart innovations and technologies		• Increase the number of functional automatic weather stations in Tanzania. • Develop digital maps that summarize recommended farm inputs, markets, depending on location, soil types, rainfall patterns, and seasons.	• Train staff in the national meteorology departments on the reporting and aggregation of weather and climate data and predictions. • National training of trainers on specific climate-smart solutions and technologies using the AAAP adaptation toolkit.
Promote natural resources management	• Promote awareness among farmers on the importance of technology use in farming and climate adaptation, e.g., the use of irrigation sensors in conserving water.	• Equip universities with remote sensing and AI software for teaching. • Introduce chameleon sensors in irrigation management.	• Provide training on the use of remote sensing data to monitor production, deforestation, and water availability.

Zambia

Interventions areas	Knowledge and analytics	Investment in middleware infrastructure	Capacity building
Development of digital climate services	• Strengthen national adaptation plans by mainstreaming digital technology.	• Develop a national integrated database management system for climate data collection, analysis, and dissemination to avoid confusion in messaging. • The Zambia Meteorological Department needs investments to properly equip it with automated weather stations; currently, there are few.	• Provide training and capacity building to national early warning systems to improve coordination and knowledge sharing on disaster preparedness and implement other management practices. • Provide training to the Zambia Meteorological Department to enable it to provide precise climate, and weather predictions for Zambia.
Facilitating access to advisory services and markets through digitalization	• Develop climate science communication mechanisms in Zambia that use all local languages and integrate these into mobile applications for climate information dissemination. Currently, some languages are not covered.	• Establish a farmer e-registration platform to connect farmers in the Zambezi region to other agriculture value chain actors, such as agro-input suppliers, aggregators, financial service providers, etc. • Create farmer information centers with solar TVs and radios in all districts to ease information access. • Promote business models that target rural women farmers with low-cost smartphones. • Develop more user-friendly geological maps that summarize crop, soil, and rainfall information in each location.	• Train media personnel and farmers on interpreting climate and weather information from weather stations.
Promotion of climate-smart innovations and technologies	• Undertake a feasibility study on the uses, policies, and regulatory issues of digital agriculture with a focus on climate adaptation and resilience for food and nutrition security in the region.	• Increase the number of functional automatic weather stations in Zambia.	• Train staff in the national meteorology departments on the reporting and aggregation of weather and climate data and predictions. • National training of trainers on specific climate-smart solutions and technologies using the AAAP adaptation toolkit.

Promote natural resources management	• Promote awareness among farmers on the importance of technology use in farming and climate adaptation, e.g., the use of sensors in irrigation.	• Introduce Chameleon sensors for irrigation management.	• Provide training on the use of remote sensing data to monitor production, deforestation, and water availability.

Zimbabwe

Interventions areas	Knowledge and analytics	Investment in middleware infrastructure	Capacity building
Development of digital climate services	• Strengthen national adaptation plans by mainstreaming digital technology.	• Develop a national integrated database management system for climate data collection, analysis, and dissemination to avoid confusion in messaging. • Upgrade the Zimbabwe Meteorological Department with automated weather stations.	• Provide training and capacity building for national early warning systems to improve coordination and knowledge sharing on disaster preparedness and implement other management practices. • Provide training to the Zimbabwe Meteorological Department on digital solutions to provide precise climate and weather predictions.
Facilitating access to advisory services and markets through digitalization	• Develop climate science communication mechanisms in all local languages and integrate these into mobile applications for climate information dissemination. Currently, some languages are not covered.	• Establish a farmer e-registration platform to connect farmers in the Zambezi region to other agriculture value chain actors, such as agro-input suppliers, aggregators, financial service providers, etc. • Develop geological maps that summarize crop, soil, and rainfall information for each location.	• Train media personnel and farmers on the interpretation of climate and weather information from weather stations.
Promotion of climate-smart innovations and technologies	• Ensure that relevant digital technologies (e.g., drones, smartphones, internet equipment, etc.) are exempt from import duties and taxation.	• Increase the number of functional automatic weather stations in Zimbabwe. • Provide fiscal incentives and reduce taxes and import duties on key adaptation technologies, e.g., smartphones, drones, irrigation sensors, etc.	• National training of trainers on specific climate-smart solutions and technologies using the AAAP adaptation toolkit.

Promote natural resources management	• Promote awareness among farmers on the importance of technology use in farming and climate adaptation, e.g., using Chameleon sensors for irrigation.	• Introduce digital animal trackers, soil moisture meters, and Chameleon sensors to improve agricultural productivity and help adapt to climate change.	• Provide training on the use of remote sensing data to monitor production, deforestation, and water availability. • Introduce water accounting frameworks.

Zambezi River Basin

Interventions areas	Knowledge and analytics	Investment in middleware infrastructure	Capacity building
Development of digital climate services	• Develop regional adaptation priorities and shared regional tech-based vision and guidelines to ensure long-term sustainable management of resources, as they are transboundary.	• Develop a regional integrated database management system for climate data collection to collate all information stored on institutional climate databases and ensure the systematic storage of climate data. • Establishment of a regional innovation hub/data center/platform for coordination and knowledge sharing of climate-smart digital agriculture technologies across national innovation partners, governments, and other stakeholders	• Provide training and capacity building to national early warning systems to improve coordination and knowledge sharing on disaster preparedness and implement other management practices. • Strengthen the SADC Climate Services Centre to enable it to provide precise climate and weather predictions across all the Zambezi River Basin countries. • Organize policy dialogues among stakeholders on regional pooling of insurance and weather risks across the Zambezi region.
Facilitating access to advisory services and markets through digitalization	• Develop climate science communication in SADC local languages and integrate these in mobile applications for climate information dissemination (only 26% internet penetration).		

Promotion of climate-smart innovations and technologies	• Undertake a feasibility studies on the uses, policies, and regulatory issues of digital agriculture with a focus on climate adaptation and resilience for food and nutrition security in the region.	• Develop cross-country harmonization templates and guidelines to implement regional pooling of weather risks as a model to improve climate risk sharing and transfer in the Zambezi basin countries. • Integrate national climate observation networks into a unified regional observation network to easily predict and disseminate climate information in the region. • Increase the number of functional automatic weather stations, available under the control of the SADC Climate Services Centre to ensure that predictions are precise and reliable in the region.	• Facilitate knowledge sharing between national networks of hydrogeological and meteorological observatories to improve the dissemination and use of water-related information. • Strengthen coordination among member states to mitigate both non-climate and climate stressors affecting transboundary ecosystems and promote their effective management. • Train staff in the national meteorology departments on regional reporting and aggregation of weather and climate data and prediction. • Regional training of trainers on specific climate-smart solutions and technologies using the AAAP adaptation toolkit.
Promote natural resource management			• Provide regional training on water accounting approaches and tools, e.g. the Water Accounting + framework which integrate remote sensing data with existing hydromet data to provide the information needed for sustainable water management.

Annex 2: Case studies

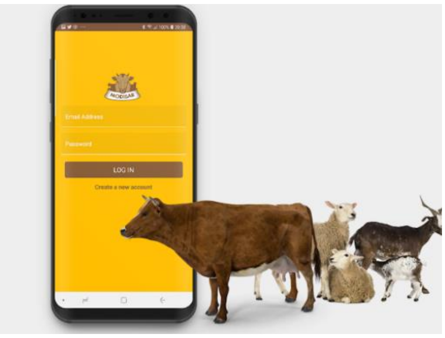
Case studies on the use of digital platforms – one from each country.

Angola

DecolaAgro is an app focusing on sharing knowledge within the Angolan agricultural sector. Its main goal is to make knowledge accessible among the numerous stakeholders (small and large producers, agricultural workers, universities, etc.), preparing Angola to leap from traditional farming into a more digital and modern agriculture.

Botswana

Modisar Farm Management (desktop) application is a productivity software application that can be installed on a farmer's computer or laptop and allows the farmer to capture information about his or her farm faster. Modisa(r) is a Setswana word meaning "herdboy".



The app can run without an internet connection, which is very useful for remote, rural regions. The platform helps a farmer understand and better manage their farm. It maintains farm records, keeps track of inventory and livestock, and sends reminders for tasks that need completion. One of the best features of Modisar is its expense and profit tracker. This allows farmers to see their financial history and educates them on how to increase profits in the future. Modisar won the Orange Social Venture Prize in 2014 for Innovation, which was launched at a packed event at the Botswana Innovation Hub.

Malawi

Early Warning Systems Modernized Climate Information and Early Warning systems (M-CLIMES) and Participatory Integrated Climate Services for Agriculture (PICSA) are some early warning systems currently being used in Malawi to adapt to climate change. To strengthen access to climate and weather information as well as agro advisories, communities receive messages through SMS and Radio. PICSA1 is reaching 12,000 households in eight districts through Government extension officers and lead farmers, whom received weather and climate information.

Mozambique

A **Virtual Farmers Market (VFM)** has been formed to integrate smallholder farmers to formal markets. The VFM provides market information, weather forecast information, and training, and also integrates e-extension services for improved agricultural production and productivity. In December 2021, WFP broadcasted 16 radio spots on good agricultural practices and supported the contact between 25 schools and 49 farmers associations.

Namibia

Farm4Trade Namibia provides technological solutions to empower breeders and public and private institutions in the livestock sector to improve their productivity practices. The company was founded in 2018, in Windhoek, Namibia, and is the first resource center to offer free services to breeders and livestock farmers while promoting the advantages of Farm4Trade applications. The goal is to provide the community and Farm4Trade clients with a comfortable and accessible experience to obtain the information needed to manage their farms. Offering a physical space makes it accessible to passersby, encouraging walk-ins and creating a buzz in the community. The first Farm4Trade resource center is broadly supported by an agreement with the Faculty of Agriculture and Natural Resources of the University of Namibia (UNAM) to collaborate on the implementation of the project in the country. They plan to work together in the preparation and execution of the training activity for farmers. In order to do that, they will be involved and give job opportunities to students to promote project activities in their community.

Tanzania

The **MkulimaHub** app enables farmers to record data such as their agriculture activities, type of crops cultivated, size of the farm, as well as access to agriculture inputs like fertilizers, seeds, pesticides, etc. The app is the product of Rotai, in collaboration with BRITEN, which implemented the Farm to Market Alliance (FtMA) program, a coalition of Yara, Syngenta, Rabobank, Bayer, the World Food Programme (WFP), and the Alliance for the Green Revolution in Africa (Agra). It also assists farmers in utilizing financing and trade opportunities, including loans and insurance.

Zambia

A2-Field Area Measure App was developed by the Zaimbian – German Agricultural Knowledge and Training Centre (AKTC Zambia- Germany). AKTC introduced the "Field Area Measure" app to its farmers in 2019. The app measures distances and field areas. The AKTC teaches farmers how to measure distances and field areas and how to get the coordinates of a particular point by using the app. It is available in both Android app stores and uses GPS technology that usually comes with each mobile device; therefore it is interoperable and likely to continue being useful in the future.

Using this app, farmers can measure their fields using a smartphone instead of manually measuring distances and areas, which is time-consuming and tedious. With the use of the app, accurate quantities of inputs like agrochemicals and fertilizer can be applied per area, guaranteeing optimum input usage. During the training, AKTC also teaches farmers how to use their smartphones to access information on weather updates, market prices, and agronomic advice from relevant internet sites and apps. It also teaches farmers how to use social media platforms such as Twitter and Facebook to access information from other farmers worldwide.


Photo: © AKTC

The center also introduced tractor service providers and emerging farmers to GPS-based technology.

Source: (AKTC Zambia- Germany, 2021).

Zimbabwe

Eco Farmer, the one-stop shop for farming services providing weather index-based insurance app offers a one-stop shop for farmers as it allows them to access information on farming inputs, markets, and extension services that can increase farmer productivity. Climate change is impacting the agriculture sector through climate hazards that have resulted in crop loss through floods, droughts, and dry spells. Farmers have the opportunity to insure their crops through the Eco Farmer app and receive compensation in the event of crop loss due to climate hazards. The subscription is very low, making it affordable for farmers to insure their crops. Eco Farmer is provided by Econet, one of the biggest network providers in the country with the highest SIM card subscription, and all farmers using Econet services can register for weather index-based insurance. In the event of crop loss, farmers are compensated to allow a quick recovery compared to non-insured farmers. Other services offered by Econet include electronic transactions through the Ecocash service, which is very useful as cash transactions are not always possible. Farmers can now make and receive payments in the comfort of their homes, allowing them more time for farming and increasing their chances of improving productivity.