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NESTLER

NESTLER oNe hEalth SusTainabiLity partnership between EU-AFRICA for food sEcuRity

Deliverable D1.1
NESTLER Platform Requirements

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Definitions, Acronyms and Abbreviations

ASAL	Arid and Semi-Arid Land
ASF	African Swine Fever
CBPP	Contagious Bovine Pleuropneumonia
CBSD	Cassava Brown Streak Virus Disease
CEMAC	Economic and Monetary Community of Central Africa
CMVD	Cassava Mosaic Virus Disease
CS	Case study
EFS	Ethiopian food systems
EU	European Union
F.CFA	Central African CFA franc
FMD	Foot and Mouth Disease
FS	Food Security
GDP	Gross Domestic Product
GDPR	EU General Data Protection Regulation no. 2016/679
GMO	Genetically Modified Organism
IPC	Integrated Food Security Phase Classification
MLN	Maize Lethal Necrosis disease
PM	Project Manager
PMT	Project Management Team
PPE	personal protective equipment
SNNPR	Southern Nations and Nationalities People's Region
SSA	Sub-Saharan Africa
TAD	transboundary animal disease
UNFSS	United Nations Food Systems Summit

Executive Summary

Deliverable D1.1 outlines the findings of the research on food security in Africa. Historical case studies will be reviewed to understand the potential threats to the food security roadmap. These findings will be used to design the NESTLER platform to meet the needs of its users.

The use cases for the NESTLER platform, taking into account the historical case studies, were grouped into three categories: crop-based farming, livestock farming and aquaculture farming. The identification of user and technical requirements for the NESTLER platform are presented and a brief overview of the high-level NESTLER architecture has been developed to address the emerging functional and non-functional requirements.

1 Introduction

The deliverable D1.1: NESTLER platform requirements is the first deliverable of WP1. The objective of this work package is to build interdisciplinary consensus among the different stakeholders contributing to the development of a sustainable EU-Africa partnership for One Health, with the aim of:

- to review the food security roadmap for both continents (EU and Africa) for potential long-term impacts of increasingly global and interconnected supply chain logistics
- to develop a repository of historical case studies where agricultural production has been affected by pests, extreme climatic conditions (e.g., floods, droughts) and other causes.

This deliverable is based on three WP1 tasks:

- T1.1: Review of (national) risks on food security roadmap
- T1.2: Archive of historical case studies on food (in-)security due to supply chain disruptions
- T1.3: Formal requirements for NESTLER platform development

As a first step, the African partners research historical case studies that had occurred in their regions in the past. In order to gain a clearer understanding of these adverse events, these examples are examined further. For each case, key information such as the year of outbreak, the region and category affected, the severity of the outbreak and the impact on the ecosystem and economy are documented. In addition, potential mitigation and prevention measures are recorded.

In the next section, user and technical requirements are identified based on historical case studies and group into four different use cases:

1. crop – based farming
2. livestock farming
3. aquaculture farming
4. Zoonotic Diseases

Afterwards, it is provided a detailed description of the technical requirements, which covers IoT devices, satellite imagery specifications, equipment requirements etc. Moreover, functional and non – functional requirements are extracted for the NESTLER platform and a brief description of the high-level NESTLER architecture was designed to cover the emerging requirements.

Finally, a review of the national risks on the food security roadmap was carried out to highlight the need for a comprehensive approach to food security in Africa, which will be used for the development of the NESTLER platform.

2 Identification of Case Studies

In order to identify the most important use cases and capture the user requirements, we have followed a two path approach:

Review of historical Use cases: Historical use cases have been analysed and a repository of historical case studies that have affected agricultural cultivation resulting from pests, extreme climatic conditions (such as floods and droughts) has been developed. A review of historical case studies is a valuable outcome suitable for addressing the overall goal, which is to build the interdisciplinary consensus among the different stakeholders contributing to the development of a sustainable partnership between EU-Africa for the One Health initiative.

Capturing of User Requirements: Capturing user requirements has also been a critical step in achieving the broader goal of WP1 and project in general, Identifying and analysing user requirements was central for successful deliverable D1.1 development. The methodologies followed to capture the user requirements included;

1. ***Surveys and Interviews:*** Professionals and institutions with required information were engaged through face-to-face surveys and interviews to understand their sentiments on the topics of interest.
2. ***Market Research:*** There was Investigation of different user requirement trends and identification in reference to the needs of deliverable. Data was systematically obtained, analysed, and interpreted for actionable decision-making
3. ***Observation and Analysis:*** From observations and interactions of different records, this enabled to get and interrelate with multiple information of need which was analyzed.

2.1 Cameroon

Cameroon, whose capital is Yaoundé lying at the junction of western and central Africa, Its ethnically diverse population is among the most urban in western Africa [1]. The, located in the south-central part of the country. The urban population of Cameroon is growing quickly, and secondary cities are where the majority of this expansion is occurring. Even with high rates of engagement in food production, livestock raising, and a robust informal food marketing system, one of the household food security surveys conducted in 2017 indicated that two-thirds of households experienced severe food insecurity, and from the several historical case studies within the country. Below are some of the major pointed out cases [2].

Table 1: Historical case studies for Cameroon

CS 1.1 Bird Flu	
Year of outbreak	2016
Affected region	Center/ South/ West
Category affected	Poultry
Description	The virus had gone from the main farm in the Center region to the main poultry market in Yaoundé and even in the sub-region. Then, this virus

	ended up in the Western region. Then it exploded and spread to almost all markets in the Central, South, and West basin.
Severity for the affected category	High
Effect on the ecosystem	Supply of eggs and chicken meat was interrupted.
Severity for humans	Social effect: Loss of investment, loss of jobs, supply of eggs and chicken meat interrupted.
Effects on economy	Loss estimated at around 20 billion F.CFA. More than 160,000 jobs lost, the production of table eggs has fallen from 5 million to around 2 million eggs per day. In the "broiler" component, the production outlook for 520 million chickens has been revised downwards to 26 million at the end of 2017.
Possible mitigation actions/Countermeasures	Implementation of emergency stamping-out operations in the identified foci, their destruction by incineration and burial under the supervision of the heads of the veterinary services. Installation of sanitary barriers at the level of poultry farms, with prohibition of access to any unauthorized person, during the period of the conduct of stamping-out operations and disinfection of outbreaks by special teams.
Possible prevention measures	Establishment of a surveillance and early warning system in Cameroon and in all the CEMAC States.
More Info	Bird flu is recurrent in Cameroon, there have been three cases of epidemics: 2006; 2016 and 2017
CS 1.2 Black Pod	
Year of outbreak	1999
Affected region	Center/ South/South-West
Category affected	Cocoa
Description	The attacked fruits show one or more brown spots, hard to the touch, covered with a creamy-white spore layer. The disease also attacks the leaves, the wood of twigs or roots. In Cameroon, brown rot is the main factor limiting the cocoa production, causing losses of up to 80% when conditions are favourable
Severity for the affected category	High
Effect on the ecosystem	Decrease in the size of the orchard, drop in production, loss of interest in cultivation by farmers
Severity for humans	Poor living conditions for the farmer and his family.
Effects on economy	Loss of output, including several hundreds of billions and reduction in GDP
Possible mitigation actions/Countermeasures	Control methods used are the fight chemical, genetic control, cultural control and biological control

Possible prevention measures	Application of cultural practices that contribute to creating conditions unfavourable to the development of the pathogenic agent or to limit the pressure of the inoculum: the maintenance of the plantation and the shading adjustment
More Info	Black pod rot is one of the most devastating cocoa diseases to date. Lack of control over shade management, climate change and the high cost of pesticides are increasingly aggravating the situation.
CS 1.3 Coffee Cherry Borer	
Year of outbreak	1998
Affected region	Center/South-West/Est/West
Category affected	Coffee (Robusta)
Description	The female bark beetle enters the cherry, digs galleries and lays eggs. From these eggs will come larvae which feed on the seed, cause serious damage when emptying it.
Severity for the affected category	High
Effect on the ecosystem	Decrease in the size of the orchard, drop in production, loss of interest in cultivation by farmers.
Severity for humans	Poor living conditions for the farmer and his family, abandonment of plantations.
Effects on economy	Loss of output, including several hundreds of billions and reduction in GDP.
Possible mitigation actions/Countermeasures	Use of chemical pesticides
Possible prevention measures	The prevention of harvesting sanitation by removing diseased cherries and burning them away from the plantation.
CS 1.4 Drought	
Year of outbreak	2015
Affected region	North
Category affected	Crops, livestock
Description	Drought defines the state of an environment faced with a significantly long and significant lack of water so that it has impacts on flora, fauna and societies.
Severity for the affected category	High
Effect on the ecosystem	Famine, disease, declines in production that compromise food security, disappearance of species, appearance of invasive species such as Chromolaena odorata and insect pests.

Severity for humans	Diseases, migrations, famine, poverty, loss of livelihoods
Effects on economy	Degradation of natural resources, displacement of populations, disruption of economic activities, especially agricultural and increasingly heavy economic and social costs, lack of drinking water, Losses are estimated at around $1.5 million US
Possible mitigation actions/Countermeasures	Dispersion of livestock in several places to avoid collective death; storage of hay and fodder; construction of attics on stilts (to limit predator attacks); construction of dykes on water crossings; Burying jars full of water as means of preservation; displacement/migration of the population; transhumance to regions with high potential pastoral (grazing, water); construction of bunds to flood the vertisols (Karal) and the digging of furrows to facilitate infiltration waters; modification of the agricultural calendar and nursery watering/irrigation; postponement of certain festive events in order to ensure food security;
Possible prevention measures	Establishment of the Directorate of Civil Protection and the national risk observatory coordinate all contingency plans for risk management.
CS 1.5 Flood	
Year of outbreak	2010 and 2020
Affected region	North/West
Category affected	Crops, livestock, aquaculture
Description	A flood is an overflow of water that submerge land that is usually dry and causes a lot of damage
Severity for the affected category	High
Effect on the ecosystem	More than 3 thousand destroyed infrastructures (houses, schools, hospitals, roads and bridges), lower water quality, cause sedimentation and erosion
Severity for humans	More than 3 million people affected (injured, dead, homeless), loss of livelihoods
Effects on economy	Fatality and damage; nearly 58,824 hectares of crops destroyed, including corn, several hundred head of cattle were killed and several fish ponds damaged.
Possible mitigation actions/Countermeasures	Resettlement of victim populations, care of the injured and affected families.
Possible prevention measures	Development of flood risk prevention plans, monitoring of risk areas
CS 1.6 Socio Political Crisis	
Year of outbreak	2015 and 2022

Affected region	Far North, South-West, North-West
Category affected	Crops & livestock
Description	A political crisis is a serious phase in the evolution of the political situation of a State: it can lead to strikes, demonstrations, social movements, riots or, more seriously, a revolt or a war.
Severity for the affected category	High
Effect on the ecosystem	Drastic drop in the production of certain cash crops such as cocoa and sweet bananas. Cessation of livestock-related activities, loss of cattle. Destruction of plantations, cattle theft, increase in illegal activities such as cattle theft.
Severity for humans	Violence, Migration of populations, kidnapping with demand for ransom, loss of human life, extreme poverty of the displaced, rape of women and children, depressive illnesses, loss of houses, destruction of hospitals, schools, loss of livelihoods.
Effects on economy	All sectors of the economy are affected, with a reduction in GDP. Losses estimated at several billion F.FCA.
Possible mitigation actions/Countermeasures	
Possible prevention measures	Establishment of organisations promoting dialogue, popularisation of bilingualism, collaboration between populations and law enforcement.
More Info	Establishment of state structures for crisis management.

2.2 Uganda

Uganda at times referred to as the pearl of Africa whose capital city Kampala is bordered to the east by Kenya, to the north by South Sudan, to the west by the Democratic Republic of the Congo, to the south-west by Rwanda, and to the south by Tanzania [3]. Despite being estimated that about 70% of Uganda's working population is employed in agriculture [4], both big and small holder farmers across the country face a wide range of agricultural production risks, with climate change and variability presenting new risks and vulnerabilities. Below are some of the historical case studies from the country.

Table 2: Historical case studies for Uganda.

CS 2.1 COVID-19	
Year of outbreak	2020
Affected region	Uganda, Africa, EU
Category affected	Humans

Description	Coronavirus (COVID-19) is an infectious respiratory disease caused by caused by the SARS-CoV-2 virus
Severity for the affected category	High
Effect on the ecosystem	Wildlife and their habitat exploitation
Severity for humans	Fatalities and Damage, Loss of investment, loss of jobs, and disruptions of transport systems
Effects on economy	Disrupted the market and production- supply chain
Possible mitigation actions/Countermeasures	Lock down, PPEs, Health education campaigns
Possible prevention measures	Adherence to Standard Operating Procedures like (Hand washing, Face masks), Immunisation
CS 2.2 Locusts	
Year of outbreak	2020
Affected region	Northern and Eastern region of Uganda (Acholi, Elgon, Karamoja, Lango, and Teso subregions)
Category affected	Crops
Description	Locusts are short-horned grasshoppers distinguished by their density-dependent behavioural, physiological, and migrate in swarms
Severity for the affected category	High
Effect on the ecosystem	Consumption of green vegetation thus ecosystem destruction
Severity for humans	Led to famine and starvation and thus death
Effects on economy	Threatened livelihoods, eroded people's savings, and pushed people further into poverty
Possible mitigation actions/Countermeasures	Resistant crops, Spraying
Possible prevention measures	Improve Desert locust preparedness by strengthening the capacities for real-time surveillance, rapid verification and deployment of control teams.
CS 2.3 Cattle/ Livestock Rustling	
Year of outbreak	2022 to Date
Affected region	North-Eastern Region of Uganda (Karamoja Subregion and Neighbouring districts)
Category affected	Livestock
Description	Forceful acquisition of livestock from the owners (mainly cattle)

Severity for the affected category	High
Effect on the ecosystem	Typically leads to migration, thus increasing population pressure on area moved to/natural resources
Severity for humans	Violence, disability, Loss of lives, damage of property, loss of livelihoods
Effects on economy	Disrupts business flow, Increased poverty, high cost of
Possible mitigation actions/Countermeasures	Security to maintain peace
Possible prevention measures	Engage authorities to uphold cattle rustling policies and laws, increased surveillance and security in high-risk areas/ Disarmament
More Info	Alternative livelihoods that favour the regions
CS 2.4 Tick and Borne Diseases	
Year of outbreak	Rainy seasons
Affected region	Cattle corridors, pastoral regions of Uganda and areas adjacent to national parks
Category affected	Livestock
Description	Ticks are small, wingless, bloodsucking arthropods that causes Tick borne diseases such as East Coast fever Babesiosis
Severity for the affected category	High
Effect on the ecosystem	Affects tourism by wildlife loss and loss livestock as well
Severity for humans	Zoonoses, affects animals' productivity (Milk, meat and hides), use of antibiotics can affect humans
Effects on economy	Affect the export and import trade of livestock and its products
Possible mitigation actions/Countermeasures	Use of Environmentally friendly pesticide products and medicines
Possible prevention measures	Control strategies against ticks should be aimed at cutting their biological cycle

2.3 Ethiopia

Ethiopia is located in the horn of Africa and has a diverse topography with an altitude ranging from 125 m below sea level in the Danakil Depression to 4620 m above sea level in the Ras Dashin [5]. The climate varies from temperate type in the highlands to hot arid in the lowlands. The country is the second most populous in Africa with nearly 120 million inhabitants. Ethiopia's economy is dependent on agriculture, which accounts for 33 percent of the total GDP, 80 percent of exports, and supports an estimated 75 percent of the country's workforce [6]. The livelihood of the rural community depends mainly on crop production and livestock rearing. Hence, given the inherent link of these livelihood activities to natural

resources, they are largely at the mercy of uncertainties driven by climate change, including extreme events such as drought and flooding in lowland areas of the country. Frequent occurrence of drought and flooding in the country created conducive environmental conditions for various disease outbreaks, tsetse fly, desert locust and invasive aquatic weed infestation with the consequent significant negative impact on crop, livestock and fish production. The net effects of these climate crises affected the livelihood of people and led millions to the greatest hunger crisis, mass displacement, livestock death and degradation of natural resources including surface water and soil. Scanning the spatial and temporal analysis of climate extremes which are directly or indirectly responsible for the occurrence of other disasters is very crucial to strategically design long-lasting interventions and prevention measures for the country and other African countries in general. Hence, the Table 3 below presents the major historical cases which resulted in food insecurity in Ethiopia and affected production of export commodities to EU-Africa countries that require sustainable mitigation and prevention measures.

Table 3: Historical case studies for Ethiopia.

CS 3.1 Drought	
Year of outbreak	Occurs every 3-4 years, devastating drought in 1984 and recently persistent since 2021
Affected region	In 1984- Northern, eastern and central Ethiopia mainly Wollo, Tigray, Gonder, Hararghe, Arsi, Bale and currently (since 2021 Southern and eastern lowlands of Ethiopia mainly Borana in Oromia region and parts of Somali and Afar regions
Category affected	Crops and Livestock
Description	Occurs primarily due to severe EL Nino and change in general atmospheric circulation, affecting mainly farmers and pastoralists, causing starvation and malnutrition with a cumulative significant impact on the national economy.
Severity for the affected category	High
Effect on the ecosystem	Severe/serious
Severity for humans	IIn 1984 - 7.75 million people in famine, more than 300,000 death and 3 million displaced (out of 40 million total population)
Effects on economy	Currently (since 2021), more than 20 million people affected, about 8 million faced food insecurity and acute malnutrition, including 2.9 million children and pregnant/ lactating women, water shortage (13 million in need of water), Psychological distress, migration
Possible mitigation actions/Countermeasures	An estimated 1 billion USD loss in GDP through death of more than 4 million cattle in Borana and Somali pastoral production systems alone, Food shortage, hyperinflation

Possible prevention measures	Water harvesting and storage during normal years, developing underground water, early warning systems, establish feed reserve schemes
More Info	Environmental management /afforestation, spring and water conservation, reservoir management, policy instruments
CS 3.2 Desert Locust	
Year of outbreak	In 1958, 1986,1992, 1995, 2007, and twice a year in 2020 which was the worst in 25 years in Ethiopia, Somalia and Kenya (about 6 major cases)
Affected region	Rift Valley escarpments southern and eastern Ethiopia (part of Afar, Somali, Hareri, Amhara, Tigray and east Oromia with the highest incidence
Category affected	Crops and Livestock (grazing lands)
Description	World's most destructive migratory pest; damage crops, pastures, fodders and trees; fly long distances in swarms and cover large areas in a short time, consuming equivalent to its weight.
Severity for the affected category	High
Effect on the ecosystem	Severe/serious
Severity for humans	Food insecurity for about 8.6 million people, loss of pastureland for the livestock
Effects on economy	High food cost, high cost for locust control, reduced Agri-products in the invaded area
Possible mitigation actions/Countermeasures	Advanced technologies of satellites for locust systematics and ecology
Possible prevention measures	Integrated management, coordinated finance and logistics, research, satellite technologies for detection of locust migration and breeding tracts.
More Info	In 1958, 1986,1992, 1995, 2007, and twice a year in 2020 which was the worst in 25 years in Ethiopia, Somalia and Kenya (about 6 major cases)
CS 3.3 Foot and Mouth Disease (FMD)	
Year of outbreak	1997 -2016
Affected region	Different parts of the country
Category affected	Livestock (Cattle, sheep and goats)
Description	Foot and mouth disease (FMD) is a severe, highly contagious viral disease of livestock that has a significant economic impact. The disease affects cattle, sheep, goats, swine and other cloven-hoofed ruminants. It is a transboundary animal disease (TAD) that deeply affects the production

	of livestock and disrupts regional and international trade in animals and animal products. The disease is estimated to circulate in 77% of the global livestock population, in Africa, the Middle East and Asia, as well as in a limited area of South America.
Severity for the affected category	The disease was first detected in 1957 and spread by infected animals mainly through contact with contaminated farming equipment, vehicles, clothing, and feed, and by domestic and wild predators. The virus causes a high fever lasting two to six days, followed by blisters inside the mouth and near the hoof that may rupture and cause lameness. The morbidity rate can reach up to 100%. Outbreaks with the highest incidence occur in central Ethiopia, with overall herd- and animal-level prevalence of 57.6% and 11.9%, respectively; on average 35 outbreaks per year in Amhara region between 1999-2016
Effect on the ecosystem	High
Severity for humans	Medium
Effects on economy	Food insecurity (shortage of animal source food, loss of cash income, low draft animal supply for farming)
Possible mitigation actions/Countermeasures	Impedes export of livestock and meat to international markets; an export loss of USD 100 million in 1998 and USD 14 million in 2005/2006. Also caused a loss of 2.4 million USD in livestock trade industries during 2013/14.
Possible prevention measures	Routine vaccination, proper management and hygienic condition of animals and production sites
More Info	Controlled movement, establishment of quarantine sites and disease-free zones, vaccinations
CS 3.4 Contagious Bovine Pleuropneumonia (CBPP)	
Year of outbreak	1996 – 2016
Affected region	Different parts of the country (Amhara, Somalia, Oromia, Gambela including quarantine sites for export
Category affected	Livestock- cattle
Description	CBPP is a highly infectious cattle disease, which is caused by mycoplasma mycoides. Cases indicated 25% morbidity and more than 10% mortality rate. The economic effects of CBPP in a cattle population are enormous, often resulting in heavy losses.
Severity for the affected category	High
Effect on the ecosystem	Low

Severity for humans	Food insecurity, Loss of household income
Effects on economy	Ethiopia loses over US 8.96 million per year (205.6 million ETB every year from 1996 to 2016)
Possible mitigation actions/Countermeasures	Proper animal management, proper feed and feeding management, routine treatments
Possible prevention measures	Controlled movement, quarantine sites, disease free zones, vaccinations
CS 3.5 Bird Flu (H5N1)	
Year of outbreak	2005
Affected region	Poultry breeding/multiplication centres in different parts of the country (Addis Ababa, eastern Somali region; Gubere Poultry Center, Southern Nations and Nationalities People's Region (SNNPR)
Category affected	Poultry and wild birds
Description	Bird flu, also called avian flu, is a strain of influenza (flu) that infects mostly wild water birds, domestic birds (poultry) and animals fed on infected birds. This strain belongs to influenza A type viruses. High risk due to migratory birds to east Africa
Severity for the affected category	High
Effect on the ecosystem	High
Severity for humans	Poultry meat scarcity, loss of assets, disease infestation
Effects on economy	Loss of cash income from poultry, extended ban on the import of all poultry products
Possible mitigation actions/Countermeasures	Strict quarantine measures, restriction in movement of poultry and their products
Possible prevention measures	Avoid direct contact with wild birds and touch sick or dead birds, escape bird faeces, surface or water source that might be contaminated with their saliva and faeces without wearing personal protective equipment (PPE)
CS 3.6 Flood	
Year of outbreak	Severe in 2012 and 2022
Affected region	Afar, Gambella, SNNPR, Amhara, Somalia regions and Dire Dawa town
Category affected	Humans, crops, livestock and infrastructure
Description	Due to the heavy rain in July and August in the highlands and lowlands of Ethiopia, mainly Afar, Gambella, Amhara, South-West Ethiopia, Somalia regions and Dire-Dawa town are affected frequently by flood. For instance, in the last three years (2020-2022) about 500,000 people

	have been affected and about 300,000 people were displaced due to flood in Ethiopia.
Severity for the affected category	High
Effect on the ecosystem	High
Severity for humans	Displacement from residents, destruction and loss of farm crops and livestock, loss of asset
Effects on economy	Farmland and grazing land devastation through erosion and silt accumulation, total loss of crops and grazing land. High cost for dike maintenance and enforcement, and high cost for construction of new flood protection facilities
Possible mitigation actions/Countermeasures	Construction of dikes in the catchment and dams for holding excess water during main rainy season
Possible prevention measures	Afforestation in the catchment, dam construction to hold excess water and establish early warning system
CS 3.7 Trypanosomiasis	
Year of outbreak	Occurs seasonally every year at different prevalence rate at different regions of the country
Affected region	Western and Southern regions of the country (Oromia, SNNPR, Amhara, Beninshangul Gumuz, and Gambella)
Category affected	Livestock and Crop
Description	Trypanosomiasis is a serious disease in domestic livestock that causes a significant negative impact in food production and economic growth in many parts of the Sub Saharan African. Trypanosomosis affects both humans and animals. The disease results in loss of livestock and agricultural productivity with severe socio-economic impacts.
Severity for the affected category	High
Effect on the ecosystem	Medium
Severity for humans	Food insecurity; loss of asset (livestock)
Effects on economy	Annual losses to the national economy are estimated on exceed US$200 million, due to its direct and indirect impact to the agricultural and livestock production
Possible mitigation actions/Countermeasures	Restriction of cattle movement, good husbandry of animals at risk, suitable treatment

Possible prevention measures	Control of tsetse fly population, use of trypano tolerant breeds; bush clearing and proper management of game animals on which can host tsetse; use of insecticides (aerial spray)
CS 3.8 Water Quality Deterioration	
Year of outbreak	Since 2002
Affected region	Lakes Tana, Ziway, Hawasa, Abaya, Koka
Category affected	Fish and Livestock
Description	Lakes of Ethiopia are recognized for their outstanding biological diversity, fish production and societal significance. However, the lakes are facing substantial threats due to anthropogenic factors such as intensified pollution from point and non-point sources and increased water abstraction for the growing irrigation. Currently a decline of 20% of fish production was reported from the major fish producing lakes. Moreover, the nutrient rich effluents that entered the lakes through runoff create conducive conditions for eutrophication and toxic algae development that affect fish production and the health of livestock and human's dependent on the lake water.
Severity for the affected category	High
Effect on the ecosystem	Medium
Severity for humans	Shortage of fish in the local market, waterborne and water related human diseases, reduced productivity of livestock (milk and meat)
Effects on economy	High cost for fish import and disease treatment, food insecurity and loss of endemic animals
Possible mitigation actions/Countermeasures	Control point source pollution, catchment restoration, buffer zone delineation, regular monitoring for lake eutrophication
Possible prevention measures	Establish water treatment plants for domestic and industrial wastes, enforce national and international waste water disposal laws and regulations, establish small scale aquaculture, buffer zone and catchment protection
CS 3.9 Invasive aquatic weeds	
Year of outbreak	Since 2014
Affected region	Lakes Tana, Koka, Ziway, Abaya and River Awash
Category affected	Fish and Livestock
Description	Invasive aquatic weeds are of great concern in Ethiopia, posing particular problems on aquatic biodiversity and fisheries in major water bodies and surrounding agricultural land. Most importantly, water hyacinth is very notorious and can cover most parts of the lakes in a few years. Water

	hyacinth reduced fish production from major water bodies mainly by invading fish landing sites, encroaching the fish breeding areas and altering the water chemistry. It also created obstacles to boat navigation and destroyed fishing gears. Furthermore, it reduces grazing lands and raises livestock production cost in lake areas.
Severity for the affected category	High
Effect on the ecosystem	High
Severity for humans	Fish shortage, reduced productivity of livestock (milk and meat)
Effects on economy	Foreign currency fish import, high cost for weed removal, food insecurity and loss of endemic organisms
Possible mitigation actions/Countermeasures	Implement integrated control mechanism (Physical, mechanical, biological and chemical), restocking fish fingerlings from hatcheries, control nutrient runoff from the catchment
Possible prevention measures	Satellite based monitoring of infestation, apply control mechanisms, restocking fish fingerlings from hatcheries, control nutrient runoff from the catchment, control by utilisation

2.4 Rwanda

Rwanda is one of the most densely populated countries in Sub-Saharan Africa (SSA) with the population of 13 million people and population density 525 per km^2 [7]. Paradoxically there is overwhelming evidence that off-farm employment is also dependent on agricultural sector productivity and income growth. Fortunately, while the industrial sector is responsive to capital growth, the agricultural sector is more responsive to technological innovations. Hence the sustainable solutions to productivity decline and food insecurity relies on pro-poor technology interventions. Despite this, African countries, especially those located in the eastern African region have been facing unusual changes in their weather patterns, driven by climate change during the last few decades. Among the disasters, drought and flooding have caused significant crop loss, death of farm animals and damage to the ecosystem. For this, Rwanda has made important development gains in food security and economic growth during the last two decades. However, due to disasters such as frequent drought, heavy rain, flooding, and disease outbreaks, the country encountered low agricultural productivity leading to food insecurity which in turn has an impact on people's livelihood [8]. Furthermore, the frequent occurrence of drought and flooding created favourable conditions for disease outbreaks like rift valley fever, cassava and other crop diseases, and foot and mouth diseases, and its spread that impacts on economic growth of the country. In view of these, identifying the major historical cases and understanding the conditions leading to their occurrence and trends are important to suggest possible prevention and adaptation strategies for building an agricultural resilience framework across the country and beyond. Ensuring sustainable agricultural development and economic growth under such prevailing challenges require strong cooperation and partnership both among the African countries and also with other potential partners such the EU.

Consequently, the Table 4 below presents the major historical cases (both livestock and crop) which have significantly resulted in food supply disruptions with possible mitigation measures in Rwanda.

Table 4: Historical case studies for Rwanda.

CS 4.1 Contagious Bovine Pleuropneumonia (CBPP)	
Year of outbreak	1995
Affected region	Mainly former Umutara Province
Category affected	Mainly cattle
Description	The affected area was host to large cattle population from neighboring countries where CBPP was endemic. Subsequently, the disease situation in the country became aggravated by a near total absence of operational veterinary services. with loss of large number of cattle
Severity for the affected category	High (90%)
Effect on the ecosystem	Serious
Severity for humans	Disruption in meat and milk value chain, higher
Effects on economy	Reduced income for farmers, Loss of revenue due to Livestock market closer and restriction in sell of livestock and livestock product, High loss of livestock (around 200,000 HC deaths). Number of farmers opted to return to neighbouring countries with the remaining cattle, this contributes to the Country livestock fragile base.
Possible mitigation actions/Countermeasures	compulsory cycle mass vaccination and treatment of clinical cases; community awareness about the disease
Possible prevention measures	Continued epidemio - surveillance twice a year; community awareness; controlled livestock movement and livestock markets monitoring
CS 4.2 Foot and Mouth Disease (FMD)	
Year of outbreak	1994
Affected region	Mainly former Umutara Province
Category affected	Mainly cattle
Description	The affected area was host to a large cattle population from neighbouring countries where FMD was endemic. Subsequently, the disease situation in the country became aggravated by a near total absence of operational veterinary services. with the loss of a large number of cattle. A common factor that increased outbreaks was the smuggling in of cattle from neighbouring countries.
Severity for the affected category	Medium (60%) due to disruption in meat and milk value chain

Effect on the ecosystem	Serious
Severity for humans	Higher
Effects on economy	Reduced income for farmers. Loss of revenue due to Livestock market closer and restriction in sell of livestock and livestock products.
Possible mitigation actions/Countermeasures	Mass vaccination and stamping out of infected animals
Possible prevention measures	Continued epidemio -surveillance twice a year; community awareness; controlled livestock movement and livestock markets monitoring
CS 4.3 Rabies	
Year of outbreak	Every year
Affected region	Endemic country-wide
Category affected	Dogs
Description	Law morbidity, mortality in affected species and in human's 100%
Severity for the affected category	High (100% fatal)
Effect on the ecosystem	Serious
Severity for humans	High
Effects on economy	Limited: Costs mainly associated with disease control
Possible mitigation actions/Countermeasures	Annual vaccination and destroy of stray dog or sterilization
Possible prevention measures	Annual vaccination and destroy of stray dog or sterilization
CS 4.4 Brucellosis	
Year of outbreak	Endemic
Affected region	Country-wide
Category affected	Mainly cattle
Description	Law morbidity, insignificant mortality and higher abortions
Severity for the affected category	lower
Effect on the ecosystem	
Severity for humans	High
Effects on economy	Limited: Costs mainly associated with disease control
Possible mitigation actions/Countermeasures	Vaccination of young females using RB51 vaccine, epidemic surveillance and culling of positive animals. Encouraging using AI techniques for reproduction

Possible prevention measures	Vaccination of young females using RB51 vaccine, epidemio - surveillance and culling of positives animals
CS 4.5 Mastitis	
Year of outbreak	Not applicable
Affected region	Country-wide
Category affected	Mainly cattle
Description	High morbidity, insignificant mortality
Severity for the affected category	Lower
Effect on the ecosystem	
Severity for humans	None
Effects on economy	Reduction of milk and income, loss due milk rejection at Milk Collection Centres
Possible mitigation actions/Countermeasures	Treatment of all infected after antibiogram
Possible prevention measures	Treatment of all infected after antibiogram
CS 4.6 Tick Borne Diseases (ECF, Anaplasmosis, Heart Water, Babesiosis)	
Year of outbreak	Not applicable (NA)
Affected region	Endemic country-wide
Category affected	Mainly cattle
Description	Tickborne diseases are recorded where specific tick spp are found..specific ticks of economic importance include those that transmit ECF (Rhipicephalus spp) and Anaplasmosis (Amblyomma spp). These tick spp are widely distributed in the country.
Severity for the affected category	High (70-80%)
Effect on the ecosystem	None
Severity for humans	None
Effects on economy	Big loss in terms of cattle death, high mortality and reduction of income. Cost of disease control and treatment is very high.
Possible mitigation actions/Countermeasures	Tick control and vaccination
Possible prevention measures	Tick control through spraying with effective acaricide; vaccination of high value cattle
CS 4.7 Lumpy Skin Disease (LSD)	

Year of outbreak	Endemic
Affected region	Endemic country-wide
Category affected	Mainly cattle
Description	Highly contagious viral disease mechanically transmitted by a range of arthropods including biting insects and ticks
Severity for the affected category	High morbidity and low mortality
Effect on the ecosystem	Land degradation
Severity for humans	Economic
Effects on economy	Limited, significant production losses
Possible mitigation actions/Countermeasures	Vaccination treatment and control, of cattle movement
Possible prevention measures	Vaccination
CS 4.8 Black Quarter	
Year of outbreak	Can occur in any season but has been observed mostly in rain seasons
Affected region	Endemic country-wide
Category affected	Cattle and Sheep
Description	Soil Borne bacterial infections occur during the rainy season and affect cattle and sheep. In sheep, infections normally follow muscle injury allowing penetration of the causative bacteria Affected subjects often die suddenly
Severity for the affected category	High morbidity and high mortality
Effect on the ecosystem	Land degradation due to lack of fertiliser
Severity for humans	Economic
Effects on economy	Loss is due to animal death and cost of vaccination
Possible mitigation actions/Countermeasures	Annual vaccination, Hygienic disposal of carcasses
Possible prevention measures	Annual vaccination, Hygienic disposal of carcasses
CS 4.9 Swine Erysipelas	
Year of outbreak	Endemic
Affected region	Endemic country-wide
Category affected	Pigs

Description	Disease due to a bacterium Erysipelothrix rhusiopathiae, main symptom is reddish colours appearing particularly on ears, neck, flank and legs. Morbidity and mortality is very high and the spread is very quick. Treatment is done using Penicillin and Phenylbutazone, vaccination is also possible but done every 6 months. Biosecurity is the most effective measure of control.
Severity for the affected category	High
Effect on the ecosystem	Economic
Severity for humans	Lower
Effects on economy	Big loss in terms of pig death, high mortality cost of disease control and treatment very high.
Possible mitigation actions/Countermeasures	Vaccination, treatment and biosecurity measures.
Possible prevention measures	Vaccination, Biosecurity measures
CS 4.10 African Swine Fever (ASF)	
Year of outbreak	1984
Affected region	Country -wide
Category affected	Pigs
Description	Disease due to a virus, main symptom is reddish colour appearing particularly on ears, neck, flank and legs. Morbidity and mortality are very high and the spread is very quick. There is no treatment or vaccine. Biosecurity is the most effective measure of control.
Severity for the affected category	High
Effect on the ecosystem	None
Severity for humans	None
Effects on economy	Big loss in terms of pig death, high mortality and Cost of disease control very high.
Possible mitigation actions/Countermeasures	Biosecurity measures only because there is no vaccine.
Possible prevention measures	Biosecurity only because no vaccine
CS 4.11 Newcastle Disease	
Year of outbreak	Endemic
Affected region	Country wide

Category affected	Poultry
Description	The disease affects the flock at all ages particularly in the young. The symptoms are general signs like sleeping syndrome, but the main characteristic of the disease is a bluish diarrhoea and petechiae inside proventriculus mucus when post mortem is performed.
Severity for the affected category	High
Effect on the ecosystem	None
Severity for humans	None
Effects on economy	Very high because of high morbidity and mortality
Possible mitigation actions/Countermeasures	Vaccination, treatment with antibiotics and vitamins
Possible prevention measures	Vaccination and biosecurity, and establishment of a surveillance and early warning system
CS 4.12 Gumboro Disease	
Year of outbreak	Endemic
Affected region	Country wide
Category affected	Poultry
Description	The disease affects the young flock at about 8 weeks of age. The symptoms are general signs like sleeping syndrome, but the main characteristic of the disease is petechiae on the breast muscles.
Severity for the affected category	High
Effect on the ecosystem	None
Severity for humans	None
Effects on economy	Very high because of high morbidity and mortality
Possible mitigation actions/Countermeasures	Vaccination, treatment with antibiotics and vitamins
Possible prevention measures	Vaccination and biosecurity, establishment of a surveillance and early warning system
CS 4.13 Trypanosomiasis	
Year of outbreak	Endemic
Affected region	Eastern province (Kayonza, Gatsibo, Nyagatare and Kirehe districts)
Category affected	Cattle

Description	Trypanosomiases is a hemoparasite transmitted to cows by Tsetse fly bites. Symptoms are loss of appetite, loss of weight and milk production decrease, hair dressed and death after a long time of illness
Severity for the affected category	High
Effect on the ecosystem	As the disease is transmitted by Tsetse flies, people can destroy forests for mitigating the disease
Severity for humans	None
Effects on economy	High losses due the weight loss, decreased milk production, cost of prevention and treatment products and deaths
Possible mitigation actions/Countermeasures	Use of drugs like Diminazene for treatment and Trypamidium for prevention, Tsetse fly control
Possible prevention measures	Tsetse fly control by use of traps and bush clearing. Chemicals like Trypamidium are also used in prevention
CS 4.14 Varroosis	
Year of outbreak	Endemic
Affected region	Country wide
Category affected	Bees
Description	Varroa mite is an external parasite for bees belonging to Arachnida. The common species is Varroa destructor. It is a parasite which feeds and reproduces on Apis mellifera. A very high mortality appears in bees colonies
Severity for the affected category	High
Effect on the ecosystem	When bees die, the pollination of plant decreases.
Severity for humans	None
Effects on economy	Very high because of decrease of honey production
Possible mitigation actions/Countermeasures	Chemicals like powdered sugar roll, alcoholic wash, acaricide like pyrethroids, Formic acid, Thymol are used. However, it is very difficult to combat varroosis
Possible prevention measures	IPM (Integrated prevention methods) is recommended by combining cultural (reduce reproduction), mechanical (kill by physical means like trapping) and chemical methods.
CS 4.15 Peste Des Petits Ruminants (PPR)	
Year of outbreak	2020

Affected region	Suspected in districts bordering Uganda, Tanzania and Burundi, but cases are basically found in Nyagatare, Gatsibo, Kayonza and Kirehe districts
Category affected	Sheep and Goats
Description	Peste des Petits ruminants is a viral disease. It affects only goats and sheep. Clinical signs are fever, loss of appetite, pneumonia, coughing, nasal and lacrimal discharges, diarrhoea. It is highly contagious and lethality is high.
Severity for the affected category	Medium
Effect on the ecosystem	None
Severity for humans	None
Effects on economy	Loss of revenue for farmers due to livestock deaths
Possible mitigation actions/Countermeasures	Annual vaccination and epidemio-surveillance
Possible prevention measures	Annual vaccination and animal movement control
CS 4.16 Helminthiasis	
Year of outbreak	Endemic
Affected region	Country – wide
Category affected	All domestic animals (cattle, goat, sheep, pigs, poultry, rabbit)
Description	The damage is caused by all larval instars which feed on tomato plants at any growth stage. The larvae feed inside the leaves producing necrotic galleries on leaves. Galleries can also be formed on stems and the growth of affected plants is reduced. Holes appear on affected fruits which can drop before the maturity stage
Severity for the affected category	Medium
Effect on the ecosystem	None
Severity for humans	Some species are zoonotic
Effects on economy	Big loss due to weight loss, decrease of milk production and death
Possible mitigation actions/Countermeasures	Hygiene is the main mitigating measure to avoid eggs and larva spreading. Regular deworming at least every 3 months for the whole herd
Possible prevention measures	Hygiene and systematic deworming
CS 4.17 Outbreak of Fall Armyworm	
Year of outbreak	2017

Affected region	Country -wide
Category affected	Maize, sorghum
Description	Initial fall armyworm damage appears as ragged holes in the leaves of maize plants. Larvae will also move to the ear as plants begin to tassel and young ears become available. The ear may be partly or totally destroyed. Damage to the ear may be much more important than leaf damage.
Severity for the affected category	Medium (60%)
Effect on the ecosystem	Misuse of pesticides (overdose and high frequency of application), pesticides residues remnant in the environment
Severity for humans	Food insecurity, depletion of households incomes, health hazards caused by the use of pesticides
Effects on economy	Low productivity, decreased incomes and food availability, increased food prices, production costs and importation of pesticides
Possible mitigation actions/Countermeasures	Early warning and monitoring systems, utilisation of fall armyworm tolerant or resistant varieties, utilisation of biological and chemical control
Possible prevention measures	Early warning and monitoring systems, utilisation of fall armyworm tolerant or resistant varieties, utilisation of biological and chemical control
CS 4.18 Outbreak of Maize Lethal Necrosis disease (MLN)	
Year of outbreak	2013
Affected region	Country -wide
Category affected	Maize
Description	Diseased plants develop chlorotic mottle on the leaves starting from the leaves in the whorl and extending upwards toward the leaf tip, mild to severe leaf mottling, dwarfing and premature aging of the plants,
Severity for the affected category	High (100%)
Effect on the ecosystem	Loss of biomass commonly used as feed, mulching and manure (diseased plants are uprooted and destroyed)
Severity for humans	Food insecurity, depletion of households incomes
Effects on economy	Low productivity, decreased incomes and food availability, increased food prices, production costs and disruption of seed system (zero tolerance)

Possible mitigation actions/Countermeasures	Monitoring systems, utilisation of MLN tolerant or resistant varieties, utilisation of MNL free seeds, avoid transport of maize residues from infected areas to other places
Possible prevention measures	Monitoring systems, utilisation of MLN tolerant or resistant varieties, utilisation of MNL free seeds, avoid transport of maize residues from infected areas to other places
CS 4.19 Outbreak of Banana Xanthomonas Wilt Disease	
Year of outbreak	2005
Affected region	Country – wide
Category affected	Banana
Description	Infected stems produce a thick yellow ooze 5–15 minutes after being cut. Pockets of cream-yellow coloured bacterial ooze within leaf bases of the stem. Yellow and brown streaking in vascular tissues, especially the stem. Wilting of bracts, followed by shrivelling and rotting of the male buds.
Severity for the affected category	High (100%)
Effect on the ecosystem	Loss of some local banana varieties, loss of biomass commonly used as feed, mulching and manure (diseased plants are uprooted and destroyed)
Severity for humans	Food insecurity, depletion of households' incomes
Effects on economy	Low productivity, decreased incomes and food availability and increased food prices
Possible mitigation actions/Countermeasures	Monitoring systems, utilisation of clean planting materials (from tissue culture), uprooting and destroying diseased plants
Possible prevention measures	Monitoring systems, utilisation of clean planting materials (from tissue culture), uprooting and destroying diseased plants
CS 4.20 Outbreak of Banana Fusarium Wilt Disease	
Year of outbreak	2001
Affected region	Country -wide
Category affected	Banana
Description	Symptoms include yellowing, stunting, and death of seedlings and yellowing and stunting of older plants. Infected plants wilt readily, lower leaves yellow and dry, the xylem tissues turn brown, and the plant may die. In the early stages of disease, the roots are not rotted.
Severity for the affected category	High (100%)

Effect on the ecosystem	Loss of several local banana varieties, loss of biomass commonly used as feed, mulching and manure (diseased plants are uprooted and destroyed)
Severity for humans	Food insecurity, depletion of households' incomes
Effects on economy	Low productivity, decreased incomes and food availability and increased food prices
Possible mitigation actions/Countermeasures	Monitoring systems, utilisation of clean planting materials (from tissue culture), uprooting and destroying diseased plants, use of resistant varieties
Possible prevention measures	Monitoring systems, utilisation of clean planting materials (from tissue culture), uprooting and destroying diseased plants, use of resistant varieties
CS 4.21 Outbreak of Cassava Mosaic Virus Disease (CMVD)	
Year of outbreak	2001
Affected region	Country -wide
Category affected	Cassava
Description	Symptoms include yellowing, stunting, and death of seedlings and yellowing and stunting of older plants. Infected plants wilt readily, lower leaves yellow and dry, the xylem tissues turn brown, and the plant may die.
Severity for the affected category	High (100%)
Effect on the ecosystem	Loss of CMVD susceptible varieties which were highly preferred by farmers
Severity for humans	Food insecurity, depletion of households incomes, shift from cassava to other crops such as maize
Effects on economy	Low productivity, decreased incomes and food availability and increased food prices
Possible mitigation actions/Countermeasures	Monitoring systems, utilisation of resistant/ tolerant varieties and best crop management practices
Possible prevention measures	Monitoring systems, utilisation of resistant/ tolerant varieties and best crop management practices
CS 4.22 Outbreak of Cassava Brown Streak Virus Disease (CBSD)	
Year of outbreak	2009
Affected region	Country -wide
Category affected	Cassava

Description	The disease is characterised by distinct vein chlorosis and streak symptoms on leaves and stems and necrosis of storage roots. This necrosis can encompass large areas of the root, rendering it inedible so that the entire cassava harvest can be lost
Severity for the affected category	High (100%)
Effect on the ecosystem	Loss of all local and improved CMD varieties
Severity for humans	Food insecurity, depletion of households' incomes, shift from cassava to other crops such as maize
Effects on economy	Low productivity, decreased incomes and food availability and increased food prices
Possible mitigation actions/Countermeasures	Monitoring systems, utilisation of resistant varieties and best crop management practices
Possible prevention measures	Monitoring systems, utilisation of resistant varieties and best crop management practices
CS 4.23 Outbreak of Mango Mealybug	
Year of outbreak	2019
Affected region	Country -wide
Category affected	Mango, citrus species, guava, banana and ornamental plant species
Description	Mealybugs suck sap from tender leaves, petioles and fruits. Seriously attacked leaves turn yellow and eventually dry. This can lead to shedding of leaves, inflorescences, and young fruit.
Severity for the affected category	High (100%)
Effect on the ecosystem	Utilisation of pesticides with wide spectrum, misuse of pesticides (overdose and high frequency of application); disruption of ecosystem equilibrium
Severity for humans	Depletion of households incomes.
Effects on economy	Low productivity, decrease in produce quality, decreased incomes; increased mango and citrus fruits production costs, prices and importation
Possible mitigation actions/Countermeasures	Monitoring systems, utilisation of biological control, appropriately use of pesticides, best agricultural management practices
Possible prevention measures	Monitoring systems, utilisation of biological control, appropriately use of pesticides, best agricultural management practices
CS 4.24 Passion Fruit Woodiness Diseases	

Year of outbreak	2002
Affected region	Country -wide
Category affected	Passion fruits
Description	On the leaves, dark green patterns develop with light yellow spots. The leaves are often distorted, puckered and crinkled. The fruits are smaller than normal, deformed with thick skins and small centres containing the pulp. The symptoms are said to be worse in cool weather.
Severity for the affected category	High (100%)
Effect on the ecosystem	Disruption of passion fruit cropping systems
Severity for humans	Depletion of households' incomes
Effects on economy	Low productivity, decrease in produce quality, decreased incomes; increased passion fruits production costs, prices and importation
Possible mitigation actions/Countermeasures	Monitoring systems, best agricultural management practices, utilisation of clean planting materials via tissue culture
Possible prevention measures	Monitoring systems, best agricultural management practices, utilisation of clean planting materials via tissue culture
CS 4.25 Antestia Bug	
Year of outbreak	2006
Affected region	Country -wide
Category affected	Coffee
Description	Both adults and nymphs cause severe damage to green berries by feeding and indirectly by the transmission of a fungus (Nematospora coryli), which causes rotting of beans and resulting in potato taste. The bug also attacks flower buds and shoots causing blackening of flower buds with no flower or fruit set.
Severity for the affected category	low (40%)
Effect on the ecosystem	Utilisation of pesticides
Severity for humans	Depletion of households' incomes
Effects on economy	Low productivity, decrease in produce quality (potato taste defect), decreased incomes; increased coffee production costs
Possible mitigation actions/Countermeasures	Monitoring systems, best agricultural management practices, appropriately use of pesticides
Possible prevention measures	Monitoring systems, best agricultural management practices, appropriately use of pesticides

CS 4.26 Unexpected Drought Spell Periods	
Year of outbreak	2016
Affected region	Whole country, specifically eastern and southern parts
Category affected	All crops
Description	Typical drought stress symptoms in plants include leaf rolling, stunning plants, yellowing leaves, leaf scorching, permanent wilting
Severity for the affected category	Medium (50%)
Effect on the ecosystem	Disruption of ecosystem equilibrium, loss of crop species, outbreak of new diseases and pests
Severity for humans	Food insecurity, depletion of households' incomes, increase in malnutrition and health problems
Effects on economy	Low crop productivity, decrease in produce quality, decreased incomes, depletion of households' incomes and national revenues
Possible mitigation actions/Countermeasures	Drought resilient agricultural practices such as drought tolerant crop varieties, mulching, greenhouses and hydroponics; irrigation; reforestation; crop insurance
Possible prevention measures	Drought resilient agricultural practices such as drought tolerant crop varieties, mulching, greenhouses and hydroponics; irrigation; reforestation; crop insurance
CS 4.27 Unexpected Heavy Rains and Flooding	
Year of outbreak	1999
Affected region	Unexpected heavy rains in the whole country and flooding in marshlands and along rivers
Category affected	All crops
Description	Flower, leaf, or fruit drop are all symptoms of waterlogging stress on plants. Root crops may show areas of cell death that appear as dark areas. Plants damaged by flooding are usually elongated and weak. Plants lose colour, turning gradually white, and leaves have a mud film. The symptoms of flooding like lodging due to strong wind, strong rainfall, and long period (e.g. a week) of cloudiness
Severity for the affected category	Medium (50%)
Effect on the ecosystem	Disruption of ecosystem equilibrium, loss of crop species, outbreak of new diseases and pests, increase in severity of fungal diseases
Severity for humans	Food insecurity, depletion of households' incomes, increase in malnutrition and health problems, loss of human lives

Effects on economy	Low crop productivity, decrease in produce quality, decreased incomes, depletion of household incomes and national revenues. loss of livestock, destruction of infrastructures
Possible mitigation actions/Countermeasures	Erosion control, reforestation, watershed management, rural resettlement; crop insurance
Possible prevention measures	Erosion control, reforestation, water management, rural resettlement; crop insurance
CS 4.28 Landslides	
Year of outbreak	1999
Affected region	Northern, western and southern parts
Category affected	All crops
Description	Bulging ground appears at the base of a slope. Water breaks through the ground surface in new locations. Fences, retaining walls, utility poles, or trees tilt or move. A faint rumbling sound that increases in volume is noticeable as the landslide nears.
Severity for the affected category	low (40%)
Effect on the ecosystem	Disruption of ecosystem equilibrium, loss of crop species
Severity for humans	Food insecurity, depletion of households' incomes, increase in malnutrition and health problems, loss of human lives
Effects on economy	Decreased incomes, depletion of households' income and national revenues, loss of livestock, destruction of infrastructures
Possible mitigation actions/Countermeasures	Reforestation, rural resettlement, crop insurance
Possible prevention measures	Reforestation, rural resettlement, crop insurance
CS 4.29 White Grubs	
Year of outbreak	2011
Affected region	Southern and western parts
Category affected	All crops
Description	White grub larvae are the damaging stage and live in soil where they feed on plant roots. The aerial parts of affected plants become yellow to brown and they can dry. The growth of plants is affected and the height is reduced.
Severity for the affected category	low (37%)
Effect on the ecosystem	Loss of crop species, misuse of pesticides

Severity for humans	Food insecurity, depletion of households' incomes, health hazards caused by the use of pesticides
Effects on economy	Low productivity, decrease in produce quality, decreased incomes
Possible mitigation actions/Countermeasures	Make deep tillage up to 40 cm to expose the white grub larvae so that birds can eat them; Picking and killing of larvae through crushing, burning or application of insecticide
Possible prevention measures	Apply good agricultural practices, regular monitoring and seed coating
CS 4.30 Tuta Absoluta	
Year of outbreak	2015
Affected region	Southern and western parts
Category affected	Tomatoes
Description	The damage is caused by all larval instars which feed on tomato plants at any growth stage. The larvae feed inside the leaves producing necrotic galleries on leaves. Galleries can also be formed on stems and the growth of affected plants is reduced. Holes appear on affected fruits which can drop before the maturity stage
Severity for the affected category	High (100%)
Effect on the ecosystem	Loss of tomato varieties and misuse of pesticides
Severity for humans	Food insecurity, depletion of households' incomes, health hazards caused by the use of pesticides
Effects on economy	Low productivity, decrease in produce quality, decreased incomes
Possible mitigation actions/Countermeasures	Regular monitoring and pesticide application
Possible prevention measures	Apply good agricultural practices, regular monitoring
CS 4.31 Fish Death	
Year of outbreak	2016 and 2021
Affected region	Muhazi Lake, Rwamagana District, Munyiginya and Musha Sectors and Kayonza district, Kawangire sector, Eastern province of Rwanda
Category affected	Fish
Description	After Physio-chemical parameters analysis, it was, therefore, concluded that the cause of fish death was due to low Dissolved Oxygen in water. The oxygen deficiency in this zone of lake Muhazi was caused by the algal bloom. The algal bloom in this particular area was triggered some days before this event. There was the wind which caused the mixing of the deep water of the lake containing a lot of nutrients with upper water.

	The minerals plus the good sunshine caused a quick development of algae called “algal bloom”. These phytoplankton produce Oxygen during the day by Photosynthesis but consume a lot of oxygen during the night. Consequently, the fish did not get enough oxygen and died.
Severity for the affected category	High (100%)
Effect on the ecosystem	High
Severity for humans	Food insecurity, depletion of households’ income
Effects on economy	Low productivity, decreased incomes
Possible mitigation actions/Countermeasures	Check different water parameters [Dissolved Oxygen (DO), pH, Temperature, NH4, NO3, and Water transparency] on a daily basis; Monitor phosphorus and nitrogen levels since their high concentrations influence the fast growth of algae that the ecosystem cannot handle which is known as “algal bloom”. In return, this seriously reduces oxygen in the water. Move their cages to give enough space between one cage and another to facilitate the water exchanges which helps to increase the oxygen level where DO has been observed to be not suitable for tilapia life. Reduce the stocking density in each cage. Harvest the mature fish between the range of 500 g to 1kg.
Possible prevention measures	(1)Monitor the lake regularly (once a month) to record water parameters and limnological data at different layers of the lake mostly focusing on-site with cage fish farming; (2) Fast track the inclusion of aquaculture in the subsidised insurance scheme like other commodities in agriculture and animal resources; (3) Develop cage fish farming Guidelines for each lake (Kivu, Burera, Ruhondo, and Muhazi) that were recommended to be suitable for cage fish farming in RWANDA; (4) Monitor farms regularly to avoid exceeding the capacity of given concession is also a high priority; (5) Limit the number of fish farming projects in shallow lakes; and (6) Training of farmers on water parameter monitoring and biosecurity measures for their Projects.

2.5 Nigeria

Nigeria [9] whose national capital is Abuja is located on the western coast of Africa with a diverse geography, with climates ranging from arid to humid equatorial. However, Nigeria’s most diverse feature is its people with the country having abundant natural resources, notably large deposits of petroleum and natural gas. Despite the country being a leader in various types of agricultural production, such as palm oil, cocoa beans, pineapple, and sorghum and being a large global exporter in this sector. Oil, fruits, nuts, seeds are among the ten best performing, the country’s agricultural sector faces many challenges which impact on its productivity and below are some of the documented historical case studies [10].

Table 5: Historical case studies for Nigeria.

CS 5.1 Fall Armyworm Infestation	
Year of outbreak	2016
Affected region	The infestation affected many states in Nigeria, including Borno, Adamawa, Gombe, Bauchi, Taraba, Plateau, Kaduna, and Kano, among others
Category affected	Maize, sorghum, millet, and other cereal crops.
Description	The Fall Armyworm infestation is a destructive pest that attacks maize and other cereal crops. The larvae of the pest feed on leaves, causing significant damage to the plants, leading to a reduction in crop yield.
Severity for the affected category	The infestation caused significant damage to maize crops, with up to 50-80% yield losses reported in some areas.
Effect on the ecosystem	The infestation could have negative impacts on the cereal farming ecosystem, as it may disrupt the food web and affect other organisms that depend on the crops.
Severity for humans	The infestation had negative impacts on food security, as maize and other cereal crops are staple foods in many parts of Nigeria.
Effects on economy	The infestation could have negative impacts on the economy, as maize is a major crop in Nigeria, and the reduction in production could lead to increased prices for the crop.
Possible mitigation actions/Countermeasures	Mitigation actions could include the use of pesticides, biological control measures, and cultural practices such as crop rotation and intercropping.
Possible prevention measures	Prevention measures could include the use of early warning systems, proper quarantine procedures, and the promotion of integrated pest management strategies.
More info	The Fall Armyworm infestation is a global problem, and it is estimated to have caused up to $3 billion in crop losses globally. The infestation was first reported in Nigeria in 2016 and has since spread to many other African countries. The Food and Agriculture Organization (FAO) of the United Nations has been working with governments and other stakeholders to help mitigate the impacts of the infestation.
CS 5.2 Maize Lethal Necrosis	
Year of outbreak	2013
Affected region	The disease has been reported in many states in Nigeria, including Plateau, Kaduna, and Kano, among others
Category affected	Maize crops

Description	Maize lethal necrosis is a viral disease that affects maize plants, causing the leaves to become yellow and the plant to become stunted. The virus is spread by insects, and once a plant is infected, there is no cure for the disease.
Severity for the affected category	The disease can cause significant damage to maize crops, leading to up to 100% yield losses in severe cases
Effect on the ecosystem	The disease could have negative impacts on the ecosystem, as it may disrupt the food web and affect other organisms that depend on maize crops
Severity for humans	The disease could have negative impacts on food security, as maize is a staple food in many parts of Nigeria. The reduction in maize production could also lead to increased prices for the crop
Effects on economy	The disease could have negative impacts on the economy, as maize is an important crop in Nigeria, with the country being one of the largest producers of the crop in Africa. The spillover effects extend to animal feed production as maize is a major input
Possible mitigation actions/Countermeasures	Mitigation actions could include the use of disease-resistant maize varieties, cultural practices such as the removal of infected plants, and the use of insecticides to control the spread of the disease
Possible prevention measures	Prevention measures could include the use of clean planting materials, the promotion of disease-resistant varieties, and the use of integrated pest management strategies.
More info	Maize lethal necrosis is a significant problem in many parts of sub-Saharan Africa, and it is estimated to cause significant economic losses each year. The disease is a major threat to food security, as maize is an important staple food in many countries in the region. Efforts are ongoing to develop disease-resistant maize varieties and to promote the use of integrated pest management strategies to help mitigate the impacts of the disease.
CS 5.3 Recurrent Flooding	
Year of outbreak	Floods are a recurring event in Nigeria, and the country has experienced several major flood events in recent years, including in 2012 and 2020
Affected region	Floods can affect many parts of Nigeria, but the areas most at risk are those located in low-lying areas and those close to rivers or other bodies of water.
Category affected	Floods can affect both crops and livestock, as well as infrastructure and homes.

Description	Heavy rainfall or the overflow of bodies of water. Floods can cause significant damage to crops, livestock, and infrastructure, and can lead to loss of life and displacement of people
Severity for the affected category	The severity of the impact of floods can vary depending on the intensity and duration of the event. In some cases, floods can cause significant damage to crops, livestock, and infrastructure, leading to economic losses and food insecurity.
Effect on the ecosystem	Floods can have negative impacts on the ecosystem, as they can disrupt the food web and affect other organisms that depend on the affected areas
Severity for humans	Floods can have significant impacts on human populations, as they can lead to loss of life, displacement of people, and damage to homes and infrastructure. Floods can also lead to food shortages and economic losses.
Effects on economy	Can lead to damage to crops and infrastructure, as well as loss of income and economic activity.
Possible mitigation actions/Countermeasures	Early warning system, as well as the promotion of sustainable land use practices to reduce the risk of flooding
Possible prevention measures	Prevention measures could include the promotion of early warning systems, the establishment of disaster management plans, and the adoption of measures to reduce greenhouse gas emissions and mitigate climate change.
More info	Floods are a significant problem in Nigeria, and the country has experienced several major flood events in recent years. Efforts are ongoing to improve flood control infrastructure and to promote sustainable land use practices to reduce the risk of flooding and mitigate the impacts of floods when they do occur.
CS 5.4 Leaf Miner (Tuta Absoluta)	
Year of outbreak	2016-2017
Affected region	The disease has been reported in many states in the northern part of Nigeria, including Kaduna, Katsina, Jigawa, Zamfara, Bauchi, Sokoto and Kano, among others
Category affected	Tomato crops
Description	Tomato leaf miners popularly known as Tuta absoluta is a serious pest in Africa. The larva feeds upon tomato plants, producing large galleries in leaves, burrowing in stalks, and consuming apical buds and green and ripe fruits

Severity for the affected category	The infestation caused significant damage to Tomato crops leading to above 80% yield losses in most cases reported in some areas.
Effect on the ecosystem	The infestation could have negative impacts on the ecosystem, as it resulted in excessive use of pesticides for the insect control which could lead to chemical pollution or environmental poisoning.
Severity for humans	The attack led to economic losses for farmers, increase in cost of living for consumers because of price increase for the crop resulting in nutritional insecurity.
Effects on economy	The attack caused output loss, equivalent to 720, 000 metric tons (MT) which is 40% of the total annual production in the country. This led to price hikes due to scarcity.
Possible mitigation actions/Countermeasures	Mitigation actions could include the adoption of integrated pest management strategies.
Possible prevention measures	Prevention measures could include the use of disease-resistant varieties, and adoption of phytosanitary measures.
More info	
CS 5.5 African Swine Fever (ASF)	
Year of outbreak	First case was in 1997 but a worse case was reported in 2019-2020
Affected region	The disease has been reported in many states in the Western and Eastern part of Nigeria
Category affected	Pigs (Livestock)
Description	There has been a sporadic attack of African Swine Fever (ASF) in the past years. Nigeria experienced repeated outbreaks of this ASF in pig herds between 1997 and 2005 in the southwest region of the country that eradicated over hundred thousand of the livestock but the recent outbreak between 2019 and 2020 claimed over 500,000 pigs which threatened the livelihoods of over 3,000 farmers and death of 4 others due to the shock.
Severity for the affected category	The infestation was very high causing nearly a million loss of pigs.
Effect on the ecosystem	The disease had impacts on the ecosystem, with environmental pollution from carcasses of infested pigs
Severity for humans	The disease led to economic losses for farmers, loss of capital, low sales from pig feed and loss of safety nets to some families.
Effects on economy	The disease had an impact on food security because pig is an important source of protein to some people in the country. It equally disrupts trade. About 20 billion naira was lost while over 20,000 jobs are at risk.

Possible mitigation actions/Countermeasures	Mitigation actions could include identification and slaughter of all infected animals. Fumigating infected pens.
Possible prevention measures	Prevention measures could include biosecurity, disease surveillance and warning systems. Vaccination strategies
More info	The ASF is a severe viral disease affecting pigs and could result in serious production and economic losses, and while there is no approved vaccine against ASF, it is not a risk to human health.
CS 5.6 Potato blight	
Year of outbreak	2022
Affected region	Plateau State
Category affected	Irish potato (Crop)
Description	Potato farming is the third most abundant root and tuber farming in Nigeria. It's a staple food in the country and currently, Nigeria is one of the best-producing Irish Potato countries in Sub-Saharan Africa. In the year 2022, the production of the crop was troubled with a strange disease simply identified as 'tomato blight'. It ravaged farms, stunts the growth and production cycle of the crop. The outbreak affected the yield of the produce leaving farmers with little or nothing to show for their investments
Severity for the affected category	The infection damaged 52,000 hectares out of the 150,000 hectares cultivated for Irish potatoes in the state.
Effect on the ecosystem	The disease could have negative impacts on the ecosystem, as it resulted in excessive use of pesticides which could lead to chemical pollution or environmental poisoning.
Severity for humans	The disease led to economic losses for farmers, hunger resulting in nutritional insecurity.
Effects on economy	The attack led to loss of potatoes worth N18 billion in the country. This led to price hikes due to scarcity
Possible mitigation actions/Countermeasures	Mitigation actions could include the adoption of integrated pest management strategies.
Possible prevention measures	Farmers opted for the use of tissue culture so that quality materials and disease-free materials can be produced.

2.6 Kenya

Kenya [11] is a country located in East Africa, bordering the Indian Ocean to the southeast. The country is known for its diverse wildlife and scenic landscapes. The climate of Kenya varies depending on the

region. Generally, the coastal areas are hot and humid while the highlands are cooler. The country has two rainy seasons: the long rains from March to May and the short rains from October to December [12]. Kenya is a major producer of tea, coffee, and horticultural products like flowers, fruits, and vegetables.

Table 6: Historical case studies for Kenya.

CS 6.1 Locust	
Year of outbreak	2020
Affected region	Multiple Regions
Category affected	Agricultural Sector
Description	In 2020 the countries in the horn of Africa as well as surrounding countries in the middle East and even India faced a deadly locust infestation. Rainy conditions, climate change, unfortunate wind directions and Covid19 meant that the perfect conditions were created for locusts to breed, creating a nearly uncontrollable infestation.
Severity for the affected category	The severity of the infestation was almost the worst seen in 75 years in the region of Kenya
Effect on the ecosystem	Pesticides used to keep the population of locusts under control contained chemicals which are harmful to humans. Articles estimate that more than 95% of the pesticides used to combat the locusts contained chemicals which were harmful to human health. They note the use of chlorpyrifos, this chemical is banned in the EU due to causing brain damage in people and even foetuses when in contact with humans.
Severity for humans	Pesticides used to fight against locusts contain chemicals which are bad for humans and foetuses. Locusts damaged crops which furthered issues of food insecurity and negatively impacted the agricultural economy in countries where the outbreak was prevalent. Rainy conditions and flooding in the Indian Ocean at the time furthered the issue by creating the perfect conditions for the locusts to breed. Added strain of Covid19 at the time also furthered the negative impacts.
Effects on economy	Economic issues particular in the Agricultural sector as many farmers lost their crops. Problems such as Covid, Flooding, Droughts and pest issues all happening consecutively meant that the scale of the issue was hard to deal with. Crop decline for a few years due to different reasons pushed many more people into food insecurity in the region, and also increased cost of goods as demand for food was not being met.
Possible mitigation actions/Countermeasures	Use of biopesticides to reduce impact on human health and surrounding ecosystems
Possible prevention measures	Use of chemicals that promote the plant's natural defence mechanisms to deter against pests e.g. chitin. Or the use of competitive species to

	locusts, as this will help reduce the damage done against non-target species.
More info	Alternative methods of administering the pesticides to target an area better and to avoid damage to the wider ecosystem. Being careful to not use groundwater contaminating chemicals near water sources for instance.
CS 6.2 Flood	
Year of outbreak	2020
Affected region	Multiple Regions
Category affected	Agricultural Sector
Description	The downpour caused flooding in many areas as rivers such as the Nzoia broke its banks and caused people to have to flee and rivers like the Turkana flooded nearby land. Furthermore, the rains also loosened the earth and caused landslides in areas, causing damage to land.
Severity for the affected category	High
Effect on the ecosystem	Flooding damaged infrastructure as well as animal habitats and left lots of arable land left unusable. Harmful animals such as poisonous snakes were displaced from their habitats and forced to encroach in spaces where humans' dwell, causing further problems. Flooding in quick succession meant that animals were left unable to cope with the rapid changes in climate, and so many species are currently struggling with loss of habitat and food chain damage.
Severity for humans	The effects of the flooding left an estimated 40,000 people homeless and a further 116,000 people displaced. Landslides caused by flooding caused damage to infrastructure and meant that access to essential services such as hospitals was also reduced. Loss of crops and livestock due to flood also pushed people further into food insecurity.
Effects on economy	Lots of money required to repair the damage to infrastructure caused by the flooding. Loss of crops mean that the agricultural sector took a massive loss, and the biggest section of Kenya's workforce is in agriculture. This pushed more people into food insecurity and placed pressure on the government to alleviate stresses caused by food insecurity and displacement due to weather conditions.
Possible mitigation actions/Countermeasures	Use of alternative water sources to accommodate for times of drought, e.g. purifying water from the sea.
Possible prevention measures	Use of flood barriers around lakes and rivers that are likely to burst their banks during periods of heavy flooding.

More info	GMO plants/using chemicals that can help boost the plant's defences against pests to help reduce competition for remaining crops after flooding.
CS 6.3 Drought	
Year of outbreak	2020 – 2022
Affected region	Multiple Regions
Category affected	Agricultural Sector
Description	The ongoing drought in Kenya has also been causing issues for people, animals and the economy in Kenya. The drought between 2020-2022 is among the worst droughts that Kenya has ever faced
Severity for the affected category	High
Effect on the ecosystem	The environment is also under threat due to these unpredictable changes as animals in the ecosystem are struggling to keep up with the rapid changes in weather.
Severity for humans	The crop shortages caused by the drought has put nearly 2.1million Kenyans at risk of starvation and has projected a crop loss of 50% for Maize (Kenya's most staple food source). Loss of crops due to drought also pushed people further into food insecurity. For almost five consecutive harvest seasons, farmers have been struggling to get good crop yield due to pressures caused by locusts, other pests, and climate issues. Lack of water and food sources has also meant that livestock populations are in decline, and in some areas farmers have lost all of their livestock either due to droughts.
Effects on economy	Loss of crops mean that the agricultural sector took a massive loss, and the biggest section of Kenya's workforce is in agriculture. This pushed more people into food insecurity and placed pressure on the government to alleviate stresses caused by food insecurity and displacement due to weather conditions. The climate hazards are estimated to have caused a knock of 3% to Kenya's economy, with signs that the unpredictable climate conditions are only going to become more severe.
Possible mitigation actions/Countermeasures	Use of alternative water sources to accommodate for times of drought, e.g., purifying water from the sea.
Possible prevention measures	Use of alternative water sources to accommodate for times of drought, e.g., purifying water from the sea.
More info	GMO plants/using chemicals that can help boost the plant's defences against pests to help reduce competition for remaining crops after drought.

CS 6.4 Maize Lethal Necrosis	
Year of outbreak	2021
Affected region	Kenya, with significant reports from the Rift Valley, Nyanza, and Western regions
Category affected	Agricultural Sector/ Maize crop
Description	Maize Lethal Necrosis is a viral disease that affects maize plants, causing severe symptoms including yellowing and stunting. The disease is spread by insect vectors, primarily thrips and leafhoppers. Infected plants exhibit chlorosis, necrosis, and in many cases, plant death. No cure is available once a plant is infected.
Severity for the affected category	The disease has caused significant yield losses in maize crops, with some areas experiencing up to 100% loss in severe cases.
Effect on the ecosystem	The outbreak led to disruptions in the ecosystem, particularly affecting species that rely on maize as a food source. The reduction in maize availability could have cascading effects on the food web.
Severity for humans	The impact on humans was profound, as maize is a staple food in Kenya. The disease led to food insecurity, higher maize prices, and economic strain on households.
Effects on economy	The economic impact was severe due to maize's central role in Kenya's agriculture. Significant losses were reported, affecting not just farmers but also industries dependent on maize, such as animal feed production.
Possible mitigation actions/Countermeasures	Mitigation included the introduction of disease-resistant maize varieties, implementing strict cultural practices like the removal of infected plants, and the use of insecticides to control the vectors.
Possible prevention measures	Prevention measures focused on the use of certified clean planting materials, promoting resistant varieties, and integrated pest management strategies to reduce the spread of the disease.
More info	MLN continues to be a significant threat to maize production in Kenya and other parts of sub-Saharan Africa. Ongoing research aims to develop more resistant maize varieties and improve management practices to mitigate future outbreaks.
CS 6.5 Foot-and-Mouth Disease (FMD) outbreak in Kenya in 2003	
Year of outbreak	2003
Affected region	Multiple regions across Kenya, with significant reports from Rift Valley, Central, and Eastern provinces
Category affected	Livestock, particularly cattle, sheep, and goats

Description	Foot-and-Mouth Disease (FMD) is a highly contagious viral disease affecting cloven-hoofed animals, including cattle, sheep, and goats. The disease is characterized by fever, blisters in the mouth and on the feet, lameness, and reduced milk production in dairy animals. FMD can spread rapidly through contact with infected animals, contaminated equipment, or even through the air.
Severity for the affected category	The outbreak led to widespread infection in livestock, causing significant losses in meat and milk production. Infected animals often experience severe weight loss, and some may die if not managed properly.
Effect on the ecosystem	The disease can have a significant impact on the ecosystem, particularly in regions where livestock play a crucial role in the agricultural economy. The outbreak can disrupt the balance of grazing lands and affect other wildlife that may come into contact with infected animals.
Severity for humans	Although FMD does not typically affect humans, the outbreak had severe indirect effects on human populations, particularly pastoralist communities that rely heavily on livestock for their livelihoods. The outbreak led to food insecurity, reduced income, and increased poverty in affected areas.
Effects on economy	The economic impact was substantial, as livestock are a critical component of Kenya's agricultural sector. The outbreak led to trade restrictions, loss of livestock productivity, and significant financial losses for farmers. The ripple effects extended to industries such as dairy production and meat processing.
Possible mitigation actions/Countermeasures	Mitigation strategies included mass vaccination campaigns, movement restrictions for livestock, culling of infected and exposed animals, and public awareness campaigns to educate farmers about the importance of disease control measures.
Possible prevention measures	Prevention measures focused on maintaining regular vaccination schedules, enforcing quarantine protocols for new or returning animals, and improving biosecurity measures at the farm and community levels.
More info	Foot-and-Mouth Disease remains a significant threat to livestock in Kenya and other parts of Africa. Ongoing efforts aim to improve vaccination coverage and enhance disease surveillance systems to prevent future outbreaks [13] [14].
CS 6.6 Cassava Mosaic Disease (CMD) and Cassava Brown Streak Disease (CBSD)	
Year of outbreak	2020
Affected region	Widespread across Kenya, including Northern, Eastern, and Rift Valley regions
Category affected	Crops and rangelands

Description	The 2020 locust invasion in Kenya was one of the worst in decades. The desert locust (Schistocerca gregaria) swarms, driven by unusual weather patterns and favorable breeding conditions, devastated crops and pasturelands. The locusts consumed large quantities of vegetation, including staple crops like maize, sorghum, and millet, as well as grazing areas vital for livestock. The invasion posed a severe threat to food security and livelihoods, particularly in arid and semi-arid regions.
Severity for the affected category	The locust swarms caused widespread destruction of crops and rangelands, leading to significant losses in food production and pasture. Some areas reported near-total destruction of crops, with millions of hectares of farmland and grazing land affected. The impact was particularly severe in regions already facing food insecurity.
Effect on the ecosystem	The locust invasion led to significant ecological disruptions, including loss of vegetation cover, which impacted soil health and biodiversity. The destruction of rangelands affected wildlife and livestock, leading to competition for the remaining food resources. The large-scale use of pesticides to control the locusts also raised concerns about environmental and human health.
Severity for humans	The invasion severely impacted food security, particularly for pastoralist and farming communities. With the destruction of crops and grazing lands, many households faced food shortages, increased malnutrition rates, and economic hardship. The invasion also exacerbated poverty and led to displacement in some affected areas.
Effects on economy	The economic impact was substantial, with losses estimated in the hundreds of millions of dollars. The agriculture sector, a critical component of Kenya's economy, was hit hard, leading to reduced crop yields, loss of livestock, and increased prices for food. The government had to allocate significant resources for emergency response and locust control efforts, straining an already stretched budget.
Possible mitigation actions/Countermeasures	Mitigation actions included aerial and ground spraying of pesticides to control the locust swarms, monitoring and early warning systems to track locust movements, and the deployment of international assistance to support local efforts. Farmers were also advised to implement adaptive strategies such as planting fast-maturing crops and diversifying income sources.
Possible prevention measures	Prevention measures focused on enhancing regional cooperation for locust surveillance and control, improving early warning systems, and investing in research to develop more effective and environmentally friendly locust control methods. Strengthening community resilience through diversification of livelihoods and improved land management practices was also emphasized.

More info	The 2020 locust invasion highlighted the vulnerability of agricultural systems to climate-related events and the importance of international collaboration in managing transboundary pests. Ongoing efforts are needed to build resilience against future invasions. [Source: FAO, 2020; World Bank, 2020]
CS 6.7 Cassava Brown Streak Disease (CBSD)	
Year of outbreak	1990s, with increasing severity in subsequent years
Affected region	Initially reported in coastal regions, later spreading to other parts of Kenya, including Western and Nyanza regions
Category affected	Cassava crops
Description	Cassava Brown Streak Disease (CBSD) is a viral disease caused by the Cassava Brown Streak Virus (CBSV). It affects cassava plants by causing necrosis of the root tissue, which results in brown streaks within the roots, making them unmarketable and unfit for consumption. Above-ground symptoms include chlorosis, leaf distortion, and stem lesions. The virus is primarily spread through infected planting material and by whitefly vectors (Bemisia tabaci).
Severity for the affected category	CBSD can cause severe yield losses, particularly in root quality, with some affected areas experiencing up to 70% losses in marketable cassava roots. Infected plants may produce roots that are unfit for consumption or sale, significantly impacting both food security and income.
Effect on the ecosystem	The outbreak of CBSD disrupts the agricultural ecosystem, particularly in areas where cassava is a staple crop. The disease can lead to the abandonment of cassava cultivation, reducing plant diversity and affecting soil health. The reduction in cassava availability can also disrupt local food chains and negatively impact other species that rely on cassava as a food source.
Severity for humans	The disease poses a serious threat to food security in regions where cassava is a major staple. The loss of cassava crops due to CBSD leads to food shortages, increased malnutrition, and economic hardship for farming communities. The reduced availability of cassava also drives up prices, further straining household food budgets.
Effects on economy	The economic impact of CBSD is significant, particularly in regions where cassava is a primary cash crop. The disease leads to reduced income for farmers, increased costs for disease management, and losses in both local and export markets. The broader economic effects include reduced agricultural productivity, increased poverty in affected regions, and strain on local and national food systems.
Possible mitigation actions/Countermeasures	Mitigation actions include the development and deployment of disease-resistant cassava varieties, the use of clean planting materials, and

	integrated pest management practices to control whitefly populations. Extension services are crucial for educating farmers on disease recognition and management practices. Additionally, rapid response measures, such as the removal and destruction of infected plants, are essential to controlling the spread of the disease.
Possible prevention measures	Prevention measures focus on the use of certified disease-free planting materials, regular monitoring and early detection of the disease, and the promotion of resistant cassava varieties. Implementing strict quarantine measures and improving the distribution of clean seed systems are also vital in preventing the spread of CBSD.
More info	CBSD continues to be a significant threat to cassava production in Kenya and across sub-Saharan Africa. Ongoing research and development efforts are focused on breeding more resistant cassava varieties, improving disease management practices, and enhancing farmer education to prevent and control future outbreaks [15].

2.7 Zoonotic Diseases

With over 100 significant public health incidents per year, the African Region is reported to have the highest burden of public health emergencies worldwide. According to a recent analysis, the number of zoonotic disease outbreaks increased significantly (by 87%) between 2003–2012 and 2013–2022, indicating the mounting issues that the Africa region faces on a yearly basis. The trend in zoonotic disease outbreaks is upward, necessitating immediate action to improve the ability to avoid, identify, and respond to public health events in a timely manner in order to minimize their impact [16].

The increase in zoonotic disease outbreaks over the last ten years may be attributed to advancements in detection and surveillance systems, but it may also be a reflection of the indirect effects of climate change on the region., and this calls to reinforce the one-health approach in disease surveillance between EU and African. Through different strategies such as the NESTLER Project, Strategies for adaptation, well-informed public health plans and policy modifications, and the creation of suitable instruments to enhance regular disease surveillance data and response systems for the benefit of both human and animal health will be urgently required.

Some of the most important zoonoses as summarized in

Table 7 include Lassa fever/Viral hemorrhagic fevers, Crimean-Congo haemorrhagic fever (CCHF), Rift Valley fever (RVF), Mpox (formerly known as monkeypox), Anthrax, Ebola Virus disease, Rabies and Yellow fever. The identification and prioritization of zoonotic diseases of greatest national concern is important to enable focused and guided use of limited resources optimally. These findings in the project are crucial to the future surveillance, prevention, and control strategies for zoonotic diseases with a targeted allocation of resources. Clinical presentation of these disease varies and ranges from mild febrile illnesses to haemorrhagic and/or encephalitis fevers/meningitis, as well as death in humans. The well-known mosquito-borne Rift Valley fever (RVF) is among the emerging diseases associated with severe morbidity and deaths of both humans and livestock with huge economic impact. RVF outbreaks

have become frequent in Kenya the most recent affected at least four counties of the northern corridor resulting in at least 10 human deaths.

Table 7 summarizes some of the most important historical cases for zoonotic diseases in

Table 7: Historical case studies for zoonotic Diseases

CS 7.1 Lassa fever	
Year of outbreak	2003–2012 and 2013–2022
Affected region	Western Africa
Category affected	Humans and Animals
Description	Lassa fever is an acute viral hemorrhagic illness caused by Lassa virus, a member of the arenavirus family of viruses.
Severity for the affected category	Endemic in Benin, Ghana, Guinea, Liberia, Mali, Sierra Leone, Togo and Nigeria, but probably exists in other West African countries as well.
Effect on the ecosystem	Wildlife and their habitat exploitation Human exposure hinges significantly on LASV ecology, which is in turn shaped by various parameters such as weather seasonality and even virus and rodent-host genetics
Severity for humans	Impairments such as Deafness, Fatalities and Damage
Effects on economy	Disrupted the market and production- supply chain
Possible mitigation actions/Countermeasures	PPEs, Health education campaigns, and surveillance
Possible prevention measures	Supportive care to patients, Avoiding/managing contacts with Rodents and proper hygiene
CS 7.2 Crimean-Congo haemorrhagic fever (CCHF)	
Year of outbreak	2003-2012 and 2013 - 2022
Affected region	Africa, the Balkans, the Middle East, and Asia.
Category affected	Humans and Animals
Description	Crimean-Congo haemorrhagic fever (CCHF) virus causes severe viral haemorrhagic fever outbreaks and is primarily transmitted to people from ticks and livestock animals. Human-to-human transmission can occur resulting from close contact with the blood, secretions, organs or other bodily fluids of infected persons.
Severity for the affected category	High, CCHF outbreaks have a case fatality rate of up to 40%. Endemic in Mauritania, Senegal, Namibia and Uganda

Effect on the ecosystem	Environmental, climatic, and anthropic factors influence CCHF spatial distribution. Animal mobility and age play a role in disease spread.
Severity for humans	CCHF outbreaks pose a threat due to high case fatality rates (10–40%), and Prevention and treatment remain challenging.
Effects on economy	Workforce disruptions, Healthcare costs, Agricultural sector disruption since it affects livestock, Tourism and trade
Possible mitigation actions/Countermeasures	Supportive care, Diagnostic tests, prophylaxis and treatment,
Possible prevention measures	Vigilance in surveillance, prevention, and control measures is crucial to mitigate its impact.
CS 7.3 Rift Valley fever	
Year of outbreak	2003–2012 and 2013–2022.
Affected region	East, South and Western Africa
Category affected	Humans and Animals
Description	Rift Valley Fever (RVF) is caused by a virus carried by mosquitoes that can spread to livestock or people. People get RVF through contact with blood, body fluids, or tissues of infected animals.
Severity for the affected category	High; there is an observable increasing trend in the number of RVF outbreaks Countries with the highest reported outbreaks include Uganda, Mauritania, Kenya, South Africa, Senegal and Mali.
Effect on the ecosystem	Affects wildlife due to its zoonotic nature
Severity for humans	Infection can cause severe disease in humans.
Effects on economy	The disease results in significant economic losses due to death and abortion among RVF-infected livestock
Possible mitigation actions/Countermeasures	Avoiding or minimizing exposure to infected ticks by using tick repellents, wearing protective clothing and early and correct removal of ticks are recommended,
Possible prevention measures	Manage interactions between people, their livestock and wildlife.
CS 7.4 Monkey pox	
Year of outbreak	2001-2022, 2023
Affected region	Central and Western African countries, East Africa
Category affected	Humans and Animals

Description	Mpox (formerly known as monkeypox) is a disease Mpox is a zoonotic disease [17], meaning it can be spread between animals and people caused by infection with a virus, known as *Monkeypox virus*. This virus is part of the same family as the virus that causes smallpox. The virus that causes mpox has been found in small rodents, monkeys, and other mammals that live in these areas.
Severity for the affected category	It has been recorded in at least 30 countries, with over 1,000 confirmed cases, however it is endemic, or found regularly, in parts of Central and West Africa. The large majority of Monkeypox were reported in Central African countries: DRC, followed by CAR, Cameroon and Congo. And the most recent being Uganda
Effect on the ecosystem	Its impact on the broader ecosystem is not well-documented. However, any disease outbreak can disrupt local ecosystems by affecting wildlife populations, food chains, and ecological interactions.
Severity for humans	Those typically at higher risk of more severe symptoms include people who are pregnant, children and persons that are immunocompromised, including people with untreated and advanced HIV disease.
Effects on economy	Measures to control outbreaks, healthcare costs, and potential disruptions to trade and travel can all influence economic outcomes
Possible mitigation actions/Countermeasures	Vaccination can also help prevent infection for those at risk. If you have any specific questions or need further information, feel free to ask!
Possible prevention measures	Avoiding physical contact with infected individuals, rodents and monkeys Practicing good hygiene
CS 7.5 Anthrax	
Year of outbreak	2003–2012 and 2013–2022
Affected region	Sub Saharan Africa
Category affected	Humans and Animals
Description	Anthrax is caused by Bacillus anthracis, which forms spores that survive for years in the environment. Cattle, sheep, and goats are at the highest risk of developing anthrax, but other farm animals, as well as wildlife and humans, can contract the disease.
Severity for the affected category	A 2.5-fold increase Countries most affected include Zimbabwe, Kenya and Uganda
Effect on the ecosystem	Environmental distribution of viable spores determines risky landscapes for herbivore exposure and subsequent anthrax outbreaks, contaminate soils, bioterrorism

Severity for humans	Causes morbidity and mortality
Effects on economy	Disrupted the market and production- supply chain
Possible mitigation actions/Countermeasures	Wearing of protective gear, Disposal of dead livestock, PPEs, Health education campaigns, and surveillance
Possible prevention measures	Vaccine for both human and livestock is available through the human vaccine has limited availability, such as for military personnel.
CS 7.6 Ebola Virus disease	
Year of outbreak	2001, 2014
Affected region	East and West Africa
Category affected	Humans and Animals
Description	Ebola is a rare but severe illness caused by ebolaviruses where Fruit bats of the Pteropodidae family are thought to be natural Ebola virus hosts. Ebola spreads through close contact with blood, secretions, organs, or other bodily fluids of infected animals (e.g., fruit bats, chimpanzees, gorillas) or humans.
Severity for the affected category	The average Ebola case fatality rate is around 50%. Case fatality rates have varied from 25–90% in past outbreaks, depending on circumstances and the response. DRC appears with the highest number of Ebola disease outbreaks in Africa with 12 outbreaks reported between 2001–2022 (37.5%), followed by Uganda (25%) and Congo (15.6%).
Effect on the ecosystem	Complex interactions between environmental changes, human behavior, and healthcare interventions.
Severity for humans	The average Ebola case fatality rate is around 50%. Case fatality rates have varied from 25% to 90% in past outbreaks, depending on circumstances and response efforts.
Effects on economy	Ebola outbreaks have far-reaching consequences beyond health, impacting trade, tourism, and livelihoods.
Possible mitigation actions/Countermeasures	Supportive care with rehydration and symptom management improves survival. Monoclonal antibody treatments (mAb114 and REGN-EB3) are recommended.
Possible prevention measures	Outbreak control involves various actions, including patient care, infection prevention, surveillance, and community engagement.
CS 7.7 Rabies	

Year of outbreak	2003–2012 and 2013–2022.
Affected region	Rabies is a serious public health problem in over 150 countries and territories, mainly in Asia and Africa,
Category affected	Humans and Animals
Description	It is a viral, zoonotic, neglected tropical disease with Dog bites and scratches causing 99% of the human rabies cases,
Severity for the affected category	Causes tens of thousands of deaths annually, with 40% being children under 15.
Effect on the ecosystem	Affects wildlife health, behaviour, and population dynamics, with potential consequences for ecosystems.
Severity for humans	Once symptoms appear, rabies is almost always fatal.
Effects on economy	The global cost of rabies is estimated to be around US$ 8.6 billion per year including lost lives and livelihoods, medical care and associated costs, as well as uncalculated psychological trauma.
Possible mitigation actions/Countermeasures	Post-exposure prophylaxis (PEP), Awareness
Possible prevention measures	Dog vaccination and bite prevention. Efforts to control rabies should consider both human and wildlife aspects to mitigate its impact
CS 7.8 Yellow fever	
Year of outbreak	2001-2022, 2023
Affected region	Most Africa Countries, Central and South America
Category affected	Humans and Animals
Description	Yellow fever is an epidemic-prone mosquito-borne preventable disease that is transmitted to humans by the bites of infected mosquitoes. Yellow fever is caused by an arbovirus (a virus transmitted by vectors such mosquitoes, ticks or other arthropods) transmitted to humans by the bites of infected *Aedes* and *Haemagogus* mosquitoes.
Severity for the affected category	As of 2023, 34 countries in Africa and 13 countries in Central and South America are either endemic for, or have regions that are endemic for, yellow fever.
Effect on the ecosystem	Yellow fever presence is associated with specific geographic and environmental factors, altitude, rainfall, diversity of non-human primate hosts, and temperature significantly influence the distribution of yellow fever cases

Severity for humans	The risk of yellow fever is highest in tropical forested environments where sylvatic transmission occurs. However, urban outbreaks demonstrate that the risk persists even in urban areas. Yellow fever can range from asymptomatic or mild cases to severe haemorrhagic fever. Severe cases have a case fatality rate of 30%–60%[3]
Effects on economy	Measures to control outbreaks, healthcare costs, and potential disruptions to trade and travel can all influence economic outcomes
Possible mitigation actions/Countermeasures	Epidemic preparedness and response, Health Education
Possible prevention measures	Vaccination, Vector control,

Though there is no 'one size fits all' approach to achieving the intersectoral collaboration, and significant resource mobilization and co-operation is required to realize a One Health approach, when it comes to gorilla/wildlife conservation there are significant common efforts. For example CTPH, member of the NESTLER consortium, has recently established a ***Gorilla Health and Community Conservation Centre***[1] where wildlife, livestock and human samples are collected and during comparative analysis studies, early warnings for disease outbreaks are shared with Uganda Wildlife Authority, Bwindi Community Hospital, Local government health and veterinary partners and partner NGOs for interventions on preventing cross-disease transmission between people, gorillas, and livestock.

It should be underlined that for pandemic cases, such as the **COVID-19 pandemic in other to prevent** diseases between gorillas and humans, the health protocol considered:

- Minimizing direct and indirect contact between gorillas and people to prevent the introduction of the SARS-CoV-2 virus to human-habituated gorillas.
- Behavior Change Communication for Conservation through community volunteers such Village Health and Conservation Team (VHCT) that carry conservation messages that focus on educating local communities about basic health and hygiene to reduce the risk of disease transmission from people to gorillas.

2.8 Water quality for aquaculture activities

Aquaculture activities require specific water quality conditions to ensure the health and growth of aquatic organisms. Poor water quality can lead to numerous problems such as disease outbreaks, reduced growth rates, and even death of the fish. While many of the parameters outlined in the EU Water Framework Directive (Directive 2000/60/EC) [18] are relevant to overall water quality, certain parameters are particularly important for aquaculture. These include both physico-chemical and biological quality elements that directly impact the health of farmed fish or other aquatic species. Some of the most important parameters are:

[1] https://ctph.org/gorilla-health-centre/

- ***Chemical and Physico-Chemical Quality Elements***.
  - ***Dissolved Oxygen:*** Dissolved Oxygen is essential for the respiration of fish and other aquatic organisms. Low oxygen levels can lead to stress or mortality in farmed species.
  - ***Temperature:*** Different species have specific temperature ranges for optimal growth. Sudden changes or inappropriate temperatures can affect metabolism, growth rates, and immune responses.
  - ***pH:*** Most aquaculture species thrive within a specific pH range (usually between 6.5 and 8.5). Extreme pH levels can cause stress, reduce growth, and increase susceptibility to disease.
  - ***Nitrogen (***Ammonia, Nitrite, Nitrate): High concentrations of ammonia and nitrite are toxic to fish. Nitrate is less toxic but should still be monitored.
  - ***Phosphorus:*** While essential in small amounts, excessive phosphorus can lead to algal blooms, which can deplete oxygen levels and produce harmful byproducts.
  - ***Salinity:*** Important for species in brackish water or marine aquaculture. The salinity must be maintained within a specific range suitable for the species being cultured.

- ***Pollutants***
  - ***Priority Substances and Other Pollutants:*** including Heavy Metals, pesticides and Industrial Chemicals.
  - ***Organic Pollutants:*** Elevated levels can lead to oxygen depletion as they are broken down by bacteria, creating a harmful environment for fish.

- ***Biological Quality Elements***
  - ***Phytoplankton:*** An important food source in certain aquaculture systems, particularly in extensive systems where natural food production is relied upon.
  - ***Macrophytes and Phytobenthos:*** Important for habitat structure and can influence water quality by stabilizing sediments and competing with algae for nutrients.
  - ***Benthic Invertebrate Fauna:*** Acts as an indicator of water quality. A diverse and balanced benthic community suggests good water quality, which is beneficial for aquaculture.

- ***Hydrological and Morphological Quality Elements.***
  - ***Flow Conditions:*** Adequate water flow is important to ensure proper oxygenation and removal of waste products. Stagnant water can lead to the buildup of harmful substances and create an unsuitable environment for aquaculture.
  - ***Water Exchange and Renewal:*** Crucial in maintaining water quality by diluting and removing waste products and excess nutrients.

Within NESTLER, we aim to establish automated methods for measuring various parameters in (near)real time. As such we focus on the water quality parameters such as pH, temperature, dissolved oxygen, total ammonia, and total suspended solids. Additional parameters that can be measured with additional

handheld equipment or laboratory analysis may be considered during the pilots execution. Nevertheless, NESTLER approach is to provide a sustainable low-cost solution that can operate without the need of costly equipment and laboratory analysis in large volumes and in low-income countries.

3 NESTLER Platform Requirements

The use cases relevant to the NESTLER project are classified into three main categories based on the historical case studies of each African partner, including Cameroon, Uganda, Ethiopia, Rwanda, Nigeria, and Kenya. Specifically, the following three use cases emerged:

1. Crop-based farming
2. Livestock farming
3. Aquaculture farming

In this section, NESTLER's Platform user and technical (functional and non – functional) requirements are identified. Each farming type has unique requirements that the system must be able to meet to provide value to the users.

3.1 User Requirements

User requirements are generated with the aim of addressing the specific needs and challenges of farmers.

3.1.1 Crop-based farming

Table 8: User requirements about crop – based farming.

ID	Requirement Description
REQ.US.1.01	The user wants to be informed about environmental factors that affect crop growth (i.e., soil moisture, temperature, electrical conductivity, etc.).
REQ.US.1.02	The user wants to be informed about crop quality.
REQ.US.1.03	The user needs to have access to accurate and up-to-date data about weather conditions on the field (i.e., temperature, relative humidity, wind speed and direction, etc.).
REQ.US.1.04	The user wants to be informed about crop-specific recommendations for planting schedules, seed varieties, and optimal growing conditions based on local climate and soil data.
REQ.US.1.05	The user needs to be informed about appropriately use of pesticides.
REQ.US.1.06	The user needs to detect diseased parts of plants (leaves, etc.).
REQ.US.1.07	The user needs to detect diseased pods of cocoa (i.e., black pod rot).
REQ.US.1.08	The user needs to detect rotten pods of cocoa.
REQ.US.1.09	The user needs to know shade management techniques for cocoa, based on environmental parameters (i.e., humidity).
REQ.US.1.10	The user needs to detect diseased berries of coffee (i.e., bark beetle).
REQ.US.1.11	The user wants to be informed about warning alerts based on disease outbreaks (i.e., remove diseased coffee pod).

REQ.US.1.12	The user wants to be informed about early warning alerts for potential diseases based on crop type, growth stage and local weather conditions.
REQ.US.1.13	The user needs to know management strategies to prevent crops diseases.
REQ.US.1.14	Monitoring of pests based on weather conditions (i.e., locusts)
REQ.US.1.15	The user needs to detect pests on the crops.
REQ.US.1.16	The user wants to be alerted when pest infestation occurs.
REQ.US.1.17	The user needs to know management strategies to control and/or prevent pest infestation.
REQ.US.1.18	Monitoring of infected areas
REQ.US.1.19	The user needs to be informed on the weather forecast for flood occurrence as an early warning mechanism.
REQ.US.1.20	The user needs to be informed on the weather forecast for drought occurrence as an early warning mechanism.
REQ.US.1.21	Monitoring areas threatened by flooding.
REQ.US.1.22	Monitoring areas threatened by drought.
REQ.US.1.23	Development of flood risk prevention plans.
REQ.US.1.24	Automated irrigation.
REQ.US.1.25	The user needs optimal irrigation schedules based on real-time weather and soil data.
REQ.US.1.26	The platform should provide a user-friendly interface that is accessible and easy to use for farmers with varying levels of technical expertise.
REQ.US.1.27	The farmer needs to learn good agricultural practices for cocoa and coffee in the face of climate change.
REQ.US.1.28	The farmer needs to know market prices for their crops and have access to local, regional, and international markets, which helps them make informed decisions about when and where to sell their products.
REQ.US.1.29	The farmer wants to be informed about post-harvest management practices, including proper storage, processing, and transportation techniques to minimize losses and maintain product quality.
REQ.US.1.30	The user wants to be informed about opportunities for value addition and agro-processing, which can increase income and diversify product offerings.
REQ.US.1.31	The user wants to be informed about new technologies, such as precision agriculture, and digital tools, that can help optimize farm management and enhance productivity.
REQ.US.1.32	The user needs information and access to improved planting materials, especially disease-resistant and climate-resilient varieties.

REQ.US.1.33	The user needs reliable access to agricultural extension services that provide guidance, training, and support in adopting best practices, new technologies, and sustainable farming techniques.
REQ.US.1.34	The user needs information on sustainable farming practices that reduce environmental impact while maintaining or increasing productivity.
REQ.US.1.35	The user needs access to effective water management strategies, including rainwater harvesting, efficient irrigation techniques, and drought-resistant crops.
REQ.US.1.36	The user needs access to financial services such as microloans, insurance, and credit facilities tailored to the agricultural sector.
REQ.US.1.37	The user requires training and capacity-building programs on climate-smart agriculture to better cope with the impacts of climate change.
REQ.US.1.38	The user wants real-time access to market information, including demand forecasts, price trends, and consumer preferences.
REQ.US.1.39	The user needs guidance on post-harvest management practices to reduce losses and maintain the quality of produce.
REQ.US.1.40	The user is interested in information on integrating nutrition-sensitive agriculture practices, such as diversifying crops and promoting biofortified varieties.
REQ.US.1.41	The user wants strategies for developing resilient supply chains that can withstand shocks such as pandemics, natural disasters, or market disruptions.
REQ.US.1.42	The user needs access to early warning systems for natural disasters, pest outbreaks, and market shocks that could impact food security.
REQ.US.1.43	The user needs access to social safety nets, such as food assistance programs or cash transfers, during periods of food insecurity or economic hardship.

3.1.2 Livestock farming

Table 9: User requirements about livestock farming.

ID	Requirement Description
REQ.US.2.01	The user wants to be informed about how to add, update and delete information regarding their livestock in the inventory.
REQ.US.2.02	The user wants to be informed about how to make data-driven decisions about product and disease control in livestock.
REQ.US.2.03	The user wants to be informed about integration into a global market in which both the EU-Africa livestock competes with lower production costs.

REQ.US.2.04	The user wants to be informed on how both old and new livestock policies will further incorporate even greater demands with respect to the environment and animal/livestock welfare.
REQ.US.2.05	The user wants to be informed on real-time monitoring of livestock and environmental conditions, allowing farmers to make data-driven decisions about growth and disease control.
REQ.US.2.06	The user wants to be informed immediately in case an outbreak occurs through an alarm mechanism.
REQ.US.2.07	The user wants to be informed on poultry vaccination calendar and biosecurity measures before starting any poultry farming.
REQ.US.2.08	The user wants to be informed on biosecurity measures before starting any poultry farming.
REQ.US.2.09	The user wants to be informed on the weather forecast for flooding occurrence as an early warning mechanism.
REQ.US.2.10	The user wants to be informed on the desired requirement of poultry parameters.
REQ.US.2.11	The user wants to be informed on the desired poultry feeding ingredients.
REQ.US.2.12	The user wants to be informed on the performance parameters of chicken through an alarm system.
REQ.US.2.13	The user wants to be informed immediately in case an outbreak is predicted through an alarm mechanism.
REQ.US.2.14	The user wants to be informed on the weather forecast for drought occurrence as an early warning mechanism to act on implementation of appropriate interventions.
REQ.US.2.15	The user wants to be informed on the breeding area/site, movement of locust and on the mitigation and prevention mechanism in case locust swarming occurs.
REQ.US.2.16	The platform should avail the user safeguarding mechanisms and early warning system in case an FMD outbreak occurs.
REQ.US.2.17	The user wants to be informed on the proper animal management, proper feed and feeding management, routine treatments, controlled movement in case an CBPP outbreak occurs.
REQ.US.2.18	The user wants to be informed on promising feeding options, quarantine measures, hygienic condition of poultry and poultry products during outbreak.
REQ.US.2.19	The user wants to be informed on the prevention and control mechanism in case Trypanosomiasis outbreak occurs

3.1.3 Aquaculture farming

Table 10: User requirements about aquaculture farming.

ID	Requirement Description

REQ.US.3.01	The user wants to be informed about the provision of databases of several aquaculture farms both technical and economic.
REQ.US.3.02	The user wants to be informed about analysis of zootechnical performance and different constituent parts of the production and management process.
REQ.US.3.03	The user wants to be informed about the provision of environmental and social sustainability of aquaculture farming.
REQ.US.3.04	The user wants to be informed about the assessment and analysis of the economic and financial performance of aquaculture farming and structure of the production processes.
REQ.US.3.05	The user wants to be informed about specific data for mapping knowledge on the prevalence of challenges/diseases and their impact on aquaculture and related productions.
REQ.US.3.06	The user wants to be informed about several challenges including the disease occurrence by site, species, year and month affecting the fish at every level and growing stage. For the identification of the principal diseases
REQ.US.3.07	The user wants to be informed about the source of suitable fish fingerling and feed for their aquaculture farm.
REQ.US.3.08	The user wants to be informed about the trophic status and water quality of major fish producing lakes for various uses including aquaculture farming and cattle watering and have access to water quality parameters that affect production in aquaculture (i.e., water temperature, pH, etc.)
REQ.US.3.09	The user wants to be informed about the intensity of invasive aquatic weed infestation in major fishing lakes and its impact on aquaculture farming sites.
REQ.US.3.10	The users want to know suitable fish species and feed source based on local climate conditions.
REQ.US.3.11	The user needs to have access to up-to-date data about weather conditions on the aquaculture field (i.e., temperature, wind speed and direction, etc.).
REQ.US.3.12	The user wants to be informed immediately in case an outbreak occurs through a predicted alarm mechanism
REQ.US.3.13	The user wants to be informed on the weather forecast for flooding occurrence as an early warning mechanism.
REQ.US.3.14	The user wants to be informed on the weather forecast for drought occurrence as an early warning mechanism.
REQ.US.3.15	The user wants to be informed on biosecurity measures

3.2 Technical Requirements

This section provides a detailed description of the technical requirements for each use case. This includes crop-based farming, livestock farming, and aquaculture farming, and covers IoT devices, satellite imagery specifications, equipment requirements etc. Moreover, functional and non – functional requirements are extracted for the NESTLER platform.

3.2.1 Crop – based farming.

3.2.1.1 SynField Precision Agriculture IoT devices

Precision Agriculture IoT devices are a type of technology that uses sensors and other tools to collect real-time data from crops and the surrounding environment that affect agricultural production. This data is analysed using Machine Learning algorithms and other advanced techniques to provide farmers with insights and recommendations on how to optimize various aspects of crop management, including irrigation, fertilizer application, pest control, and harvest timing.

For the NESTLER project, SynField [19] for precision agriculture will be used as a starting point supported by additional developments. SynField is a flexible Precision Agriculture and Controlled Irrigation solution and has been developed by Synelixis. It offers remote monitoring of climatic, environmental and soil conditions, while also providing remote control of irrigation and water management systems. The SynField ecosystem consists of:

1. the SynField nodes, which are sensor-logging autonomous systems providing remote control.
2. the SynField Cloud Server Platform that collects all SynField data and includes the decision making and automated control system.
3. the SynField android application for remote monitoring and actuator control.
4. the SynControl android application for configuring the SynField Nodes in the field.

Each SynField node may be used as a data source, interfacing with a number of various sensors. The SynField nodes can be manually controlled remotely via the SynField Control application, which is a mobile application, or via the SynField Dashboard, available as a web application. Further developments will be performed in order for the SynField nodes to be controlled automatically based on the AI outcomes. The SynField Dashboard provides monitoring information, statistical data, configurable notifications and rules. A registered user may access information about their SynField Nodes, their sensors, the fields where SynField nodes are installed, as well as the desired services and automation (e.g. solenoid valve).

Indicatively, sensors that can be connected to SynField are depicted in Figure 1 and are able to collect data for the following factors:

- Soil Moisture
- Soil Electrical Conductivity
- Leaf Wetness
- Solar Radiation
- Light
- Soil Temperature

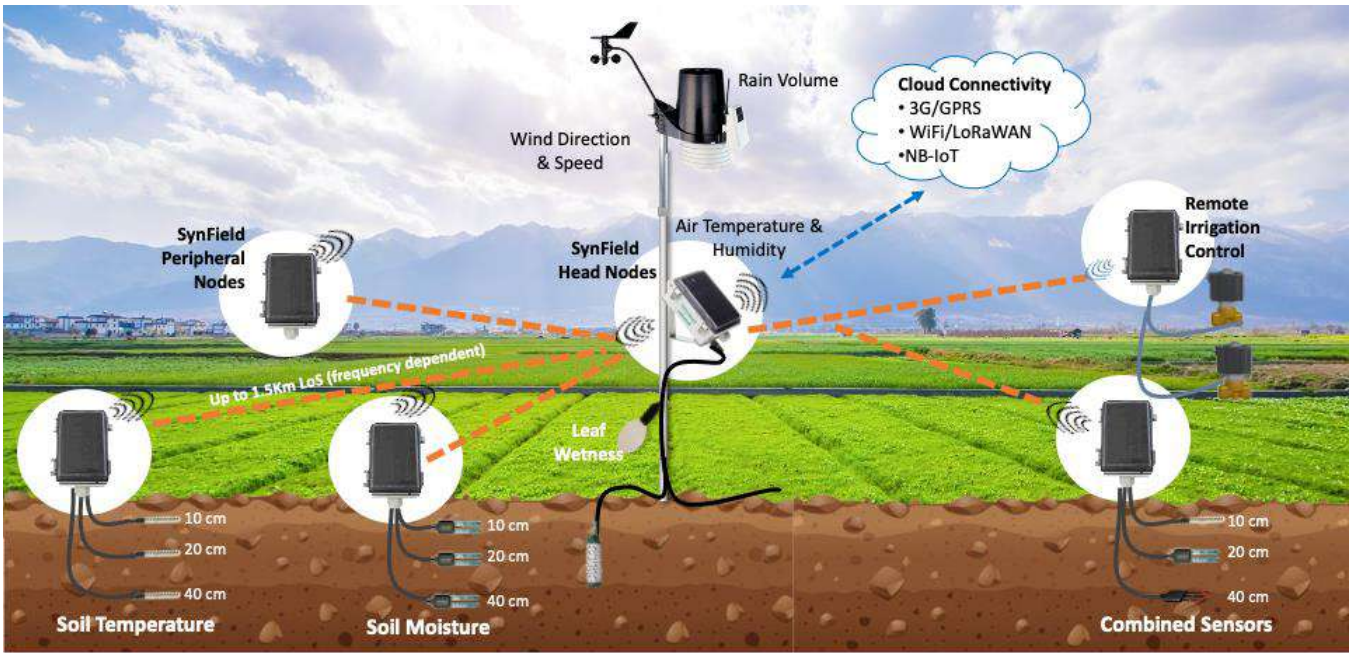

Figure 1: SynField for remote field monitoring.

IoT sensors in Precision Agriculture aims to collect real-time data of environmental factors that affect crop growth. The use of Precision Agriculture IoT devices has multiple benefits to farmers. Initially, by gathering and analysing this data, farmers can make informed decisions about the management of crops, resulting in increased yields. Moreover, by automating many aspects of crop management, Precision Agriculture IoT devices help farmers to efficiently optimize various aspects of crop productions and operations as well as to manage larger areas of land, leading to better outcomes and improved profitability. Finally, by exploiting the insights of gathered data, farmers can reduce the use of water, fertilizer and pesticides, improving resource efficiency and reducing environmental impact. Therefore, more sustainable and environmentally friendly farming practices are adopted.

At the NESTLER project, the data that will be collected from Precision Agriculture IoT devices will be used to develop and evaluate various algorithms and models for external environment and weather impact on crop-based agriculture as well as monitoring services for quality of crop yield. Specifically, this data will be utilized to implement AI/ML algorithms, aiming to extract knowledge about the interdependencies of specific crop cultivation with environmental factors. Moreover, temporal association models will be built using heterogeneous data, including among other data collected from Precision Agriculture IoT devices. By leveraging developed AI/ML models and methodologies, automated monitoring services will be created able to inform farmers and stakeholders about quality of crop yield.

3.2.1.2 Agro – Weather Stations

Agriculture is highly dependent on weather patterns, and climate change has the potential to significantly impact crops. Predictive algorithms can help farmers and policymakers to anticipate and adapt to these changes by providing early warnings of weather-related risks and enabling more accurate decision-making. Therefore, weather data needs to be collected. For this reason, the SynField Weather Station (SF-WS-02) can be used as a reliable and affordable weather station that allows farmers to measure:

- Air Temperature and Humidity
- Wind Intensity and Direction
- Rain collector
- UV and Solar Radiation (optional)

The SF-WS-02 is a modified version of Davis Vantage Pro 2 [20], that uses the mechanical parts of the Davis system, but the electronics have been replaced to interface the SynField system. This station is connected to the SynField system via a dedicated board that allows all the above sensors to communicate through a single SynField connector.

Figure 2: Davis SynField Weather Station (SF-WS-02)

The SynField system with actuators and sensors, including the weather station, is illustrated in Figure 3.

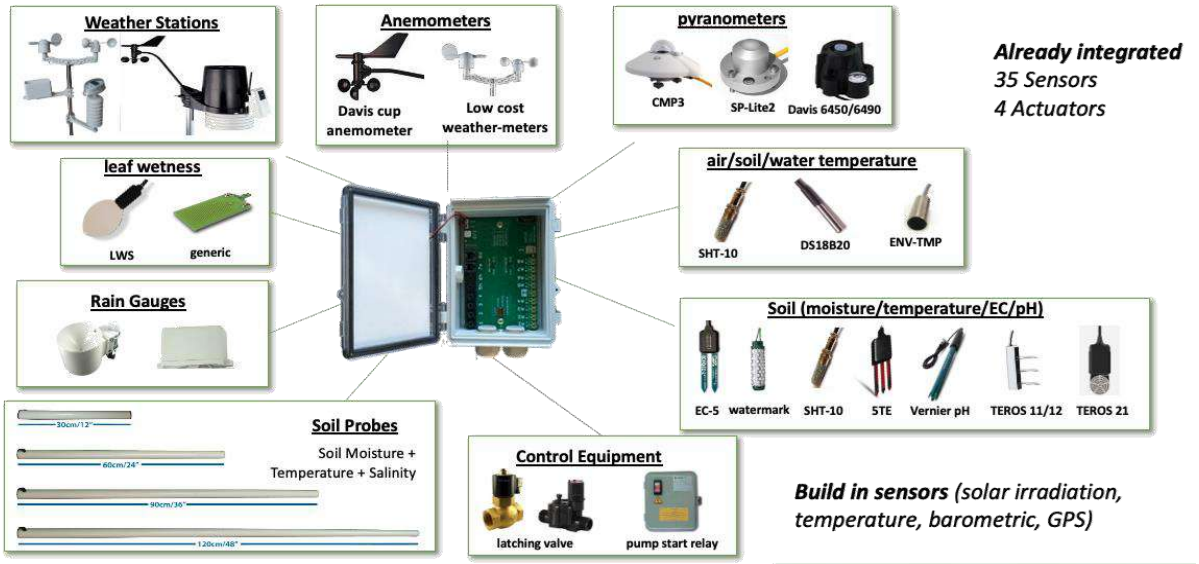

Figure 3: SynField with indicative supported sensors & actuators.

Weather stations should play a significant role in the NESTLER project by providing important information about weather conditions, which can help farmers make informed decisions. The main purposes of using weather stations in this project are:

- Accurate weather monitoring: Weather stations provide real-time data on temperature, humidity, wind speed, and other weather parameters as have already been mentioned. This information can help farmers to monitor the weather conditions in their fields accurately and make informed decisions about when to plant, irrigate, and harvest their crops.
- Crop protection: Weather stations can help also monitor weather conditions that are favourable for the growth of pests and diseases. With this information, proactive measures should be taken to protect crops.

The NESTLER project will develop predictive algorithms to evaluate the impact of weather and climate models. Advanced AI algorithms will be developed to analyse external data sources aggregated from weather stations and satellites to provide meaningful insights for farmers.

3.2.1.3 Drones

Purpose of drones in the platform architecture:

- UAV inspection services for precision farming: Video streaming services implemented from the deployment of drones for undertaking environmental surveillance.
- Implementation of computer vision toolkit to process images and video collected from the drones.
- Provision of secure communication services in the rural areas where no cellar or WiFi networks are available.
- Detection of contaminated patches of the crop in the field utilising computer vision toolkit and potentially spraying ONLY contaminated patches with pesticides, minimising level of artificial components in the crop
- Utilising computer vision tools for monitoring of the irrigation and the use of limited water resources

3.2.1.4 Satellite Imagery

The platform will integrate satellite imagery for 3 purposes: as background map in the user interface, as continuous monitoring layers, and as input to algorithms. Open-source data was selected for its availability, affordability, band selection, long temporal archive, and frequent cadence. When required, open-source data will be referenced with proper attribution.

MSI Inputs

Name	Instrument	Resolution	Bands	Level	Coverage	Cadence	Format
Sentinel-2	MSI	10m	B1-12	L2	World	5 days	SAFE

Description

The Copernicus Sentinel-2 mission, launched in 2015, comprises a constellation of two polar-orbiting satellites placed in the same sun-synchronous orbit, phased at 180° to each other. It aims at monitoring variability in land surface conditions, and its wide swath width (290 km) and high revisit time will support monitoring of Earth's surface changes. SENTINEL-2 carries an optical instrument payload that samples 13 spectral bands: four bands at 10 m, six bands at 20 m and three bands at 60 m spatial resolution [20]

Purpose

Multispectral instruments (MSI) are sensors which capture light bands at least in the visual wavelengths such as red, blue, green, frequently infrared or near infrared, and others. When the bands are combined in a composite, a true color image can be achieved (or with infrared, a false-color composite). Many algorithms which analyse the landscape can be performed on MSI-based imagery.

Justification

Sentinel-2 has a higher native resolution than other free MSI data products on the market including Landsat-8.

SAR Inputs

Name	Instrument	Resolution	Bands	Level	Coverage	Cadence	Format
Sentinel-1	IW	Varies	C	L1	World	6 days	SAFE

Description

"The mission is composed of a constellation of two satellites, Sentinel-1A and Sentinel-1B, sharing the same orbital plane, operating day and night performing C-band synthetic aperture radar imaging. SENTINEL-1 carries a single C-band SAR instrument operating at a centre frequency of 5.405 GHz. It includes a right-looking active phased array antenna providing fast scanning in elevation and azimuth, data storage capacity of 1 410 Gb and 520 Mbit/s X-band downlink capacity, supports operation in dual polarisation (HH+HV, VV+VH) and offers 4 kinds of acquisition modes. " [21].

Purpose

SAR (Synthetic Aperture Radar) is an active sensor which captures radio bands in several different wavelengths. In the case of Sentinel-1, C-band SAR is collected which allows for visualization even with clouds as the radio frequency can pass through with minimal interference. It is helpful as an additional monitoring satellite for frequently cloudy areas such as those in the tropical zones.

Justification

Sentinel-1 has the largest repository of freely available and open-sourced SAR data products on the market.

Weather

Name	Instrument	Level	Coverage	Cadence	Format
GOES-FP	SEISS	L1	World	Daily	netCDF
MeteoSAT	SEVIRI, MVIRI	L2	EU, Africa	Daily	netCDF
Sentinel-3	SLSTR	L2	World	4 days	netCDF

Description

Since 1975, NOAA's Geostationary Operational Environmental Satellites (GOES) have provided continuous imagery and data on atmospheric conditions and solar activity (space weather). The GOES-FP satellites are operated jointly by NASA and NOAA [22]

The MeteoSAT constellation consists of Geostationary satellites providing imagery for the early detection of fast-developing severe weather, weather forecasting and climate monitoring, operated by EUMETSAT [23].

The SENTINEL-3 mission is to measure sea surface topography, sea and land surface temperature, and ocean and land surface colour with high accuracy and reliability to support ocean forecasting systems, environmental monitoring and climate monitoring, operated by ESA and EUMETSAT [24].

Purpose

Weather data will be integrated into the platform as an important indicator for risk to crops for damages due to extreme patterns, such as drought, fires, floods, runoff, and frost.

Justification

GOES satellite is one of the leading free and widely available and highly utilized weather satellites on the market. MeteoSAT is perfectly positioned to measure weather patterns over Africa. Sentinel-3 is a free and widely used source of land temperature data.

Climate

Source	Variable	Unit	Resolution	Temp Res	Format
Worldclim.org	Minimum Temp	C	2.5 min	Month	GEOTIFF
	Maximum Temp	C		Month	
	Average Temp	C		Month	
	Precipitation	mm		Month	
	Solar Radiation	kJ m-2 day-1		Month	
	Wind Speed	m s-1		Month	
	Water vapor pressure	kPa		Month	

Source	Variable	Unit	Resolution	Temp Res	Format
AgERA5 (C3S)	Wind Speed	m s−1	10m	Daily	netCDF
	Dewpoint Temperature	K	0.1°	Daily	netCDF
	Temperature	K	0.1°	Daily	netCDF
	Cloud Cover	-	0.1°	Daily	netCDF
	Precipitation Flux	mm day−1	0.1°	Daily	netCDF
	Snow Thickness	Cubic cm	0.1°	Daily	netCDF
	Solar Radiation Flux	J m−2 day−1	0.1°	Daily	netCDF

Source	Variable	Unit	Resolution	Temp Res	Format
Answr	Cloud Cover	%	Km	Month	JSON
	Consecutive Dry Days	# Days	Km	Month	JSON
	Consecutive Frost Days	# Days	Km	Month	JSON
	Consecutive Summer Days	# Days	Km	Month	JSON
	Consecutive Wet Days	# Days	Km	Month	JSON
	Dew Point Temperature	C	Km	Month	JSON
	Frost Days	# Days	Km	Month	JSON
	Heating Days	# Days	Km	Month	JSON
	Ice Days	# Days	Km	Month	JSON
	Maximum Temperature	C	Km	Month	JSON

	Mean Temperature	C	Km	Month	JSON
	Minimum Temperature	C	Km	Month	JSON
	Precipitation Days (10mm)	Mm	Km	Month	JSON
	Precipitation Days (50mm)	Mm	Km	Month	JSON
	Precipitation Flux	mm	Km	Month	JSON
	Snow Thickness	cm	Km	Month	JSON
	Solar Radiation	Watt * sqkm-1	Km	Month	JSON
	Volumetric Soil Moisture	%	Km	Month	JSON

Source	Variable	Severity	Resolution	Temp Res	Format
Answr	Cold wave risk	L, M, H	Km	Month	JSON
	Drought Probability	%	Km	Month	JSON
	Flood Severity	Meters	Km	Month	JSON
	Heat Wave Probability	% LoO	Km	Month	JSON
	Windstorm Probability	% LoO	Km	Month	JSON

Description

Worldclim is a database of high spatial resolution global weather and climate data. These data can be used for mapping and spatial modelling. The data are provided for use in research activities [25].

AgERA5 Agrometeorological indicators from 1979 to present derived from reanalysis dataset contains daily surface meteorological data from 1979 to present for agricultural and ecological use cases. AgERA5 is based on the hourly ECMWF ERA5 data from ground level [26]. Answr provides the aggregated monthly statistics for each climatic variable [27]

Purpose

Understanding prior conditions which led to outbreaks of diseases in the pilot areas as well as risk to crops requires understanding of the climatic conditions under which they occurred. Climate data represents the overarching trends in weather over a longer time span. Climate data from 1970-2000 will be used as the long-term historical climatic input into the NESTLER platform.

Justification

Worldclim.org has been widely cited in numerous fields as a single repository for different kinds of climatic data over a long-time span. Additionally, the C3S (Copernicus Climate Change Service) is supported by ESA and is available freely and via API. Finally, the ANSWR platform has unique and easily accessible datasets with a basic ranked system to evaluate risk to crops, wildlife, assets, and people.

Elevation

Name	Projection	H. Datum	V. Datum	Unit	Resolution	Coverage	Format
SRTM	Geo	WGS84	EGM96	Meter	1 arc sec	World	GEOTIFF

Description

NASA's Shuttle Radar Topography Mission (SRTM) was released in 2015 based on data collected from February 2000 [28]. SRTM used an imaging radar to map the surface of Earth numerous times from different perspectives. The combination of these radar data was processed at JPL to produce a 30m global topographic map created by bouncing radar signals off Earth's surface and back to the shuttle.

Purpose

Elevation data will assist in the mapping and GIS aspects of the data analysis on the platform. SRTM is a standard and widely used dataset in many different fields and all kinds of projects.

Justification

SRTM has been a standard in many industries as a basic and free worldwide terrain dataset.

Connectivity

Satellite imagery will be connected to the platform via API (Application Programming Interface) and cloud repository connections. Inputs which are not available via API directly will be first download and stored in the cloud using AWS S3 Bucket, which includes access to all AWS tools. From the bucket, access is available via API.

Dataset	Access	Location
Sentinel-1	API	https://scihub.copernicus.eu/
Sentinel-2	API	https://scihub.copernicus.eu/
Sentinel-3	API	https://scihub.copernicus.eu/
GOES-FP	API	https://power.larc.nasa.gov/docs/services/api/
MeteoSAT	API	http://api.eumetsat.int/data/download/
WorldClim.org	Cloud	https://worldclim.org ; https://docs.aws.amazon.com/AmazonS3/latest/API/Type_API_Reference.html
AgERA5	API	https://cds.climate.copernicus.eu/
Answr	API	https://docs.answr.space/
SRTM	API, Cloud	https://opentopography.org/developers

3.2.1.5 Crop Quality Evaluation Devices

New crop quality evaluation devices will be deployed, and field tested, with cassava identified as the test case. The device estimates crop quality based on the electrical reflection and impedance properties of the sample being tested. The test instrument generates a low-power RF signal, at a single fixed frequency. The signal is injected into the sample under test (SUT) via a coaxial probe. The test instrument determines the amount of RF power reflected from the sample via the probe.

The device will connect with the NESTLER platform through readily available mobile networks in Nigeria, where a set of pilot studies will be conducted with consortium partner, IITA. Figure 4 shows the connection of the crop quality measurement device to the NESLTER platform, and a picture of the prototype device, respectively.

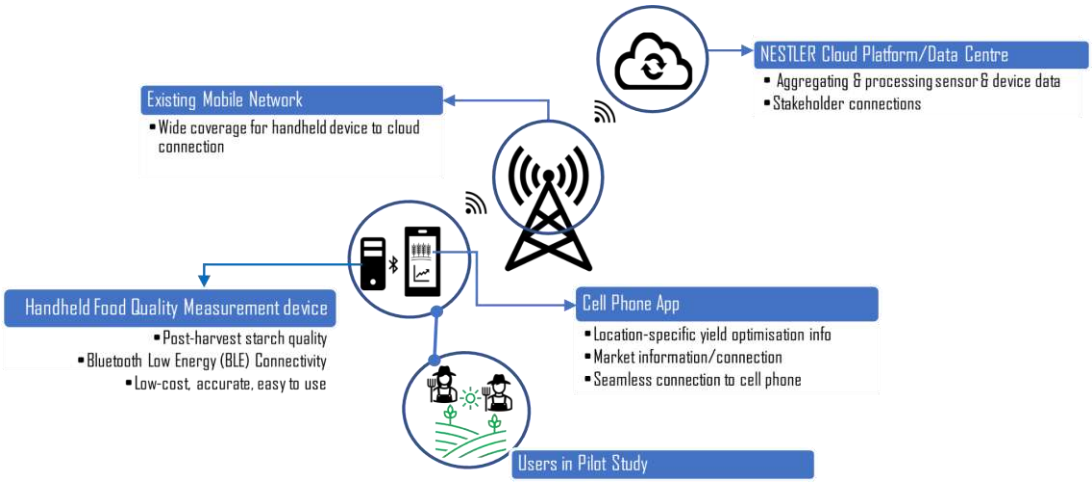

Figure 4: Connection of the crop quality measurement device

The devices are designed with Bluetooth Low-Energy (BLE) modules, through which captured data from crops will be uploaded directly to mobile phones held by users involved in the pilot study (farmers, industrial processors, plant breeding researchers etc). Measured crop quality data and associated metadata (geolocation, time stamp, user ID, device ID etc) will be uploaded to the NESLTER cloud database once the user is within the coverage of the local mobile networks. This eliminates the requirement of specially provisioned connectivity for this NESTLER subsystem and advances its commercial viability. The mobile phones connected to the handheld devices will have software installed to manage the retrieval and archiving of data from the handheld quality measurement device and subsequent upload to the NESTLER cloud platform. The design specification for crop quality measurement device is shown in Table 10.

Table 11: Design specification for crop quality measurement.

Design goals	• Improved data collection, management, and reporting. • Add wireless connectivity. • Improved user interface. • Improved power supply economy and reliability (rechargeable Li-ion battery, USB charging). • Add probe temperature measurement.
Processor	ESP32/Heltec (dual-core 32-bit MCU)/ Cypress PSoC
User Interface	• LED bar-graph starch level indication. • OLED display. • 5 keys for user input.
Connectivity	• Bluetooth (BLE). • Micro SD card backup data storage.

Power supply	Integral Li-Ion battery with USB/solar charge controller.

3.2.2 Livestock farming

Livestock monitoring with IoT devices refers to the use of connected sensors and wearable devices to track the behaviour, health, and other key parameters of livestock and their environment in real time. This technology is designed to enable livestock producers to keep track of their animals and make data-driven decisions that can improve the overall health and productivity of their livestock or even prevent any potential health hazards.

3.2.2.1 Wearable devices

The Federation of Veterinarians in Europe advises [29] all involved in animal farming to use animal-based indicators for assessing the welfare conditions of farmed animals on a routine basis. The regular monitoring of animal welfare allows the early identification of animal health and welfare issues at farm level and timely implementation of corrective measures. The adoption of suitable tools/protocols for the implementation of routine checks at adequate frequency is fundamental to improve responsiveness allowing the prevention and/or early identification of animal health and welfare issues. Technological tools to support data collection and analysis exist and are in constant development. However, not all of these devices are suitable or applicable for NESTLER defined scenarios. During the project, we will analyse existing solutions and select the most appropriate wearable devices for NESTLER applications. The most obvious candidates are:

- GPS animal collars tracking animals and showing their location in real time
- Ear tag sensors for measuring behavioural indicators like posture, gait, vocalization, and external temperature which can help in evaluating the health and welfare of animals.
- Remote animal health monitoring systems
- ECG systems which are used on racing horses, etc.

Typical example of a GPS animal collar is shown in Figure 5 below.

Figure 5:Typical example of a GPS animal collar.

In some cases, IoT devices developed for other applications, could be adopted and utilised as wearable if this will contribute to improved wellbeing of animals. Typical examples could be weather temperature and various gas measuring sensors. When analysing and selecting the most appropriate tools, we will be working in close coordination with end users and stakeholders, ensuring that the selected or developed tools are suitable for NESTLER applications and could be integrated within NESTLER Platform.

3.2.2.2 Agro-Weather Stations

Weather stations are an essential tool for monitoring weather conditions in livestock farming, too. These stations can collect data on a range of weather parameters, including temperature, humidity, wind speed, and precipitation, as have already been mentioned in crop-based farming (Agro – Weather Stations). This information can be used to help farmers make decisions about feed management, water management, and other factors that affect the health and productivity of livestock.

3.2.2.3 Air Quality IoT device

Livestock operations can generate significant amounts of air pollution (ex. ammonia, methane, etc.). These pollutants can have negative impacts on both the environment and public health. Air quality sensors can help farmers monitor, control, and record the characteristics of the air and take steps to reduce their emissions if needed. For this purpose, the SynAir [30] IoT device (Figure 6), which transmits data to the SynField cloud, can be used. There are three different models (Basic, City & City+) available that measure:

- Temperature
- Relative humidity
- Barometric pressure
- CO2

- Particulate Matter (PM1.0, PM2.5, PM4, PM10)
- Total volatile organic compounds (VOC)
- NO2 Detection
- CO Detection
- Ethanol Detection
- O2
- Ozone
- NO2

One of the key benefits of air quality sensors is that they can provide real-time data on air quality conditions. This allows farmers to identify areas of the operation that are generating high levels of pollution and take corrective action.

Figure 6: Synelixis SynAir device solution

3.2.3 Aquaculture farming

The monitoring of aquaculture using thermal cameras, motion sensors, agro-weather stations and IoT devices may provide valuable data on water quality, temperature, weather conditions, and other parameters affecting aquaculture operations. These technologies may assist farmers in managing their aquaculture in a more efficient and adaptable manner, thereby mitigating potential negative impacts.

3.2.3.1 Thermal cameras (RINI)

High-resolution thermal imaging cameras are useful for locating focused groundwater discharge to the land surface and surface water. They also could be used for monitoring melioration and help farmers to minimise use of valuable water resources without any negative effects on yields of crop. In NESTLER we will use thermal imaging cameras to monitor water thermal signatures of interest, such as moisture of the soil, stream confluence mixing and evaluation of thermal refugia. One of the technical challenges associated with this task is to find a good compromise between the cost of the thermal imaging cameras and their performance, as high-performance cameras are prohibitively expensive for applications in agriculture. Therefore, we will use low-cost cameras which could be integrated with a smart phone and will enhance their performance through a use of advanced video analytics algorithms specifically adopted for NESTLER applications. There are a number of suppliers of thermal imaging cameras who have this product but for NESTLER applications we will use FLIR One camera which will meet NESTLER requirements for both cost and performance. Figure 7 below illustrates FLIR One thermal imaging camera working on smart phone.

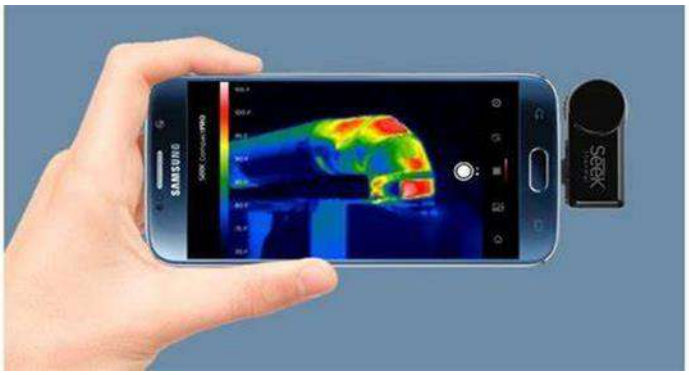

Figure 7: FLIR One thermal imaging camera working on smart phone.

3.2.3.2 Motion sensors

Motion sensors could prevent stock animals from contaminating clear water resources. To achieve this, NESTLER will implement motion sensors for deterring animals from clear water reserves and integrate these sensors with the NESTLER platform for continuous monitoring. This will raise alarms and ensure maintenance of freshwater resources. The market of motion sensors is overcrowded with solutions for home use, but these will not be suitable for NESTLER as not all of the available sensors may have the right interface of API for integration. During the project we will select the most appropriate sensor and integrate it with the NESTLER Ecosystem.

3.2.3.3 Agro-Weather Stations

Weather conditions can have a significant impact and ultimately affect the health and productivity of aquatic organisms in aquaculture. Agro-weather stations are another type of monitoring technology that can be used to improve production and optimize growing conditions, as have already been mentioned in crop-based farming (Agro – Weather Stations).

Here are some specific ways that agro-weather stations can be used in aquaculture monitoring:

- Predicting weather-related issues: Agro-weather stations can be used to predict potential weather-related issues, such as storms, extreme temperatures, or drought. By monitoring weather patterns, farmers can take proactive steps to prepare for these events and minimize potential damage to their operations.
- Optimizing water management: Agro-weather stations can also be used to monitor precipitation levels and adjust water management practices accordingly. By monitoring precipitation levels, farmers can determine when to supply water in the ponds and when to conserve water, optimizing water usage and minimizing waste.

3.2.3.4 Water Quality IoT device

Water quality is one of the most important factors in aquaculture, as it directly affects the health and growth of aquatic organisms. Synelixis can launch a new IoT device called SynWater, which is a Water-quality sensor suite with up to 4 liquid sensors, such as:

- Temperature
- pH
- Dissolved Oxygen (DO)
- Electrical Conductivity (EC)

- Oxidation Reduction Potential (ORP)

This station is connected to the SynField system that allows all the above sensors to communicate through a single SynField connector.

Water quality IoT devices can provide real-time data on water quality, allowing farmers to adjust as needed to maintain optimal growing conditions. Here are some specific ways that water quality IoT devices can be used in aquaculture monitoring:

- Detecting water quality issues early: By monitoring water quality in real-time, farmers can detect issues such as low oxygen levels early, allowing them to take action to address the issue before it becomes a significant problem.
- Improving feed management: Water quality IoT devices can also be used to monitor the impact of feed on water quality. By monitoring water quality after feeding, farmers can adjust feed amounts and schedules to optimize growth and production.

3.2.3.5 Satellite Imagery

For the Aquaculture farming weather and climate data will be used as described in section 2.2.1.4

Weather

Name	Instrument	Level	Coverage	Cadence	Format
GOES-FP	SEISS	L1	World	Daily	netCDF
MeteoSAT	SEVIRI, MVIRI	L2	EU, Africa	Daily	netCDF
Sentinel-3	SLSTR	L2	World	4 days	netCDF

Climate

Source	Variable	Unit	Resolution	Temp Res	Format
Worldclim.org	Minimum Temp	C	2.5 min	Month	GEOTIFF
	Maximum Temp	C		Month	
	Average Temp	C		Month	
	Precipiation	mm		Month	
	Solar Radiation	kJ m-2 day-1		Month	
	Wind Speed	m s-1		Month	
	Water vapor pressure	kPa		Month	

Source	Variable	Unit	Resolution	Temp Res	Format
AgERA5 (C3S)	Wind Speed	m s−1	10m	Daily	netCDF
	Dewpoint Temperature	K	0.1°	Daily	netCDF
	Temperature	K	0.1°	Daily	netCDF
	Cloud Cover	-	0.1°	Daily	netCDF
	Precipitation Flux	mm day −1	0.1°	Daily	netCDF
	Snow Thickness	Cubic cm	0.1°	Daily	netCDF
	Solar Radiation Flux	J m−2 day−1	0.1°	Daily	netCDF

Source	Variable	Unit	Resolution	Temp Res	Format
Answr	Cloud Cover	%	Km	Month	JSON
	Consecutive Dry Days	# Days	Km	Month	JSON
	Consecutive Frost Days	# Days	Km	Month	JSON
	Consecutive Summer Days	# Days	Km	Month	JSON
	Consecutive Wet Days	# Days	Km	Month	JSON
	Dew Point Temperature	C	Km	Month	JSON
	Frost Days	# Days	Km	Month	JSON
	Heating Days	# Days	Km	Month	JSON
	Ice Days	# Days	Km	Month	JSON
	Maximum Temperature	C	Km	Month	JSON
	Mean Temperature	C	Km	Month	JSON
	Minimum Temperature	C	Km	Month	JSON
	Precipitation Days (10mm)	Mm	Km	Month	JSON
	Precipitation Days (50mm)	Mm	Km	Month	JSON
	Precipitation Flux	mm	Km	Month	JSON
	Snow Thickness	cm	Km	Month	JSON
	Solar Radiation	Watt * sqkm-1	Km	Month	JSON
	Volumetric Soil Moisture	%	Km	Month	JSON

Source	Variable	Severity	Probability	Resolution	Temp Res	Format
Answr	Cold wave risk	L, M, H	%	Km	Month	JSON
	Drought Probability	%		Km	Month	JSON
	Flood Severity	Meters	N/A	Km	Month	JSON
	Heat Wave Probability	% LoO		Km	Month	JSON
	Windstorm Probability	% LoO		Km	Month	JSON

3.3 Functional Requirements

The Functional requirements of the NESTLER project are presented in Table 12, giving a unique identifier, a name and a description.

Table 12: Functional requirements of the NESTLER platform

ID	Requirement Name	Requirement Description
REQ.FN.01	Authentication/ Authorization	The system shall support a mechanism to authenticate/authorize users.
REQ.FN.02	IoT data collection	Data should be collected from the farming fields from various IoT devices and sensors (SynField, wearable devices on livestock, smartphones, etc).
REQ.FN.03	IoT data transmission	IoT data should be transmitted to the centralized NESTLER platform utilising the best available communications infrastructure or a dedicated communication system provided by NESTLER.
REQ.FN.04	Crop quality measurement device (cassava)	Handheld device that provides a quick measurement of the starch content of cassava fresh and gives a read out.
REQ.FN.05	Mobile application platform for crop quality	Mobile app that receives and stores crop quality information and metadata including measurement time, geo stamp and device/user ID. Platform also handles transmission of data to cloud server and makes measured data available to other stakeholders in the value chain.
REQ.FN.06	IoT data storage	The platform must support storage of precision agriculture and weather IoT data in any agreed format.
REQ.FN.07	Processed data storage	The platform shall support the storage of data processed by internal NESTLER Backend modules.
REQ.FN.08	Data access	The platform should provide access to IoT measurements.
REQ.FN.09	Monitoring	The platform should have the ability to run supervised and unsupervised algorithms and models for monitoring purposes.
REQ.FN.10	Data geo-visualization	The platform could provide geo-visualization of data.
REQ.FN.11	Data reports	The platform could provide the ability to export reports in a range of formats (e.g., pdf, image, office) of measurements, model outcomes etc
REQ.FN.12	IoT sensors/devices management	The platform could provide options to manage/view sensors/devices.
REQ.FN.13	Weather monitoring	Weather conditions must be monitored.
REQ.FN.14	Weather impact assessment	The platform must provide weather impact assessment on agriculture.
REQ.FN.15	Economic risk assessment	NESTLER could develop economic risk assessment models for predicting the yield quality.

REQ.FN.16	IoT device connectivity	The devices must support connectivity.
REQ.FN.17	Receiving control commands	The devices could receive control commands from the NESTLER platform. To support this requirement, NESTLER communications solution must enable bi-directional communications.
REQ.FN.18	Pest infestation identification	The platform should utilize Deep Learning algorithms to identify pest infestation.
REQ.FN.19	Disease outbreaks module	Platform should contain models which proactively predict the onset of disease outbreak.
REQ.FN.20	Disease outbreaks alert	Dashboard should alert users about disease outbreaks.
REQ.FN.21	Automated and manually irrigation	The platform should provide automated and manually irrigation.
REQ.FN.22	Satellite image processing	The platform should be able to process Sentinel-1 and Sentinel-2 images using the ESA SNAP software.
REQ.FN.23	Historical data processing	The platform should process historical data.
REQ.FN.24	Satellite image exposure API	The platform should be able to expose the processed data using a standard OGC compliant API.
REQ.FN.25	Standard APIs	Standard APIs should be used to interface with external platform services.

3.4 Non - Functional Requirements

The Non-Functional requirements of the NESTLER project are listed in Table 13, giving a unique identifier, a name and a description.

Table 13: Non – functional requirements of the NESTLER platform

ID	Requirement Name	Requirement Description
REQ.NFN.01	Low latency	The required amount of time to transmit data to the platform should be minimized. If communications infrastructure in a given location is available, the data transmission should be in real time. If communication infrastructure is not available (temporarily or permanently due to rural location) the measured data should be stored locally and be transmitted once communications is restored or from the location where communication is available.
REQ.NFN.02	Availability	The platform should support high availability.
REQ.NFN.03	Scalability	The platform should be able to integrate additional components, such as additional data sources. In addition, the platform should support hierarchical architecture.
REQ.NFN.04	Usability	The platform should be developed to be simple, intuitive and efficient for the end users and easy to understand.
REQ.NFN.05	Security & Privacy	The platform should be secure and prevent unauthorized access to private information.
REQ.NFN.06	Reliability	The platform should indicate potential malfunctions.
REQ.NFN.07	Power efficient & Hybrid electrically powered devices	The platform devices should factor in usage in remote areas with limited access to electric power supply and be designed for power efficiency. As much as possible, the devices should be designed for hybrid power supply options including solar, battery and mains power supply.
REQ.NFN.08	Accuracy	New devices should be designed to meet minimum requirements of accuracy and functionality provided by existing alternative systems
REQ.NFN.09	Rapid testing	Test devices should be capable of rapid, non-destructive measurement, typically within a few seconds
REQ.NFN.10	Durability and ruggedness	Device should be designed to withstand harsh conditions and usage that is typical of farm equipment and devices.

3.5 NESTLER High Level Architecture

The high-level NESTLER architecture has been designed to cover the identified Functional and Non-Functional requirements, as shown in Figure 8. Additionally, a brief description of the high-level architecture has been provided. The detailed architecture, accompanied with diagram and description, will be provided in Deliverables of WP4.

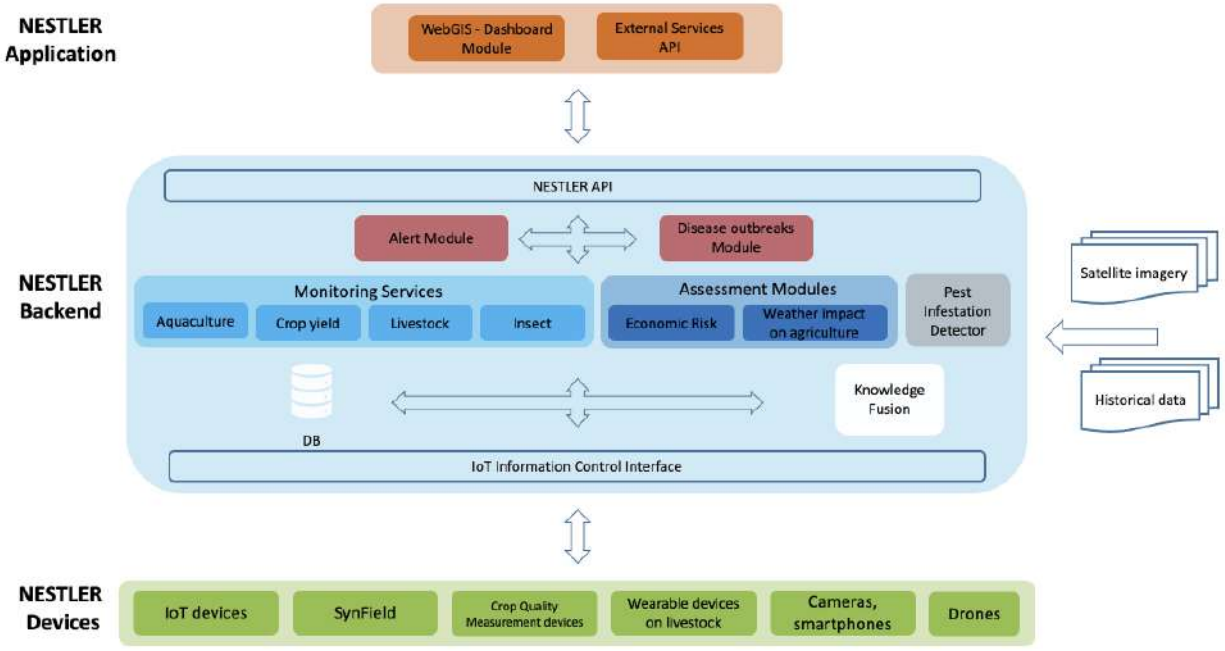

Figure 8: High-level architecture of NESTLER.

The high-level NESTLER architecture is divided into 3 main groups of components:

1. NESTLER Devices component which includes all physical devices, such as IoT Sensors/Actuators, SynFiled, cameras, drones, smartphones, wearable devices on livestock, that will be connected to the NESTLER platform along with the wireless communication platform that will be implemented during project lifetime. All these connected devices will feed the NESTLER platform with appropriate data sources from agricultural, livestock and aquaculture farming.
2. NESTLER Backend component that contains all innovative functionalities and modules described in Functional requirements. It should be mentioned that the NESTLER system will implement appropriate endpoints for the ingestion of monitoring data observed and collected by third-party platforms, on top of the native NESTLER Devices. NESTLER follows the International Data Spaces Association (IDSA) approach, which is the state of the art in Data Space and IoT interoperability [31]. The IDSA working groups and the standardization coordination group, as well as the IDSA technical team, work diligently with key bodies at ISO, CEN/CENELEC and W3C and advise the European Commission on advancing global standards for data spaces. Third-party platforms will be able to publish relevant live measurements and / or historical data in NESTLER backend platform, provided that the aforementioned data are translated to the common NESTLER data model, via appropriate adapters. In this manner, the NESTLER API will not only support the essential operations as required by NESTLER's architectural components but will also serve as an enabler for interoperability with third-party sources, outside the NESTLER ecosystem.

   In the presented high-level architecture, the following modules are identified:

   - IoT Information Control Interface: Controls the communication with the remote NESTLER devices and performs a first level processing in order to filter the incoming information discarding data

that are not suitable for NESTLER Backend modules operations. Afterwards the refined data are forwarded to NESTLER database for storing.

- Monitoring Modules:
  - Crop yield: Algorithms will be developed to utilize historical data, environmental factors, data from NESTLER devices and processed outputs of other NESTLER modules with the aim of extracting valuable information about the quality of crop yield.
  - Livestock: Constantly evaluates information that is stored in the database for monitoring livestock wellbeing, utilizing supervised and unsupervised classification algorithms. Depending on the evaluation results, appropriate notifications are raised.
  - Aquaculture: Continuously monitors aquaculture conditions through relevant information forwarded from NESTLER devices and gathered in the database. In case of emergency proper alarms are signalled.
- Pest Infestation Detector: Based on historical case studies coupled with geographical information, deep-learning models are employed capable of identifying the appearance of pests on leaves. Additionally, pest categorization results are produced and stored in the database.
- Assessment Modules:
  - Weather impact on agriculture: Implements temporal association models (weather models) that enables cross-correlation of data from sensor networks and earth observation repositories. Moreover, algorithms and methodologies are combined into a single framework with the help of information fusion algorithms (data association, state estimation and decision fusion).
  - Economic Risk: Calculates the economic risk assessment model building upon similar published models. Additionally, algorithms for predicting the risk index are trained using deep-learning architectures, such as regression.
- DB: Stores NESTLER's Backend data collected either from sensor feeds or from other Backend internal modules. Furthermore, upon registering predefined data values triggers appropriate modules / alerts.
- Disease outbreaks Module: Implements adapted algorithms and models that enable the detection of anomalies and proactively predict possible disease outbreaks.
- Monitoring – Alert Module: Taking advantage of NESTLER's Backend monitoring and prognostic services, this module signals alerts regarding the wellbeing of livestock, the state of agricultural cultivation and possible forthcoming events.
- NESTLER API: Publish towards the application level programs the services / data / alerts that are implemented from the NESTLER's Backend mechanisms.

3. NESTLER Application that utilizes NESTLER's Backend API functionality combined with adapted algorithms and models to present the current state of agricultural fields and livestock and identify possible upcoming situations.

- WebGIS – Dashboard Module: Provides the user interface with the operator that supports the following functionality:
  - Presents an overall dashboard that integrates all remotely collected data from NESTLER's devices, offer insights into the state of farming and pinpoint alerting events / predictions.
  - Offers on demand features for detecting pest and localizing their appearance.
  - Provides intuitive information on the expected impact of the climate.
- External Services API: Supports APIs towards external platform services in order to offer NESTLER's functionality to interested parties.

4 Food Security Roadmap

This section is related to T1.1 – *Review of (national) risks on food security roadmap*, which is part of WP1 – *One-Health stakeholder engagements and sustainability roadmap requirements*. The objective is to engage stakeholders representing the EU-Africa High Level Policy Dialogue Platform on Science, Technology, and Innovation committee to gather insights into the challenges often encountered by the farmers during cultivation, and engaging operational personnel involved in the food cultivation process in Africa to identify the challenges commonly encountered resulting in either low-quality food production and/or loss of crop yield due to pest.

Additionally, the T1.1 will engage with regional authorities and national representatives for building an agricultural resilience framework across the following categories, namely (i) Sustainable intensification, (ii) Agriculture and food systems for nutrition, (iii) Expansion and improvement of agricultural markets and trade and (iv) Cross-cutting issues.

4.1 Review of risks on food security roadmap in Cameroon

In Cameroon, food insecurity essentially results from inadequate food consumption (10.7% of the population), negative coping strategies based on food consumption or on livelihoods (respectively 10.2% and 17.2% of households), or economic vulnerability, with 33.2% of the population spending 65% or more on food. In addition, 1.1% of households suffer from severe to very severe hunger. Overall, the food insecurity situation has deteriorated from 12.8% in 2019 to 20.4% in 2020. The North West (40.0%), South West (30.7%), Littoral (25.1%), the Far North (24.8%), Adamaoua (22.1%) and the West (20.5%), which are suffering the effects of various humanitarian crises, are the most affected by the food insecurity. In order to ensure the food security of the most vulnerable populations, the following recommendations are made after a National Food and Nutrition Security Survey (ENSAN) in September 2020 [32]:

- Provide emergency humanitarian assistance to food insecure populations severe, especially in the North West, South West, East and Far North regions.
- Ensure the nutritional education of populations living in regions where the diet is not very diversified and presenting micronutrient deficiencies.
- Implement resilience programs to strengthen the livelihoods of vulnerable households over the long term.
- Set up stocks of food products and agricultural seeds throughout the national territory.
- Pay special attention in terms of assistance to female-headed households who tend to be more vulnerable.

Table 14: Risks on food-security roadmap encountered in crop subsector (Cameroon).

Risk FS1.1.1: Limited number of improved, adapted and end users preferred varieties	
Type of stakeholder	Government/Private Research Institutes
Role of stakeholder	Implementer of Agricultural policies

Description of the challenge	Limited number of improved, adapted and end users preferred varieties. Consumption inadequate food
Type of crop	Cash crops, food crops
Name of the crops	Cocoa, Coffee, Cassava, Maize, Potatoes, tomatoes, Rice
Region	All agro-ecological zones
Season	Throughout all seasons
Severity	Moderate
Effects to the Ecosystem	Decrease in plant biodiversity, extension of local seeds to the detriment of improved seeds
Severity for Human	• Food insecurity. • Depletion of households' income. • Food deficiency disease.
Effects to the Economy	• Low productivity. • Decreased income and food availability. • Increased food prices and food imports.
Possible Mitigation actions	• Set up stocks of food and seed products agricultural across the territory national • Introduction and development of improved crop varieties
Possible ways to prevent it	Introduction and development of improved crop varieties
Risk FS1.1.2: High price of agricultural fertilizers and limited access to them	
Type of stakeholder	Government/Private Research Institutes
Role of stakeholder	Implementer of Agricultural policies
Description of the challenge	Limited access and high prices of fertilizer
Type of crop	Cash crops, food crops
Name of the crops	Cocoa, Coffee, Cassava, Maize, Potatoes, tomatoes, Rice
Region	All agro-ecological zones
Season	Throughout all seasons
Severity	High
Effects to the Ecosystem	Poor production and productivity
Severity for Human	• Limited access to cash crops. • Food insecurity. • Depletion of households' income.
Effects to the Economy	• Low productivity. • Decreased incomes and food availability. • Increased food prices and food importation.
Possible Mitigation actions	• Introduction, development and use of organic fertilizers (cow dung, chicken droppings, household waste). • Introduction/ development of fertilizers timely and affordably.
Possible ways to prevent it	Put in place resilience programs to strengthen the livelihoods of vulnerable households over the long term.

Risk FS1.1.3: High pressure of pests and diseases	
Type of stakeholder	Government/Private Research Institutes
Role of stakeholder	Implementer of Agricultural policies
Description of the challenge	High pressure of pests and diseases
Type of crop	Cash crops, food crops
Name of the crops	Cocoa, Coffee, Potatoes, tomatoes
Region	All agro-ecological zones
Season	Rainy season and dry season
Severity	High
Effects to the Ecosystem	• Loss of some local varieties, loss of biomass commonly used as feed. • Disruption of ecosystem equilibrium. • Outbreak of emerging diseases and pests (due to pesticide resistance or killing of natural enemies).
Severity for Human	• Food insecurity. • Depletion of households' income.
Effects to the Economy	• Low productivity • Decreased incomes and food availability and increased food prices.
Possible Mitigation actions	• Monitoring systems. • Promotion and use of tolerant and resistant varieties. • Utilization of clean planting materials. • Uprooting and destroying diseased plants.
Possible ways to prevent it	• Monitoring systems. • Promotion and use of tolerant and resistant varieties • Utilization of clean planting materials. • Uprooting and destroying diseased plants.

Table 15: Risks on food-security roadmap encountered in livestock subsector (Cameroon).

Risk FS1.2.1: Limited access to veterinary services	
Type of stakeholder	Government/MoA
Role of stakeholder	Implementer of Agricultural policies
Description of the challenge	Limited access to veterinary services
Type of crop	Farm animals
Name of the crops	Pig and poultry
Region	Whole country
Season	Throughout
Severity	Moderate

Effects to the Ecosystem	High morbidity and mortality, antimicrobial resistance due to drug misuse
Severity for Human	• Unaffordable animal products by the majority of the people. • Increased resistance of microbial to drugs.
Effects to the Economy	• Reduced export earnings. • Reduced production and productivity. • Reduced access to the international market.
Possible Mitigation actions	• Strengthening prevention measures through vaccination, vector control, awareness campaign, etc • Strengthening diagnostic capacity and treatments • Improve disease surveillance systems. • Strengthening Private Public Partnership
Possible ways to prevent it	• Surveillance at Cameroonian borders • Strengthening prevention measures through vaccination, vector control, awareness campaign.

4.2 Review of risks on food security roadmap in Uganda

Food and nutrition security remain Uganda's most fundamental challenge for human welfare and economic growth. The sorry state of food and nutrition security in Uganda spells the need for strategic interventions to enable the government at various levels to meet its obligations towards the many hungry and under-nourished Ugandans [33]. Food and nutrition insecurity is an important component of the development challenge the nation faces and fundamentally undermines efforts to meet its development vision.

In Uganda, the problem is not so much on access to food but, rather, malnutrition. In comprehensively addressing these problems, Uganda Food and Nutrition Strategy (UFNS) was formulated as a guide to action for the Uganda Food and Nutrition Policy (UFNP) that was approved by the government in 2003. The vision of the UFNS is a hunger-free country without malnutrition [34].

Table 16: Risks on food-security roadmap encountered in crop subsector (Uganda).

Risk FS2.1.1: Inadequate Pest and Disease tolerant and resistant varieties	
Type of stakeholder	Government/Ministry of Agriculture, Animal Industry and Fisheries (MAAIF)
Role of stakeholder	Overseeing/creating an enabling environment in the Agricultural Sector through policies and regulations
Description of the challenge	Inadequate Pest and Disease tolerant and resistant varieties
Type of crop	Annual, Biennial and perennial
Name of the crops	cereals, tubers, roots, pulses, vegetables/fruits
Region	Whole country
Season	Throughout all seasons
Severity	High

Effects to the Ecosystem	• Biodiversity Loss • Decreases diversity and abundance of wild plants
Severity for Human	• Frequent use of herbicides alters biological composition of food which may pose a human health risk
Effects to the Economy	• Cost of cultivation is increased. • It endangers farmers and trade along with the environment.
Possible Mitigation actions	Develop and improve methods for assessing variety resistance to pests and pathogens.
Possible ways to prevent it	• Participate in updating knowledge on strains and races, to combat resistance breakage. • Study new path systems and develop methods.
Risk FS2.1.2: Counterfeit/fake agro inputs available on market	
Type of stakeholder	Government/Uganda National Bureau of Standards (UNBS)
Role of stakeholder	Providing standards, measurements and conformity assessment services for Safe, quality goods and services for all
Description of the challenge	Counterfeit/fake inputs available on market
Type of crop	All crops
Name of the crops	All crops
Region	Country wide
Season	All year round
Severity	High
Effects to the Ecosystem	Contamination of groundwater, soil and vegetation with nitrate.
Severity for Human	• Diseases occurrence. • Food and nutrition insecurity. • Reduction on households' income.
Effects to the Economy	• A lot of money is spent on buying drugs. • Quality of the harvest is poor.
Possible Mitigation actions	Monitoring systems.
Possible ways to prevent it	• Monitoring systems. • Stringent policies on agro inputs manufacturing, buy and sale.
Risk FS2.1.3: Climate and weather changes	
Type of stakeholder	Government/Metrology Authority
Role of stakeholder	Establishing and maintaining weather and climate observing stations network, collection, analysis and production of weather and climate information
Description of the challenge	Climate and weather change
Type of crop	Food and Horticulture crops
Name of the crops	Cereals, Pulses, Roots and tubers and Horticulture crops
Region	Whole country

Season	Year round
Severity	Moderate
Effects to the Ecosystem	• Effect on ecological balance • Biodivesrity loss
Severity for Human	• Food insecurity. • Depletion of households' income. • Diseases occurrence.
Effects to the Economy	• Low crop production/productivity. • Decrease of food availability and export. • Increase in food prices and importation.
Possible Mitigation actions	• Conservation promotion • Erosion control. • Reforestation. • Watershed management (irrigation and drainage), development. • Use of climate resilient crop varieties.
Possible ways to prevent it	• Erosion control. • Reforestation. • Watershed management (irrigation and drainage) and development. • Use of climate resilient crop varieties.

Table 17: Risks on food-security roadmap encountered in livestock subsector (Uganda).

Risk FS2.2.1: Livestock Feed Shortage and Coping Mechanisms	
Type of stakeholder	Government/MAAIF
Role of stakeholder	Overseeing/ creating an enabling environment in the Agricultural Sector through policies and regulations
Description of the challenge	Livestock Feed Shortage and Coping Mechanisms
Type of animal resources	Herd animals
Name of the animal species	Cattle, goats
Region	Cattle corridors of uganda
Season	Dry seasons
Severity	High
Effects to the Ecosystem	Enroachment on National Game parks
Severity for Human	Susceptibility to zoonosis
Effects to the Economy	Poor quality production of animals and its products thus affecting market
Possible Mitigation actions	Feed purchasing and feeding enset
Possible ways to prevent it	• Improved Forage Production

	• Harvesting local grass (fresh grass for cut and carry feeding) in wet season. • Forage seed/planting
Risk FS2.2.2: Poor breed performance	
Type of stakeholder	Government/MAAIF
Role of stakeholder	Overseeing/ creating an enabling environment in the Agricultural Sector through policies and regulations
Description of the challenge	Poor breed perfomance
Type of animal resources	All animals
Name of the animal species	All animal species
Region	Whole country
Season	Throughout
Severity	High
Effects to the Ecosystem	• Reduce variation. • loss of genetic diversity
Severity for Human	• Creates new diseases. • Creates a genetic depression.
Effects to the Economy	• Decreased reproductive ability. • Affects market value.
Possible Mitigation actions	• Cross breeding • Lowering the interval between successive pregnancies
Possible ways to prevent it	Lowering the interval between successive animal pregnancies
Risk FS2.2.3: Zoonotic disease challenges	
Type of stakeholder	Government/National One Health Platform (NOHP)
Role of stakeholder	Spearhead collaborative efforts amongst government sectors and NGOs to prevent, detect and respond to existing zoonotic diseases as well as emerging pandemic threats
Description of the challenge	Zoonotic disease challenges
Type of animal resources	All animal resources
Name of the animal species	All animal species
Region	Cattle corridors, protected/conservation areas of Uganda (Areas around the national game parks).
Season	All seasons
Severity	High
Effects to the Ecosystem	Threatens biodiversity by catalysing population declines and accelerating extinctions especially the wildlife.
Severity for Human	• Risk of transmission between humans and animals.

	• Morbidity and mortality challenges.
Effects to the Economy	• Poor product production thus market loss. • Loss of tourism potential.
Possible Mitigation actions	• Emphasis on WASH components. • Regular sensitization and awareness campaigns.
Possible ways to prevent it	• Promoting of Biodiversity conservation. • Effecting Policies and laws on zoonosis transmissions. • More One Health research.

4.3 Review of risks on food security roadmap in Ethiopia

Ethiopia is committed to the Sustainable Development Goals and has wholeheartedly participated in the UN Food Systems Summit (UNFSS). The Ethiopian food systems transformation (EFS) course charted by bringing together the public institutions, multilateral and bilateral organizations, the private sector, civil society organizations, and universities and research institutes. The high-level First EFS National Dialogue evaluated the current state of Ethiopian Food Systems and identified the key challenges that need to be addressed; and then identified and prioritized key 22 'game changing solutions' to address the challenges identified in the First Dialogue. The Third National Dialogue then brought together key stakeholders to launch the EFS vision and affirm Ethiopia's commitment to create a strong and equitable food system [35].

Ethiopia has made great strides in ensuring food security for all citizens. However, extensive research has identified persistent challenges that remain across the Ethiopian food system, from production to distribution to consumption. Production diversity and productivity are inhibited by limited access to appropriate inputs like fertilizer, improved crop seeds and animal breeds and agricultural technologies. Prices of nutrient dense foods have increased significantly over time making healthier diets unaffordable and for the majority. Population growth and agricultural intensification has led to soil erosion, land degradation and deforestation. Besides, animal diseases, drought, flood and loss of crop yield due to pests are the challenges too that should be addressed through engagement of stakeholders representing the EU-Africa High Level Policy Dialogue Platform and to gather insights into the challenges often encountered by the farmers during production.

Table 18: Risks on food-security roadmap encountered in crop subsector (Ethiopia).

Risk FS3.1.1: Limited and unaffordable access to fertilizer	
Type of stakeholder	Government/MoA
Role of stakeholder	Implementer of Agricultural policies
Description of the challenge	Limited access and high prices of fertilizer
Type of crop	Cereals
Name of the crops	Wheat, Barley, Teff
Region	High and mid-land areas
Season	Cropping

Severity	Moderate
Effects to the Ecosystem	Poor production and productivity
Severity for Human	• Limited access to cereals. • Food insecurity. • Depletion of households' income.
Effects to the Economy	• Low productivity. • Decreased incomes and food availability. • Increased food prices and food importation.
Possible Mitigation actions	Introduction/ development of fertilizers timely and affordably.
Possible ways to prevent it	Introduction and development of fertilizers.
Risk FS3.1.2: Poor/under development Seed System	
Type of stakeholder	Government/MoA
Role of stakeholder	Implementer of Agricultural policies
Description of the challenge	Poor/ under development seed system
Type of crop	Food and Horticulture crops
Name of the crops	Cereals, roots and tubers, pulses and horticulture crops
Region	Whole country
Season	Cropping
Severity	Moderate
Effects to the Ecosystem	Increase of plant biodiversity
Severity for Human	• Food insecurity, poor wellbeing • Depletion of households' incomes
Effects to the Economy	• Low productivity. • Decreased incomes and food availability. • Increased food prices.
Possible Mitigation actions	Strengthening the seed system through public-private partnership.
Possible ways to prevent it	Strengthening the seed system through public-private partnership.
Risk FS3.1.3: High pressure of pests and diseases	
Type of stakeholder	Government/MoA
Role of stakeholder	Implementer of Agricultural policies
Description of the challenge	High pressure of pests and diseases
Type of crop	Food and Horticulture crops
Name of the crops	Cereals, Pulses, Roots and Tubers and Horticulture crops
Region	Whole country
Season	Year round
Severity	High
Effects to the Ecosystem	• Loss of some local varieties, loss of biomass commonly used as feed. • Disruption of ecosystem equilibrium.

	• Outbreak of emerging diseases and pests (due to pesticide resistance or killing of natural enemies).
Severity for Human	• Food insecurity. • Depletion of households' incomes.
Effects to the Economy	• Low productivity. • Decreased incomes and food availability and increased food prices.
Possible Mitigation actions	• Monitoring systems. • Utilization of clean planting materials. • Uprooting and destroying diseased plants.
Possible ways to prevent it	• Monitoring systems. • Utilization of clean planting materials. • Uprooting and destroying diseased plants.
Risk FS3.1.4: Climate change and weather variability	
Type of stakeholder	Government/Metrology
Role of stakeholder	Implementer of Agricultural policies
Description of the challenge	Climate change and weather
Type of crop	Food and Horticulture crops
Name of the crops	Cereals, Pulses, Roots and tubers and Horticulture crops
Region	Whole country
Season	Year round
Severity	Moderate
Effects to the Ecosystem	Loss of biodiversity, high pressure on ecological equilibrium
Severity for Human	• Food insecurity. • Depletion of households' income. • Diseases occurrence.
Effects to the Economy	• Low crop production/productivity. • Depletion of households' income and national revenues. • Decrease of food availability and export. • Increase of food prices and importation.
Possible Mitigation actions	• Erosion control. • Reforestation. • Watershed management (irrigation and drainage), development. • Use of climate resilient crop varieties.
Possible ways to prevent it	• Erosion control. • Reforestation. • Watershed management (irrigation and drainage) and development. • Use of climate resilient crop varieties.

Table 19: Risks on food-security roadmap encountered in livestock subsector (Ethiopia).

Risk FS3.2.1: Limited access to veterinary services	
Type of stakeholder	Government/MoA
Role of stakeholder	Implementer of Agricultural policies
Description of the challenge	Limited access to veterinary services
Type of animal resources	Farm animals
Name of the animal species	cattle, sheep, goats and poultry
Region	Whole country
Season	Throughout
Severity	High
Effects to the Ecosystem	• High morbidity and mortality • Antimicrobial resistance due to drug misuse
Severity for Human	• Unaffordable animal products by the majority of the people. • Increased resistance of microbial to drugs.
Effects to the Economy	• Reduced export earnings. • Reduced production and productivity. • Reduced access to the international market.
Possible Mitigation actions	• Strengthening prevention measures through vaccination, vector control, awareness campaign, etc • Strengthening diagnostic capacity and treatments • Improve disease surveillance systems. • Strengthening Private Public Partnership
Possible ways to prevent it	Updating policies and strategies
Risk FS3.2.2: Scarcity of water and feed for animals	
Type of stakeholder	Government/MoA
Role of stakeholder	Implementer of Agricultural policies
Description of the challenge	Scarcity of water and feed for animals
Type of animal resources	Farm animals
Name of the animal species	Cattle, sheep, goats and poultry
Region	Cattle, sheep and goats especially in the lowlands and poultry in the whole country since the competition with humans
Season	Year round
Severity	High

Effects to the Ecosystem	• Increased illegal animal movements in search of water and feed resulting in spreading of diseases and access to wildlife and livestock interface and dispute among the communities. • Risk of genetic loss due to animal deaths.
Severity for Human	• Loss of animals, loss of wellbeing. • Reduced household income due to reduced animal productivity.
Effects to the Economy	Loss of export earnings
Possible Mitigation actions	• Strategy to hold rainwater/sustainable water harvesting. • Strategic policy for feed production around mega dams and watershed areas. • Strengthening of pipe water distribution for all.
Possible ways to prevent it	Sustainably effect the feed development master plan and create awareness about efficient water utilization in all the stakeholders.
Risk FS3.2.3: Low adoption of animal breeding technologies and under-performing breeds	
Type of stakeholder	Government/MoA
Role of stakeholder	Implementer of Agricultural policies
Description of the challenge	Low adoption of animal breeding technologies and under-performing breeds
Type of animal resources	Farm animals
Name of the animal species	Cattle, sheep, goats and poultry
Region	Whole country
Season	Throughout
Severity	Moderate
Effects to the Ecosystem	• Increased animals numbers leading to increase of greenhouse gas emission. • Land degradation. • Shortage of feed.
Severity for Human	• Reduced Access to animal source foods. • Climate change due to increased greenhouse emission.
Effects to the Economy	• Reduced production and productivity. • Reduced export earnings. • Reduced trade of animals and animal products.
Possible Mitigation actions	• Mobilization and training of farmers to adopt and manage improved breeds. • Training actors to adopt animal breeding technologies. • Establish and strengthen animal breeding programmes. • Restocking with improved animal breeds.
Possible ways to prevent it	Implement animal breeding strategy
Risk FS3.2.4: Poor animal husbandry practices	
Type of stakeholder	Government/MoA

Role of stakeholder	Implementer of Agricultural policies
Description of the challenge	Poor animal husbandry practices
Type of animal resources	Farm animals
Name of the animal species	Equines, Poultry, Cattle
Region	Whole country
Season	Throughout
Severity	Moderate
Effects to the Ecosystem	• Increased disease incidences. • Reduced production in both quality and quantity. • Violation of animal welfare.
Severity for Human	• Reduced quantity, quality and safety of animal source food. • Transmission of microorganisms from animal to human.
Effects to the Economy	• Increased rejection of animal products due to poor quality. • Reduced access to national, regional and international markets. • Reduced income and livelihoods of farmers.
Possible Mitigation actions	• Awareness and training of farmers and stakeholders on good animal husbandry practices. • Develop and implement Standard Operating Procedures at all levels of the livestock value chain.
Possible ways to prevent it	Develop and implement One Health System.
Risk FS3.2.5: High post-harvest loss	
Type of stakeholder	Government/MoA
Role of stakeholder	Implementer of Agricultural policies
Description of the challenge	High post-harvest loss
Type of animal resources	Bones, Hide and skin
Name of the particular animal species	Cattle, sheep, goats
Region	Whole country
Season	Mostly in holidays
Severity	Moderate
Effects to the Ecosystem	Increased animal products and inputs wastes into the environment.
Severity for Human	Reduced household income and environmental pollution.
Effects to the Economy	• Increased costs for wastes management. • Reduced harvest from animals leading to reduced contribution to Agricultural GDP.
Possible Mitigation actions	• Develop management and utilization policy. • Capacity building of livestock value chain actors.
Possible ways to prevent it	Develop and implement livestock post-harvest policy.
Possible Mitigation actions	• Develop management and utilization policy. • Capacity building of livestock value chain actors.
Possible ways to prevent it	Develop and implement livestock post-harvest policy.

Table 20: Risks on food-security roadmap encountered in aquaculture subsector (Ethiopia).

Risk FS3.3.1: Water pollution	
Type of stakeholder	Government/ Ministry of Agriculture and Ministry of Water and Energy
Role of stakeholder	Implementers of Agricultural and water resources policies
Description of the challenge	Increasing water quality deterioration in rivers and lakes
Type of animal resources	Aquatic animals
Name of the animal species	Fish
Region	Ethiopian Rift-Valley lakes, and central and northern highland lakes and rivers
Season	Throughout
Severity	High to moderate
Effects to the Ecosystem	• Sedimentation of organic wastes • Eutrophication/algal blooming • Reduced biodiversity
Severity for Human	• Limited fish supply for food • Waterborne and water-related human disease
Effects to the Economy	• High cost for water treatment/ recovery • High cost for associated disease control and treatment • Reduced fish food and income
Possible Mitigation actions	• Control point source pollution • Catchment restoration • Buffer zone delineation • Regular monitoring for eutrophication
Possible ways to prevent it	• Establish water treatment plants for domestic and industrial wastes • Enforce national and international laws for waste water disposal • Promote and support aquaculture based fish production
Risk FS3.3.2: Lack of improved fish seed and feed	
Type of stakeholder	Government (Ministry of Agriculture)
Role of stakeholder	Implementers of Agricultural policies
Description of the challenge	Absence of improved cultured fish species and aquafeed
Type of animal resources	Aquatic animals
Name of the animal species	Fish

Region	Whole country
Season	Throughout
Severity	high
Effects to the Ecosystem	Overfishing from lakes and loss of biodiversity.
Severity for Human	• Reduced fish production from aquaculture sector. • Limited fish supply for food.
Effects to the Economy	Loss of income from aquaculture sector
Possible Mitigation actions	• Establish fish seed multiplication facilities. • Encourage and support aquafeed producing industries. • Improve aquaculture fish species through selective breeding.
Possible ways to prevent it	Develop and implement aquaculture development policy.

4.4 Review of risks on food security roadmap in Rwanda

The following tables summarise the risks or challenges on the food-security roadmap in Rwanda. Table 21 presents the risks on the food-security roadmap encountered in the crop subsector and Table 22 presents those recorded in the livestock subsector.

Table 21: Risks on food-security roadmap encountered in crop subsector (Rwanda).

Risk FS4.1.1: Limited number of improved, adapted and end users preferred varieties	
Type of stakeholder	Government/RAB
Role of stakeholder	Implementer of Agricultural policies
Description of the challenge	Limited number of improved, adapted and end users preferred varieties
Type of crop	Food and Horticulture crops
Name of the crops	Roots and tubers, cereals, Pulses and Horticulture crops, tea, coffee
Region	Whole country
Season	Throughout all seasons
Severity	Moderate
Effects to the Ecosystem	Increase of plant biodiversity
Severity for Human	Food insecurity. Depletion of households' income.
Effects to the Economy	• Low productivity. • Decreased incomes and food availability. • Increased food prices and food importation.
Possible Mitigation actions	Introduction and development of improved crop varieties
Possible ways to prevent it	Introduction and development of improved crop varieties
Risk FS4.1.2: Seed system under development	
Type of stakeholder	Government/RAB

Role of stakeholder	Implementer of Agricultural policies
Description of the challenge	Seed system under development
Type of crop	Food and Horticulture crops
Name of the crops	Roots and tubers, cereals, Pulses and Horticulture crops, tea , coffee
Region	Whole country
Season	Throughout all seasons
Severity	Moderate
Effects to the Ecosystem	Increase of plant biodiversity
Severity for Human	• Food insecurity. • Depletion of households' income.
Effects to the Economy	• Low productivity. • Decreased incomes and food availability. • Increased food prices and food importation.
Possible Mitigation actions	Strengthening the seed system through public-private partnership
Possible ways to prevent it	Strengthening the seed system through public-private partnership
Risk FS4.1.3.: High pressure of pests and diseases	
Type of stakeholder	Government/RAB
Role of stakeholder	Implementer of Agricultural policies
Description of the challenge	High pressure of pests and diseases
Type of crop	Food and Horticulture crops
Name of the crops	Roots and tubers, cereals, Pulses and Horticulture crops, tea, coffee
Region	Whole country
Season	Throughout all seasons
Severity	High
Effects to the Ecosystem	• Loss of some local varieties, loss of biomass commonly used as feed, mulching and manure (diseased plants are uprooted and destroyed). • Disruption of ecosystem equilibrium. • Outbreak of new diseases and pests (due to pesticide resistance or killing of natural enemies).
Severity for Human	• Food insecurity. • Depletion of households' income.
Effects to the Economy	• Low productivity. • Decreased incomes and food availability and increased food prices.

Possible Mitigation actions	• Monitoring systems. • Utilization of clean planting materials. • Uprooting and destroying diseased plants.
Possible ways to prevent it	• Monitoring systems. • Utilization of clean planting materials. • Uprooting and destroying diseased plants.
Risk FS4.1.4: Losses due to poor post-harvest handling and processing	
Type of stakeholder	Government/RAB
Role of stakeholder	Implementer of Agricultural policies
Description of the challenge	Losses due to poor post-harvest handling and processing
Type of crop	Food and Horticulture crops
Name of the crops	Roots and tubers, cereals, Pulses and Horticulture crops
Region	Whole country
Season	Throughout all seasons
Severity	High
Effects to the Ecosystem	Possible production of environmental pollution gases
Severity for Human	• Food insecurity, • Depletion of households' income
Effects to the Economy	• Low and poor quality of the produce. • Decreased incomes and food availability and increased food prices and importation.
Possible Mitigation actions	• To avail post-harvest, handling and storage infrastructures. • Introduce new post-harvest handling, storage and processing innovation.
Possible ways to prevent it	• To avail post-harvest, handling and storage infrastructures. • Introduce new post-harvest handling, storage and processing innovation.
Risk FS4.1.5: Rapid population growth accelerating land fragmentation and continuous decrease of arable land for crops production	
Type of stakeholder	Government/RAB
Role of stakeholder	Implementer of Agricultural policies
Description of the challenge	Rapid population growth accelerating land fragmentation and continuous decrease of arable land for crops production
Type of crop	Food and Horticulture crops
Name of the crops	Roots and tubers, cereals, Pulses and Horticulture crops
Region	Whole country

Season	Throughout all seasons
Severity	High
Effects to the Ecosystem	• Disruption of ecosystem equilibrium (high pressure on exploitation of protected areas). • Loss of biodiversity.
Severity for Human	• Food insecurity. • Depletion of households' income.
Effects to the Economy	• Low and poor quality of the produce. • Decreased incomes and food availability and increased food prices and importation.
Possible Mitigation actions	• Settlement for habitat. • Family Planning.
Possible ways to prevent it	• Settlement for habitat. • Family Planning.
Risk FS4.1.6: Continuous soil infertility and degradation	
Type of stakeholder	Government/RAB
Role of stakeholder	Implementer of Agricultural policies
Description of the challenge	Continuous soil infertility and degradation
Type of crop	Food and Horticulture crops
Name of the crops	Roots and tubers, cereals, Pulses and Horticulture crops
Region	Whole country
Season	Throughout all seasons
Severity	Very high
Effects to the Ecosystem	• Disruption of ecosystem equilibrium (high pressure on exploitation of protected areas). • Loss of biodiversity.
Severity for Human	• Food insecurity. • Depletion of households' incomes.
Effects to the Economy	• Low and poor quality of the produce. • Decreased incomes and food availability and increased food prices and importation.
Possible Mitigation actions	• Use of agroforestry, • Composting and organic manure, erosion control.
Possible ways to prevent it	• Use of agroforestry. • Composting and organic manure, erosion control.
Risk FS4.1.7: Limited coordination of crop value chains	

Type of stakeholder	Government/RAB
Role of stakeholder	Implementer of Agricultural policies
Description of the challenge	Limited coordination of crop value chains
Type of crop	Food and Horticulture crops
Name of the crops	Roots and tubers, cereals, Pulses and Horticulture crops
Region	Whole country
Season	Throughout all seasons
Severity	High
Effects to the Ecosystem	Not applicable
Severity for Human	Depletion of households' income
Effects to the Economy	• Loss of production. • Decrease in quality. • Decreased incomes.
Possible Mitigation actions	Organisation and strengthening linkage of stakeholders along crop value chains.
Possible ways to prevent it	• Use of agroforestry. • Composting and organic manure, erosion control.
Risk FS4.1.8: Skills gap (knowledge on productivity, market, market standards, profitability)	
Type of stakeholder	Government/RAB
Role of stakeholder	Implementer of Agricultural policies
Description of the challenge	Skills gap (knowledge on productivity, market, market standards, profitability)
Type of crop	Food and Horticulture crops
Name of the crops	Roots and tubers, cereals, Pulses and Horticulture crops
Region	Whole country
Season	Throughout all seasons
Severity	Moderate
Effects to the Ecosystem	Not applicable
Severity for Human	Decreased of crop production/productivity and household incomes
Effects to the Economy	Decreased of crop production/productivity, household incomes and export
Possible Mitigation actions	Capacity building of key actors involved in crop production value chains
Possible ways to prevent it	Capacity building of key actors involved in crop production value chains
Risk FS4.1.9: Climate change and weather variability	

Type of stakeholder	Government/RAB
Role of stakeholder	Implementer of Agricultural policies
Description of the challenge	Climate change and weather variability
Type of crop	Food and Horticulture crops
Name of the crops	Roots and tubers, cereals, Pulses and Horticulture crops
Region	Whole country
Season	Throughout all seasons
Severity	Moderate
Effects to the Ecosystem	• Loss of biodiversity. • High pressure on ecological equilibrium.
Severity for Human	• Food insecurity. • Depletion of households' incomes. • Outbreak of human diseases.
Effects to the Economy	• Low crop production/productivity. • Depletion of households' income and national revenues. • Decrease of food availability and export. • Increase in food prices and importation.
Possible Mitigation actions	• Erosion control. • Reforestation. • Watershed management (irrigation and drainage), development. • Use of climate resilient crop varieties.
Possible ways to prevent it	• Erosion control. • Reforestation. • Watershed management (irrigation and drainage), development. • Use of climate resilient crop varieties.

Table 22: Risks on food-security roadmap encountered in livestock subsector (Rwanda).

Risk FS4.2.1: Limited access to veterinary services	
Type of stakeholder	Government/RAB
Role of stakeholder	Implementer of Agricultural policies
Description of the challenge	Limited access to veterinary services
Type of animal resources	Farm animals
Name of the animal species	Cattle, sheep, goats, pigs, poultry and rabbits

Region	Whole country
Season	Throughout
Severity	Moderate
Effects to the Ecosystem	• Antimicrobial resistance due to drug misuse. • Increased morbidity and mortality.
Severity for Human	• Increased resistance of microbial to drugs. • Increased public health impacts due to zoonotic diseases.
Effects to the Economy	• Reduced production and productivity leading to reduced income of farmers. • Reduced access to the international market.
Possible Mitigation actions	• Strengthening prevention measures (vaccination, vector control, awareness campaign, etc). • Strengthening diagnostic capacity (Laboratory: equipment, human capacity, reagents). • Treatment (improve accessibility and affordability of drugs, capacity building of practitioners). • Improve disease surveillance systems. • Strengthening Partnership (Universities, TVTs, Research organizations, NGOs, Service providers, inputs suppliers)
Possible ways to prevent it	Updating policies and strategies
Risk FS4.2.2: Scarcity of water for animals	
Type of stakeholder	Government/RAB
Role of stakeholder	Implementer of Agricultural policies
Description of the challenge	Scarcity of water for animals
Type of animal resources	Farm animals
Name of the animal species	Cattle, sheep, goats
Region	Eastern province farms and some smallholder farmers
Season	Mainly dry season
Severity	moderate
Effects to the Ecosystem	Increased illegal animal movements in search of water resulting to spreading of diseases and access to wildlife and livestock interface
Severity for Human	• Competition for water between humans and animals. • Reduced household income due to reduced animal productivity.

Effects to the Economy	Reduced production and productivity with negative impact to national economy
Possible Mitigation actions	• Putting in place mechanisms to have rainwater harvested. • Rehabilitation of existing water infrastructure (Valley dams and boreholes). • Put in place piped water infrastructure for general water distribution. • Withdrawal water from Akagera river for general water distribution in all the farms
Possible ways to prevent it	Develop and implement masterplan for water supply in farms
Risk FS4.2.3: Shortage of both quality and quantity of animal feeds	
Type of stakeholder	Government/RAB
Role of stakeholder	Implementer of Agricultural policies
Description of the challenge	Shortage of both quality and quantity of animal feeds
Type of animal resources	Farm animals
Name of the animal species	Cattle, sheep, goats, pigs, poultry, rabbit
Region	Whole country
Season	All seasons, but more in dry season
Severity	moderate
Effects to the Ecosytem	• Competition with humans for cereals and other food crops. • Reduced animal source foods for humans leading to malnutrition.
Severity for Human	• Competition with humans for cereals and other food crops. • Reduced animal source foods for humans leading to malnutrition.
Effects to the Economy	• Reduced production and productivity. • Reduced affordability of animal products. • Reduced trade of animals and animal products.
Possible Mitigation actions	• Mobilization and training of farmers to improve and maintain grazing farms and in fodder production and storage. • Diversification of animal feeds sources (e.g. by products, forage, concentrates, etc). • Strengthening improved forage seed system. • Mobilization and training of farmers to adopt technology for forage harvesting
Possible ways to prevent it	Develop and implement animal feed and feeding strategy

Risk FS4.2.4: Low adoption of animal breeding technologies and under-performing breeds	
Type of stakeholder	Government/RAB
Role of stakeholder	Implementer of Agricultural policies
Description of the challenge	Low adoption of animal breeding technologies and under-performing breeds
Type of animal resources	Farm animals
Name of the animal species	Cattle, sheep, goats, pigs, poultry, rabbits
Region	Whole country
Season	Throughout
Severity	Moderate
Effects to the Ecosytem	• Increased number of animals leading to increase of greenhouse gas emission. • Land degradation
Severity for Human	• Reduced Access to animal source foods. • Climate change due to increased greenhouse emission.
Effects to the Economy	• Reduced production and productivity. • Reduced affordability of animal products. • Reduced trade of animals and animal products.
Possible Mitigation actions	• Mobilization and training of farmers to adopt and manage improved breeds. • Training actors to adopt animal breeding technologies. • Establish and strengthen animal breeding programmes. • Restocking improved animal breeds
Possible ways to prevent it	Implement the newly developed animal breeding strategy
Risk FS4.2.5: Poor animal husbandry practices	
Type of stakeholder	Government/RAB
Role of stakeholder	Implementer of Agricultural policies
Description of the challenge	Poor animal husbandry practices
Type of animal resources	Farm animals
Name of the animal species	Cattle, sheep, goats, pigs, poultry, rabbits
Region	Whole country
Season	Throughout
Severity	Moderate
Effects to the Ecosystem	• Increased disease incidences.

	• Reduced production in both quality and quantity. • Violation animal welfare
Severity for Human	• Reduced quantity, quality and safety of animal source food. • Transmission of microorganisms from animal to human.
Effects to the Economy	• Increased rejection of animal products due to poor quality. • Reduced access to national, regional and international markets. • Reduced income and livelihoods of farmers
Possible Mitigation actions	• Awareness and training of farmers and stakeholders on good animal husbandry practices. • Develop and implement Standard Operating Procedures at all levels of the livestock value chain.
Possible ways to prevent it	Strengthen implementation of One Health System Approach (newly developed One health policy and strategy)
Risk FS4.2.6: High post-harvest loss	
Type of stakeholder	Government/RAB
Role of stakeholder	Implementer of Agricultural policies
Description of the challenge	High post-harvest loss
Type of animal resources	Farm animals
Name of the animal species	Cattle, sheep, goats, pigs, poultry, rabbits
Region	Whole country
Season	Throughout
Severity	Moderate
Effects to the Ecosystem	Increased animal products and inputs wastes into the environment
Severity for Human	• Reduced household income. • Reduced consumption of animal products.
Effects to the Economy	• Increased costs for waste management. • Reduced harvest from animals leading to reduced contribution to Agricultural GDP
Possible Mitigation actions	• Develop long shelf-life products. • Improve storage capacities. • Facilitate establishment and strengthening SMEs for animal products transformation and processing. • Capacity building of livestock value chain actors
Possible ways to prevent it	Develop and implement livestock post-harvest strategy
Risk FS4.2.7: Weak market system and consumption policy	
Type of stakeholder	Government/RAB

Role of stakeholder	Implementer of Agricultural policies
Description of the challenge	High post-harvest loss
Type of animal resources	Farm animals
Name of the animal species	Cattle, sheep, goats, pigs, poultry, rabbits
Region	Whole country
Season	Throughout
Severity	Moderate
Effects to the Ecosystem	Increased animal products and inputs wastes into the environment
Severity for Human	• Farmers sell at lower prices compared to costs of production leading to farmers dropping out from farming. • Irregular availability of animal products to consumers.
Effects to the Economy	• Reduced tax base. • Reduced contribution to Agricultural GDP.
Possible Mitigation actions	• Organize and create linkages of livestock value chain actors. • Setting up and regular updates of minimum standard prices for livestock products. • Awareness on consumption of animal products.
Possible ways to prevent it	Strengthening institution cooperation to improve market system, consumer awareness and protection

4.5 Review of risks on food security roadmap in Nigeria

Nigeria faces multiple food security risks that challenge its agricultural resilience framework across three key categories: (i) Sustainable intensification, (ii) Agriculture and food systems for nutrition, and (iii) Expansion and improvement of agricultural markets and trade. Climate change and variability, land degradation, and pest and disease outbreaks threaten sustainable intensification efforts by impacting crop yields and water availability. Malnutrition and micronutrient deficiencies are pressing issues within the agriculture and food systems for nutrition, stemming from limited dietary diversity and inadequate consumption of nutrient-rich foods. Furthermore, post-harvest losses, limited access to credit and financing, and infrastructure deficits hinder the expansion and improvement of agricultural markets and trade. Addressing these risks is crucial to building a more resilient and sustainable agricultural sector in Nigeria, ensuring food security, and promoting economic growth. In the following Table 23, we highlight some of these risks.

Table 23: Risks on food-security roadmap encountered in crop subsector (Nigeria).

Risk FS5.1.1: Negative effect of climate change and variability	
Type of stakeholder	Government agencies, crop development organizations
Role of stakeholder	Policy, product development
Description of the challenge	Climate change and variability affect crop yields and water availability, impacting food security in Nigeria.
Type of crop	All crops, but especially cereals such as maize

Name of the crops	Maize, rice, sorghum, millet, yam, cassava, cowpea, groundnut
Region	All regions of Nigeria, with varying degrees of impact
Season	Varies depending on the crop and region
Severity	Moderate to severe, depending on location, crop, and specific climate change factors
Effects to the Ecosystem	• Changes in water availability and quality • Shifts in pest and disease dynamics • Loss of biodiversity • Soil degradation
Severity for Human	Moderate to severe, with potential for malnutrition, displacement, and conflict due to resource scarcity
Effects to the Economy	• Reduced agricultural productivity. • Increased food prices. • Loss of income for farmers. • Increased reliance on food imports.
Possible Mitigation actions	Adoption of climate-resilient and drought-tolerant crop varieties
Possible ways to prevent it	• Reducing greenhouse gas emissions • Expanding renewable energy sources • Promoting sustainable land use and forestry • Encouraging climate-smart agricultural practices
Risk FS5.1.2: Limited access to improved seeds and technology	
Type of stakeholder	Seed sector, farmer associations
Role of stakeholder	Dissemination of improved seeds to the right target of regions
Description of the challenge	Limited access to improved seeds and technology restricts the ability of farmers to increase productivity and achieve food security.
Type of crop	Both staple and cash crops
Name of the crops	Maize, rice, sorghum, millet, yam, cassava, cowpea, groundnut, cocoa, oil palm, cotton
Region	All regions of Nigeria, with rural areas being more affected
Season	All seasons, as the issue is systemic
Severity	Moderate to severe, depending on location and access to resources
Effects to the Ecosystem	• Reduced agricultural productivity. • Overuse of traditional seed varieties, leading to Reduced biodiversity. • Increased pressure on natural resources due to low-yielding farming practices.
Severity for Human	Moderate to severe, with potential for malnutrition, poverty, and reduced economic opportunities.

Effects to the Economy	• Strengthening agricultural extension services. • Supporting research and development in improved seed varieties and agricultural technologies. • Developing public-private partnerships to enhance access to agricultural inputs. • Implementing farmer training and capacity building programs.
Possible Mitigation actions	• Strengthening agricultural extension services. • Supporting research and development in improved seed varieties and agricultural technologies. • Developing public-private partnerships to enhance access to agricultural inputs. • Implementing farmer training and capacity building programs.
Possible ways to prevent it	• Establishing a robust seed distribution system • Increasing investments in agricultural research and technology development • Encouraging the adoption of digital technologies for agricultural practices • Promoting policies that support access to and adoption of improved seeds and technologies
Risk FS5.1.3: Pest and disease outbreaks	
Type of stakeholder	Unmitigated pests and disease outbreaks
Role of stakeholder	Government, crop development institutions, plant health services
Description of the challenge	Pest and disease outbreaks can severely impact crop yields and livestock production, posing a significant threat to food security in Nigeria.
Type of crop	Both staple and cash crops
Name of the crops	Maize, rice, sorghum, millet, yam, cassava, cowpea
Region	All regions with varying degrees of impact depending on the specific pest or disease
Season	Varies depending on the crop, pest, and disease dynamics
Severity	Moderate to severe, depending on the scale and scope of the outbreak
Effects to the Ecosystem	Potential for pesticide resistance and contamination
Severity for Human	Moderate to severe, with potential for malnutrition, loss of income, and increased food prices
Effects to the Economy	• Reduced agricultural productivity • Increased cost of pest and disease management • Negative impacts on trade and export markets due to quality concerns
Possible Mitigation actions	• Implementation of integrated pest management (IPM) strategies • Regular monitoring and early warning systems for pest and disease outbreaks

	• Promotion of biocontrol and other environmentally friendly pest management options
Possible ways to prevent it	Strict implementation of plant quarantine regulations to prevent introduction of new pests and diseases in Nigeria

4.6 Review of risks on food security roadmap in Kenya

Kenya has many similarities in risks on food security mainly Ethiopia. Uganda and Rwanda. Thus, we can highlight, without explicitly replicating the following food security risks:

Risk FS2.1.1: Inadequate Pest and Disease tolerant and resistant varieties
Risk FS2.2.1: Livestock Feed Shortage and Coping Mechanisms
Risk FS2.2.2: Poor breed performance
Risk FS2.2.3: Zoonotic disease challenges
Risk FS3.2.2: Scarcity of water and feed for animals
Risk FS3.2.3: Low adoption of animal breeding technologies and under-performing breeds
Risk FS4.1.3.: High pressure of pests and diseases
Risk FS4.1.9: Climate change and weather variability

Nevertheless, especially for Kenya, one of the main risks is the scarcity of water (FS3.2.2) and climate change (FS4.1.9), which have led to unpredictable weather patterns, droughts, and floods that affect agricultural production. Another risk is the over-reliance on rain-fed agriculture, which also contributes to low productivity and food insecurity [36]. Over 80% of Kenya's lands are classified as arid and semi-arid Land (ASAL), based on the relatively low amounts of annual rainfall received. The Integrated Food Security Phase Classification (IPC) analysis in Kenya focuses on 23 counties/territories (Table 24) that comprise the Arid and Semi-Arid Lands (ASAL) region and whose population is generally the most food insecure given the high level of poverty, high vulnerability to shock and hazards, particularly climatic shocks linked to rainfall variability [37]. In 2023, corresponding with the harvest season, the Acute Food Insecurity IPC analysis results indicated that out of the 23 counties/territories analysed, 12 are in IPC AFI Phase 3 (Crisis) while the remaining 11 counties are classified in IPC Phase 2 (Stressed). For this analysis, around 4.4 million (27% of the analysed population) are estimated in IPC Phase 3 (Crisis) or above. This includes around 774,000 (5%) people in IPC Phase 4 (Emergency) and 3.6 million (22%) in IPC Phase 3 (Crisis). Five counties reported over 50% of their population in IPC Phase 3 or above: Turkana (50%), Garissa (55%), Mandera (55%), Marsabit (55%), and Wajir (55%), which are predominantly pastoral livelihood zones. Latest data shows a likely unprecedented deterioration in Kenya's food security situation, with over 5.4 million people experiencing acute food insecurity. In the current period, corresponding to the short rain harvest season, a slight decrease in the severity of food insecurity is observed across Kenya's arid and semi-arid lands (ASAL) areas, which presented four counties in IPC AFI Phase 4 (Emergency) in the previous season (namely Isiolo, Turkana, Marsabit and Mandera) that

improved to IPC Phase 3 (Crisis). This is mainly due to the direct impact of the rains on livelihoods in these areas. However, the improvement is expected to be limited in time, and further deterioration is projected in 2023. The provisional alleviation of food insecurity conditions in these areas in particular, however, did not translate into an improvement to the Extremely Critical level (IPC AMN Phase 5) of acute malnutrition in parts of Marsabit (Laisamis) and Turkana South, and other areas, like North Turkana, Wajir and North Horr are also projected to reach Extremely Critical levels of acute malnutrition.

Table 24: Population table for the current period

	Phase 1 [People in food security]		Phase 2 [People stressed]		Phase 3 [People in crisis]		Phase 4 [People in emergency]		Phase 5 [People in catastrophe/Famine]	
Kenya: Acute Food Insecurity [2023]	**# People**	**%**	**# People**	**%**	**# People**	**%**	**# People**	**%**	**# People**	**%**
	6,161,857	**37%**	**6,066,774**	**37%**	**3,615,790**	**22%**	**773,989**	**5%**	**0**	**0**
Baringo	293,333	40%	220,000	30%	220,000	30%	0	0	0	0
Embu	112,392	40%	140,490	50%	28,098	10%	0	0	0	0
Garissa	231,758	25%	185,406	20%	370,812	40%	139,055	15%	0	0
Isiolo	63,187	20%	142,172	45%	94,781	30%	15,797	5%	0	0
Kajiado	380,478	30%	697,544	55%	190,239	15%	0	0	0	0
Kilifi	709,801	45%	788,668	50%	78,867	5%	0	0	0	0
Kitui	614,895	50%	307,448	25%	245,958	20%	61,490	5%	0	0
Kwale	377,786	40%	472,232	50%	94,446	10%	0	0	0	0
Laikipia	196,428	35%	280,612	50%	84,183	15%	0	0	0	0
Lamu county	100,399	60%	50,200	30%	16,733	10%	0	0	0	0
Makueni	521,150	50%	312,690	30%	208,460	20%	0	0	0	0
Mandera	191,847	20%	239,809	25%	383,694	40%	143,885	15%	0	0
Marsabit	103,058	20%	128,823	25%	206,117	40%	77,294	15%	0	0
Meru	238,343	30%	397,238	50%	158,895	20%	0	0	0	0
Narok	770,400	60%	385,200	30%	128,400	10%	0	0	0	0
Nyeri	112,826	55%	61,542	30%	30,771	15%	0	0	0	0
Samburu	34,830	10%	156,734	45%	121,904	35%	34,830	10%	0	0
TANA RIVER	52,882	15%	141,020	40%	141,020	40%	17,627	5%	0	0
Taita	90,998	25%	218,394	60%	54,599	15%	0	0	0	0
Tharaka	88,855	50%	71,084	40%	17,771	10%	0	0	0	0
Turkana	204,555	20%	306,832	30%	357,971	35%	153,416	15%	0	0
Wajir	130,595	15%	261,191	30%	348,254	40%	130,595	15%	0	0
West pokot	541,061	80%	101,449	15%	33,816	5%	0	0	0	0

Compared to the same period in 2022, 15 counties were classified in IPC Phase 3 (Crisis), representing a 43% increase in population in IPC Phase 3 or above. Yet, in 2024 the severity of food insecurity is expected to worsen again: about 5.4 million people (32% of the population analysed) are projected to

face high levels of acute food insecurity (IPC AFI Phase 3 or above), of which 1.2 million people (7%) will likely be in Emergency. This latest projection represents the highest magnitude and severity of acute food insecurity in the ASAL areas in years; urgent action is required to reduce food gaps, protect their livelihoods, and prevent and treat acute malnutrition (Figure 9)

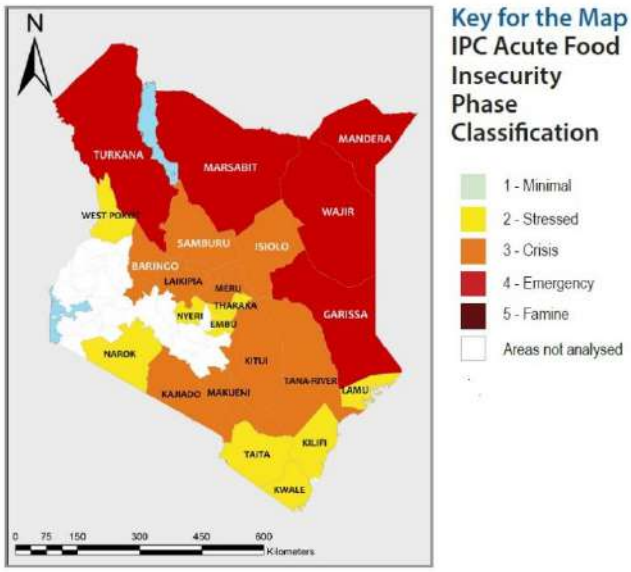

Figure 9: Map on IPC Acute Food Insecurity Phase Classification in Kenya

In addition, pests and diseases pose a serious threat to food security, with invasive pests like the fall armyworm, Tuta Absoluta and desert locusts causing significant damage to crops. Poor infrastructure, such as inadequate storage facilities and poor transportation networks, also puts Kenya's food security at risk by causing post-harvest losses and reducing access to markets.

Finally, inadequate policies and regulations to guide the food sector and inadequate investment in research and development may hamper the implementation of Kenya's food security roadmap. The COVID-19 pandemic has had a significant impact on food security, leading to supply chain disruptions, reduced incomes, and increased prices of food items, particularly for the vulnerable population. Overall, addressing these risks is crucial for successful implementation of Kenya's food security roadmap.

5 Conclusion

In conclusion, this deliverable has analysed several key aspects of food security in Cameroon, Uganda, Ethiopia, Rwanda, Nigeria and Kenya. Historical case studies were examined to gain a deeper understanding of the challenges that have arisen in the past. A review of national risks to the food security roadmap was also undertaken. The findings highlighted the need for a comprehensive approach to food security in Africa, which will be used to develop the NESTLER platform based on user needs.

In addition, the use cases relevant to the NESTLER project were classified into three main categories based on the historical case studies. These use cases were for crop - based farming, livestock farming and aquaculture farming. The user and technical requirements of the NESTLER platform were identified and a brief description of the high-level NESTLER architecture was designed to cover the emerging functional and non-functional requirements.

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