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NESTLER

oNe hEalth SusTainabiLity partnership between

EU-AFRICA for food sEcuRity

Deliverable D5.5
Evaluation of NESTLER 2nd phase platform

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Abstract	Deliverable D5.5 presents the final evaluation of the NESTLER 2nd phase platform, documenting its evolution from modular pilot-oriented tools into an integrated, cloud-native One Health decision-support environment. The report assesses operational performance, technical validation, data-collection efficiency, interoperability, pilot-demonstration evidence and stakeholder-facing value across crop, livestock, aquaculture, environmental and zoonotic-risk use cases. Particular emphasis is placed on Phase 2 enhancements, including REST API and GIS services, Kubernetes-based deployment, secure access control, dashboard integration, AI-enabled analytical services, Ecological Niche Modelling and the Zoonotic Disease Outbreak Service. The deliverable consolidates the main evaluation outcomes, identifies residual limitations and defines considerations for post-project sustainability, maintenance and scale-up.

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Definitions, Acronyms and Abbreviations

AI	Artificial Intelligence
ARIMA	Auto Regressive Integrated Moving Average
BSF	Black Soldier Fly
BSFL	Black Soldier Fly Larvae
BSFLM	Black Soldier Fly Larvae Meal
CNN	Convolutional Neural Network
DGR	Daily Growth Rates
DMO	Data Management Officer
DMP	Data Management Plan
DSS	Decision Support System
DZARC	Debre Zeit Agricultural Research Centre
EC	European Commission
ENM	Ecological Niche Modelling
EPPPA	Ethiopian Poultry Producers and Processors Association
ESA	European Space Agency
EU	European Union
FCF	Fulton’s Condition Factor
GAN	Generative Adversarial Network
GBM	Gradient Boosting Machines
GIS	Geographic Information System
GPS	Global Positioning System
IACUC	Institutional Animal Care and Use Committee
IoT	Internet of Things
KALRO	Kenya Agricultural and Livestock Research Organization
KPI	Key Perform Indicator
LDR	Light Dependent Resistor
LMIC	Low- to Middle Income Countries
ML	Machine Learning
NIR	Near Infrared Reflectance
NPK	Nitrogen, phosphorus, and potassium fertiliser
pH	Potential of Hydrogen
SRTM DEM	Shuttle Radar Topography Mission Digital Elevation Model
TL	Total Length
TW	Total Weight
UAV	Unmanned Aerial Vehicles
VSRI	Veterinary Science Research Institute
VU	Virtual User
ZDOS	Zoonotic Disease Outbreak Service

Executive Summary

NESTLER is a Research and Innovation Action establishing a One Health sustainability partnership between the European Union and African partner countries. The project addresses the interdependence of human health, animal welfare, plant production systems and environmental stability, with the aim of strengthening the safety, resilience and sustainability of food systems. Its pilot demonstrations in Uganda, Ethiopia, Cameroon, Kenya, Rwanda and Nigeria provide the operational context for validating digital, analytical and field-based interventions.

Deliverable D5.5 reports the final evaluation of the NESTLER 2nd phase platform. Building on the first-phase evaluation reported in D5.2, it assesses how the platform has matured from a set of initial technological components into an integrated, cloud-native environment. The evaluation covers WP5 activities, with emphasis on Tasks T5.2, T5.3, T5.4 and T5.5, and combines technical validation, pilot evidence, end-user feedback and One Health interpretation.

The second-phase evaluation confirms substantial progress in platform integration, interoperability and operational readiness. The final platform combines IoT and handheld field devices, Earth Observation and climate data, entomological observations, animal and aquaculture monitoring, AI-enabled backend services, GIS visualisation, dashboards and secure access-control mechanisms. These capabilities support smart irrigation, crop and pest monitoring, tomato disease recognition, poultry and aquaculture trials, environmental-risk forecasting, crop-quality monitoring and zoonotic-risk assessment.

The key components of this deliverable are summarised below:

- ✓ Evaluation of the methodological framework and performance indicators.
- ✓ Assessment of the platform evolution from Phase 1 to the final Phase 2 release.
- ✓ Technical validation of REST APIs, GIS/dashboard services, cloud deployment and Phase 2 analytical workflows.
- ✓ Evaluation of pilot demonstrations across crop, livestock, aquaculture, environmental and zoonotic-surveillance use cases.
- ✓ Assessment of ENM and ZDOS as One Health risk-intelligence components.
- ✓ End-user and stakeholder-based assessment, including adoption risks and post-project improvement needs.

The deliverable concludes that the NESTLER Phase 2 platform has reached a mature research-and-demonstration stage. It is technically credible, scientifically aligned with the One Health paradigm and relevant for food-system resilience in diverse African pilot contexts. Further exploitation should focus on sustained hosting, data-quality assurance, model monitoring, cybersecurity hardening, role-specific user support and clear post-project ownership.

1 Introduction

The NESTLER project is a strategic Research and Innovation Action funded by the European Union, representing a One-Health sustainability partnership between the EU and Africa. The project is built on the fundamental recognition that human health, animal welfare, plant systems, and environmental stability are deeply interdependent. To realize this holistic paradigm, the NESTLER platform was conceived as an integrated digital ecosystem capable of monitoring and correlating cross-sectoral data streams, including IoT sensing, Earth observation (EO), and AI-driven analytics, to provide early warning systems and decision support for a resilient food supply chain.

The development of the NESTLER platform has followed an iterative evolutionary path, progressing from the initial deployment of modular technological interventions to the final delivery of a cohesive, cloud-native integrated system. This evolution is documented through two primary stages:

- **Phase 1- Operational Evaluation**: The first phase focused on the individual performance of technical components, such as IoT frameworks for real-time monitoring and preliminary AI models for crop and livestock management. This stage involved intensive technical validation and stakeholder engagement across six African pilot countries: Cameroon, Ethiopia, Kenya, Nigeria, Rwanda, and Uganda. The evaluation identified critical performance bottlenecks, such as system uptime and data accuracy expectations, providing a roadmap for technical refinement.
- **Phase 2 - Final Integrated Release**: Building upon the insights from Phase 1, the platform evolved into a unified system that integrates all backend services, analytical models, and frontend interfaces into a single operational workflow. This final version transitioned to a cloud-native Kubernetes architecture, ensuring the high availability, scalability, and operational resilience required for continental-scale deployment.

The primary objective of this deliverable, entitled "Overview of the NESTLER platform evolution," is to provide a comprehensive evaluation of the NEST:ER platform and the transition from a collection of modular tools to a fully operational, integrated decision-support system. It presents the technical advancements, the integration of diverse AI services, such as the Zoonotic Disease Outbreak Service (ZDOS) and RinisNestler video analytics, and the iterative improvements driven by end-user feedback. It serves as a final account of how the platform has been optimized to solve targeted problems in plant, animal, human and environmental health monitoring.

The scope of D5.5 covers the entire lifecycle of the platform's development, specifically focusing on:

- ✓ The transition from a loosely coupled architecture to an integrated system platform.
- ✓ The maturation of AI and Machine Learning models, moving from standalone predictive tools to integrated services that feed directly into a unified GIS dashboard.
- ✓ The establishment of a robust security and access control model based on Identity and Access Management (IAM) and Role-Based Access Control (RBAC).
- ✓ The development of Ecological Niche Modelling (ENM) for zoonotic disease spreading and identification of outbreaks under changing climate.
- ✓ The operational validation of the platform across diverse agricultural and environmental use cases, including drought and flood forecasting, pest infestation monitoring, and zoonotic disease risk modeling

2 Methodological Framework for Platform Evaluation

2.1 Evaluation objectives and indicators

Each pilot/use case within the NESTLER platform has its own specific objectives and key performance indicators (KPIs), detailed in Deliverable D5.1 [1]. These metrics ensure that stakeholders can rely on the platform for continuous, real-time access to critical data across various use cases. Each Use Case defined in D5.1 [2] has data accuracy KPIs specific to the type of data being processed, whether it's for weather patterns, pest outbreak alerts, or yield predictions. These use case-specific KPIs assured that data accuracy was maintained across different domains. The KPIs are crucial for evaluating the effectiveness and performance of the NESTLER platform in achieving its goals. These KPIs help measure the NESTLER platform's technical performance, data accuracy, usability, and scalability, ensuring it delivers actionable insights for food security management.

The KPIs provide a measurable framework for assessing both the technical and user-centric performance of the platform. These KPIs were developed through consultations with stakeholders and benchmarking against other agricultural platforms. Deliverable D1.2 [2] introduced a set of KPIs including technical, user-centric, and impact-related metrics. More specifically:

- **Technical KPIs:** These KPIs evaluate the platform's infrastructure, including its uptime, data accuracy, and the processing speed of AI models.
    - ✓ **System Uptime:** Measures the percentage of time the platform remains operational, ensuring uninterrupted access to data and services.
    - ✓ **Data Accuracy:** Assesses the precision of real-time data, including soil moisture readings, pest detection from images, and disease surveillance.
    - ✓ **Processing Time:** Evaluates the speed at which the platform processes incoming data and delivers predictions, ensuring real-time usability.
    - ✓ **Scalability:** Assesses the platform's ability to handle an increasing volume of data and users without degradation in performance.
- **User-Centric KPIs:** These KPIs focus on user satisfaction and how easily users can engage with the platform's features.
    - ✓ **Usability:** Measures how intuitive the platform interface is for various user groups.
    - ✓ **User Satisfaction:** Collected via surveys, this KPI measures overall user experience.
    - ✓ **Adoption Rate:** Assesses the rate at which new users adopt and regularly use the platform.
- **Impact KPIs:** These KPIs evaluate how well the platform contributes to food security and decision-making.
    - ✓ **Decision-Making Impact:** Assesses how effectively the platform's insights influence critical decisions related to crop and livestock management, disease control, and food security.
    - ✓ **Sustainability Contribution**: Evaluates how well the platform supports sustainable agricultural practices by valorizing waste into high-value innovative products [alternative proteins and frass fertilizers] and promoting resilience.

For data-driven decision-making in agriculture, the accuracy of data is fundamental. The NESTLER platform collects data from a variety of sources, including IoT sensors, satellite imagery, and field reports. Maintaining the integrity of this data is essential to provide trustworthy insights to stakeholders.

2.2 Data Sources and Data Collection Methods

The following techniques were used as data sources. More specifically:

- **Surveys and Questionnaires**: Structured surveys were distributed to the stakeholders involved in each pilot site. These surveys collected information on agricultural practices, resources utilization, and perceptions of AI technologies implemented through the NESTLER platform.
- **Focus Group Discussions**: Facilitated discussions with local communities provided insights into their experiences with the NESTLER platform. These discussions allowed participants to share their challenges and successes in adopting new technologies.
- **Field Observations**: Researchers conducted on-site observations to gather real-time data (including video, voice etc) on farming practices and livestock management. This hands-on approach helped validate survey responses and provided context for the quantitative data collected.
- **Remote Monitoring Technologies**: SynField devices, Cassava handheld IoT devices and remote sensing technologies were utilized to collect data on soil health, moisture levels, crop growth, and livestock conditions continuously. This real-time data was crucial for assessing the effectiveness of interventions.
- **Entomological Observations:** Automatic and manual trapping systems were installed at pilot locations to monitor insect vector populations. These observations provide continuous and periodic data on vector presence, density and competencies. The information is used to support epidemiological analysis and risk modelling.
- **Earth Observation:** Leverages periodic data from the Copernicus Sentinel satellites to monitor environmental conditions at high spatial and temporal resolution. These data are processed to detect patterns and drivers that influence the formation and movement of locust swarms, as well as the spread of zoonotic diseases. By integrating satellite observations with modelling techniques, the system supports early warning and forecasting of outbreak risks, enabling timely and targeted interventions.

2.3 Integration of pilot demonstration data

The integration of pilot demonstration data within the NESTLER platform constitutes a key step for validating the system in real operational environments. Pilot sites deploy a variety of data collection mechanisms, including IoT-based environmental sensors (e.g. SynField [3], SynAir [4], SynWater [5]), insect vector traps (both automatic and manual), handheld devices for crop quality monitoring (e.g. Cassava), and video-based animal observation systems. In addition, Earth Observation data from sources such as Copernicus Sentinel are incorporated to provide large-scale environmental context. These heterogeneous data streams capture complementary aspects of the One Health domain, covering environmental conditions, vector dynamics, plant health, human and animal behavior.

All incoming data are ingested through standardized interfaces and APIs, ensuring interoperability across different data providers and devices. The data were harmonized in terms of spatial resolution (e.g., grid-based representation) and temporal frequency (e.g., hourly, daily or weekly aggregation), enabling consistent downstream processing. A centralized data management layer, based on PostgreSQL/ PostGIS/TimescaleDB and object storage, stores both raw and processed data, including geospatial attributes, time-series measurements, and metadata. This unified data infrastructure allows seamless integration with analytical services and ensures traceability and reproducibility of results.

The integrated pilot data feed directly into the NESTLER platform's analytical AI algorithms and backend services, including the Zoonotic Disease Outbreak Service (ZDOS). Real-time and historical observations are used to update risk indicators, calibrate models, and validate predictions against observed conditions. For example, entomological trap data enhances surveillance-based risk estimation, while IoT and satellite data improve environmental suitability modelling. This continuous data assimilation process increases the accuracy and robustness of risk assessments and supports adaptive modelling under changing environmental and epidemiological conditions.

Finally, the integration of pilot demonstration data enables comprehensive visualization and decision support through the NESTLER platform's GIS and dashboard components. Users can access spatial risk maps, temporal plots, and multimedia insights/assets (e.g., animal videos) in an intuitive interface. The availability of pilot data also facilitates performance evaluation, stakeholder engagement, and iterative system improvement. By combining real-world data with advanced analytics, the NESTLER platform delivers actionable insights that support evidence-based decision-making within the One Health Sustainability Partnership.

2.4 Ecological Niche Modelling framework

The Ecological Niche Modelling (ENM) framework aims to identify and map the persistence of vectors, hosts, and pathogens associated with zoonotic diseases and agricultural pests, and to relate this persistence to climate. The target diseases are Lassa fever, tularemia, and zoonotic cutaneous leishmaniasis, together with their associated vectors and host species. Within the context of the NESTLER project, the framework supports a One Health approach, integrating environmental, animal, and human health data to assess spatial and temporal risk patterns. The primary objective is to enable early detection of potential hotspots, support surveillance strategies, and inform decision-making for disease prevention and ecosystem management.

2.4.1 Methodological Approach

The ENM framework combines data-driven (Self-organising map, k-means clustering, and fixed-effects panel regression) and process-based modelling (ordinal differential equation) approaches to capture the complex interactions among climate, environment, and biological systems. It leverages multi-source datasets, including:

- ✓ Earth Observation data (e.g., Copernicus Sentinel)
- ✓ Climate variables (e.g., temperature, precipitation, humidity, wind)
- ✓ Land use and land cover data
- ✓ Host distribution (human population, livestock and wildlife density)
- ✓ Vector occurrence and abundance data
- ✓ Disease cases

These datasets are harmonized to a common spatial and temporal resolution and used to estimate environmental suitability through statistical, machine learning, or mechanistic models. The framework supports both species distribution modelling and disease suitability modelling, enabling flexible application across different use cases.

2.4.2 Integration with One-Health Data

The ENM framework is designed to integrate seamlessly with heterogeneous data streams collected within the platform, including:

- ✓ SynField environmental sensors
- ✓ Entomological trap observations
- ✓ Remote sensing products
- ✓ Animal monitoring systems

This integration ensures that ecological suitability models are continuously updated with near real-time data, improving the accuracy and responsiveness of risk assessments.

2.4.3 Outputs and Indicators

The framework produces spatially explicit suitability maps representing the likelihood of vector presence, host availability, or disease transmission potential. These outputs are typically normalized (e.g., values between 0 and 1) and can be mapped into risk indices (no risk/no data, low, moderate, high, critical). Key outputs include:

- ✓ Habitat suitability maps for vectors and hosts
- ✓ Environmental risk indicators
- ✓ Spatio-temporal trends in ecological conditions
- ✓ Inputs to downstream risk models (e.g., zoonotic outbreak services)

2.4.4 Application and Impact

The ENM framework supports a wide range of applications within the NESTLER project, including:

- ✓ Early warning systems for zoonotic diseases and pest outbreaks
- ✓ Targeted surveillance and monitoring strategies
- ✓ Climate change impact assessment on disease dynamics
- ✓ Decision support for public health and agricultural management

By providing a scalable and modular modelling approach, the framework contributes to sustainable ecosystem management, improved resilience to emerging risks, and enhanced cross-sectoral collaboration under the One Health paradigm.

As a conclusion, the Ecological Niche Modelling framework constitutes a core analytical component of the NESTLER platform, enabling the transformation of diverse environmental and biological data into actionable insights. Its integration with risk assessment services and geospatial visualization tools ensures that stakeholders can effectively monitor, predict, and respond to emerging zoonotic and ecological threats.

2.5 Limitations and assumptions

The methodological framework for the evaluation of the platform is based on a multi-dimensional approach that assesses technical performance, data quality, analytical capabilities, and user experience within a One Health context. The evaluation combines quantitative indicators with qualitative assessments derived from pilot demonstrations and stakeholder feedback. Data collected from IoT devices, entomological traps, handheld devices, video monitoring systems, and Earth Observation sources are used to validate the end-to-end functionality of the platform, from data ingestion to visualization and decision support. The framework emphasizes reproducibility and scalability, ensuring that evaluation results are comparable across different pilot sites and use cases.

However, the evaluation is subject to several assumptions and limitations. It assumes the availability and reliability of input data streams, although in practice data gaps, sensor malfunctions, or inconsistencies across pilot sites may affect performance metrics and model accuracy. It is worth mentioning that, over time, some sensors require re-calibration by design to maintain accuracy. Additionally, the framework assumes that environmental and epidemiological relationships captured by the models remain stable over time, which may not fully account for sudden changes due to climate variability or unforeseen events.

Limitations also arise from the heterogeneity of data sources, differences in spatial and temporal resolution, and the dependency on external services (e.g., satellite data or APIs). Finally, user feedback may be influenced by varying levels of technical expertise, which can affect the interpretation of usability indicators. Despite these constraints, the framework provides a robust basis for assessing platform performance and guiding iterative improvements.

3 Overview of the NESTLER platform evolution

This chapter provides an overview of the NESTLER Phase 2 platform evaluation by examining how the platform evolved from Phase 1, which formed a set of modular tools into an integrated, cloud-native, One Health decision-support environment. The evaluation combines three perspectives. First, it considers the platform as a food-security instrument, assessing whether the technological evolution supports more resilient crop, livestock and aquaculture systems. Second, it considers the platform as a cloud-computing system, assessing integration, scalability, availability, interoperability and security. Third, it considers the platform as a One Health surveillance asset, assessing how environmental, animal, human and plant and human-risk data are connected through models, geospatial outputs and user-facing decision support.

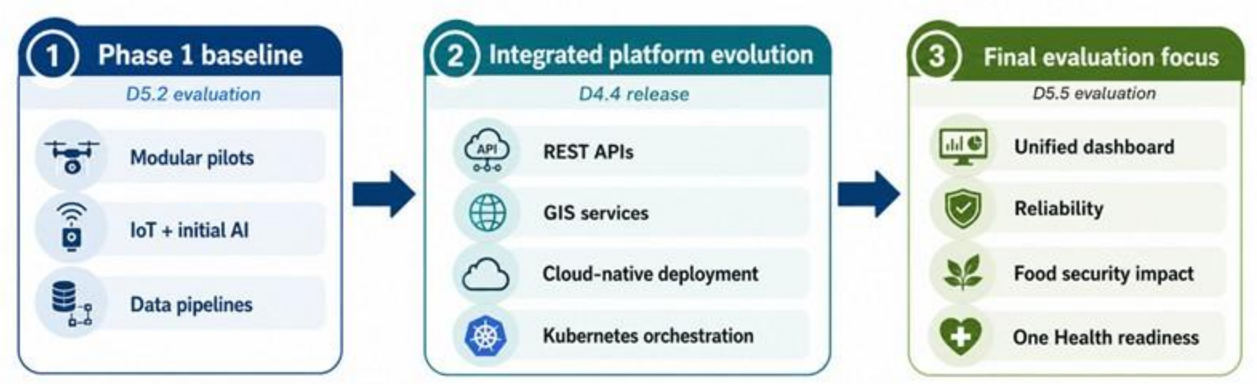


Figure 1: Evolution pathway from Phase 1 evaluation to Phase 2 integrated release and final evaluation

3.1 Evolution path and evaluation perspective

The first phase of the NESTLER platform evaluation, documented in D5.2 [7], established the baseline for assessing operational performance, data-collection efficiency, user experience and the ability of the platform to combine IoT, cloud storage and AI-driven analytics for plant, animal and human-health monitoring. In that phase, the main evaluation emphasis was placed on the functionality of individual platform components, the first integration of AI models and IoT data streams, and the capacity of the platform to respond to use-case requirements in the pilot countries.

During the second phase, the evaluation focus shifted from component-level validation to system-level operational maturity. The platform no longer operates only as a set of separate services; it functions as a coordinated digital ecosystem in which field observations, sensor streams, satellite and climate data, animal and aquaculture observations, economic-risk indicators and zoonotic-disease outputs can be accessed through common APIs, databases, GIS services and dashboards. This transition is central to the final evaluation of D5.5, because the value of the platform depends not only on the accuracy of individual algorithms but also on the reliability of the full workflow from data acquisition to decision support.

Table 1: Main evolution steps and evaluation interpretation for the NESTLER platform

Scope	Phase 1 baseline	Phase 2 extension	Evaluation interpretation
Functional scope	Individual services and pilot-specific tools were tested for feasibility.	Environmental, agricultural, animal-health, aquaculture, economic-risk and zoonotic-risk services are integrated into a unified platform workflow.	The platform demonstrates a move from technology demonstration to operational decision-support integration.
Data integration	IoT, imagery and pilot observations were introduced through heterogeneous data flows.	REST APIs, GIS services, device registration and structured observations support more consistent ingestion and traceability.	Data interoperability is materially improved, although quality assurance remains dependent on sensor calibration and field procedures.
Cloud readiness	The platform relied on modular deployments with initial scalability expectations.	The final release uses containerised services, Kubernetes deployment, replicas, ingress routing, certificates and scheduled database-backup mechanisms.	Cloud-native maturity is sufficient for project-scale operation and provides a realistic pathway for post-project hardening.
User interaction	Users interacted mainly with early dashboards and pilot-specific interfaces.	The dashboard visualises devices, traps, forecasts, risk layers, graphs, indicators and administrative functions.	The interface has matured into a shared situational-awareness environment for farmers, researchers and policymakers.
One Health value	Use cases addressing crop, livestock, aquaculture and disease-related requirements.	The platform links climate, environment, agriculture, livestock/aquaculture and vector-surveillance data in shared workflows.	The second phase better addresses One Health by connecting cross-domain evidence in spatial and temporal form.

3.2 System architecture and cloud-native deployment

The final platform release described in D4.4 presents NESTLER as an integrated system that brings together data sources, backend services, analytical models, visualisation tools and operational workflows. This is a significant architectural maturation compared with the earlier prototype stages. The architecture now follows a layered logic: data acquisition from field and external sources; ingestion through APIs and registration services; persistence in structured, spatial and object-storage components; analytical execution through backend and AI services; and decision support through dashboards, GIS layers, graphs, tables and alerts.

From a cloud-computing perspective, the most important evolution is the transition toward containerised deployment and orchestration. The use of Kubernetes allows the platform to manage workloads, services and runtime dependencies in a reproducible and scalable manner. This is consistent with current cloud-native practice, where portability, automation, self-healing and declarative configuration are used to improve availability and operational manageability. For D5.5, this is evaluated as a major positive development because the platform must support geographically distributed pilots, heterogeneous datasets and multi-stakeholder access over time.

The deployment of core services as replicated pods across different Kubernetes nodes reduces the likelihood that a single container or node failure will interrupt access to the platform. In addition, the scaling of the NESTLER REST API to three pods improves service availability under concurrent user requests and provides a practical basis for load balancing. This is not yet equivalent to a formal service-level agreement, but it demonstrates that the platform has adopted the basic operational patterns required for resilient cloud-based decision support.

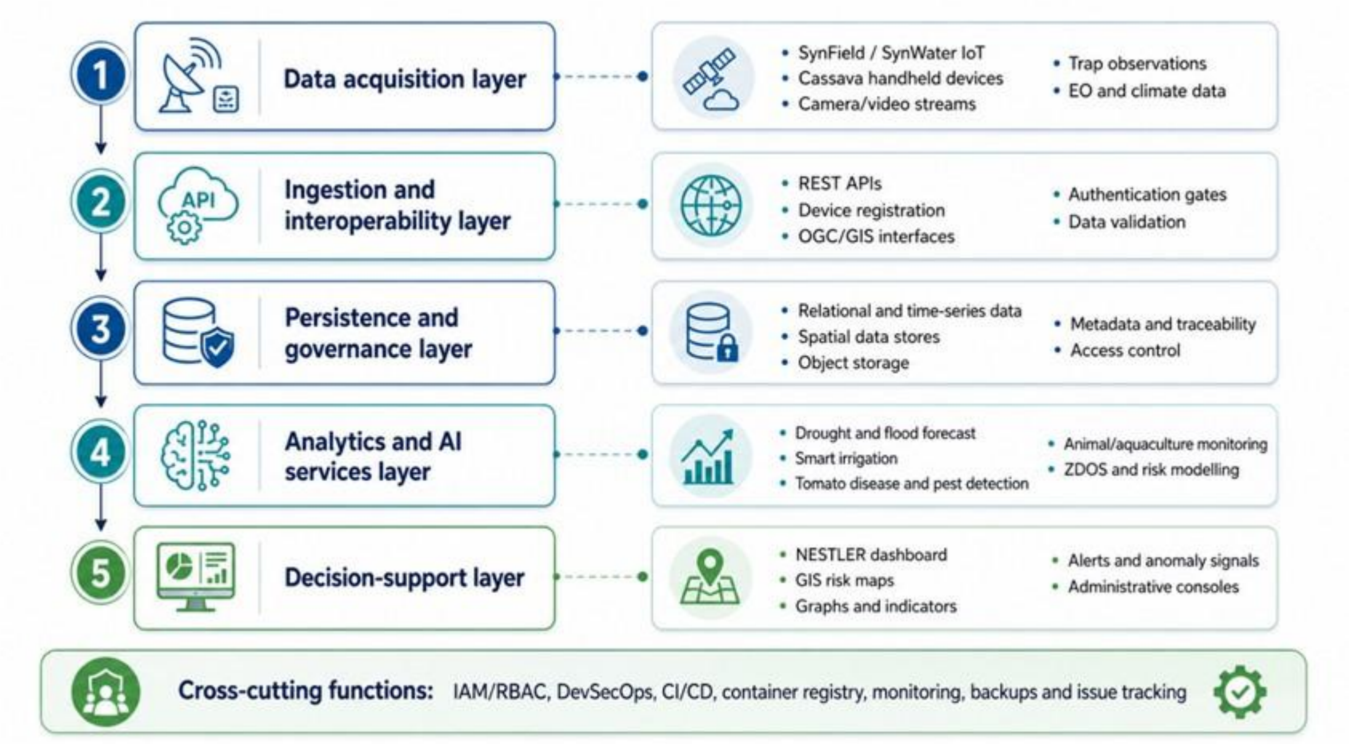


Figure 2: Logical architecture used for Chapter 3 evaluation of the NESTLER Phase 2 platform.

3.3 Data sources, data pipelines and interoperability

A central feature of the NESTLER platform evolution is the broadening of data sources and the progressive standardisation of the pipelines that connect them. The platform receives information from IoT devices, camera and video streams, entomological traps, handheld crop-quality devices, animal and aquaculture monitoring observations, Earth Observation products, weather and climate services, and pilot-specific datasets. The resulting data environment is intrinsically heterogeneous, varying in spatial resolution, temporal frequency, measurement uncertainty, file format and ownership conditions.

The platform response to this heterogeneity is the introduction of structured APIs, device registration workflows, GIS services and data-validation mechanisms. The REST API provides a communication layer between backend services, frontend components and databases. The GIS services allow spatial layers to be published and visualised using geospatial standards. The registration of devices and traps improves metadata traceability and ensures that observations are associated with the correct location, device type, pilot context and service workflow. This reduces ambiguity in downstream analytics and supports reproducible interpretation of model outputs.

For food-security evaluation, this data pipeline has practical importance. Crop and soil data support input optimisation and disease monitoring; livestock and aquaculture data support animal-health and feed-system decisions; environmental and climate data support drought, flood and pest-risk assessment; trap and vector observations support zoonotic-risk modelling. The platform therefore contributes to food security not only through isolated AI predictions but through the integration of multiple early-warning and management signals.

Table 2: Data-source integration and contribution to the NESTLER decision-support chain

Data source / input	Platform handling	Analytical use	Food-security / One Health contribution
SynField and SynWater sensors	Ingestion through IoT data flows and validation rules, including range checks and recalibration actions.	Soil, irrigation, environmental and water-condition monitoring.	Supports precision irrigation, resource efficiency and more reliable local agronomic decisions.
Cassava handheld devices	Automatic registration and structured storage through REST API extensions and IAM-authenticated operations.	Crop-quality and field-level measurements.	Improves traceability of crop-quality evidence and supports yield-quality monitoring.
Camera/video streams	Registration, backend processing and dashboard visualisation through dedicated monitoring services.	Animal, fish and poultry metrics; activity and anomaly indicators.	Supports welfare monitoring and better controlled livestock/aquaculture management.
Trap and entomological observations	Field submission through dashboard forms and integration into ZDOS pipelines.	Vector abundance, species and sex differentiation, disease-risk inference.	Strengthens surveillance-based early warning for zoonotic and vector-borne disease spread.
Earth Observation and climate data	Integrated into environmental, flood, drought, pest and risk-modelling services.	Weather impact assessment, risk maps and environmental suitability indicators.	Supports climate-smart agriculture, hazard preparedness and spatial prioritisation.
Pilot datasets and user observations	Stored and linked to service workflows, visualised as indicators, graphs, tables and maps.	Cross-pilot evaluation, model interpretation and operational feedback.	Supports evidence-based adaptation of the platform to local needs and conditions.

3.4 AI algorithms and backend services

The first evaluation of the NESTLER platform was documented in Deliverable D5.2 (M32) [1]. Since M32, the platform has undergone several enhancements, including updates to existing services and the development of new services. These improvements have led to more integrated and cohesive platform architecture. The final version of the NESTLER platform architecture has been reported in Deliverable D4.3 [7]. As a result, multiple services have been successfully incorporated into the platform, enhancing its overall capabilities and performance.

The AI portfolio includes agriculture-monitoring algorithms, animal-health monitoring algorithms for domestic and wild animals, aquaculture-monitoring algorithms, pest-identification services, tomato-disease recognition, drought and flood forecasting, smart irrigation support, smart pest detection and economic-risk modelling. D4.3 also describes the NESTLER AI Framework (NAIF), including the use of federated-learning concepts and security-oriented design elements for distributed model training. This is a strategically important direction because many agricultural and health-related datasets are sensitive, locally owned or difficult to centralise.

In this deliverable, the backend services are assessed positively on four grounds: a) the services cover the major domains defined by the NESTLER pilots, b) several services are accessible through documented APIs, which improves reproducibility and integration, c) services are progressively linked to the dashboard and GIS environment, which transforms algorithmic outputs into interpretable decision-support assets, and d) the use of containerised deployment makes service updates, rollback and replication more manageable. Remaining constraints relate mainly to model drift, uneven field data availability, external-data dependencies and the need for continuous model-monitoring procedures beyond the project period. This evolution has been driven by the need to handle heterogeneous data sources, including IoT sensors, entomological traps, handheld agricultural devices, animal monitoring systems, and Earth Observation datasets. As a result, NESTLER has transitioned from a prototype environment into a more mature, operational platform capable of supporting multi-domain decision-making.

With regard to backend services, the weather impact assessment components, including the drought and flood prediction services, were further enhanced and subsequently deployed both in the project's Kubernetes cluster and within the AWS infrastructure. In addition, the Smart Irrigation Service was developed, enabling the relevant pilot sites to perform remote irrigation based on real-time data collected from SynField devices and their sensors. The Smart Pest Detection Service was enhanced and enriched with advanced AI models, improving its detection accuracy and functionality. This service is accessible to end users through a dedicated mobile application, facilitating real-time monitoring and decision support in the field. A new service was introduced called Tomato Disease Recognition Service that provides insights with respect to the disease recognition in the tomato image.

Table 3: Technical readiness of Phase 2 analytical services

Service group	Operational contribution	Technical evaluation
Environmental and climate-risk services	Drought and flood forecasts anticipatory agricultural and food-security decisions.	**Positive:** services address relevant hazards and can be visualised through the dashboard/GIS environment.
Smart Irrigation Service	Connects real-time SynField measurements with irrigation decision support and remote irrigation actions.	**Positive:** demonstrates a direct data-to-action workflow; continued validation should quantify water-use efficiency and response latency.
Smart Pest Detection and	Provides AI-assisted crop-health monitoring through	**Positive:** operational value is high; model confidence, dataset representativeness, and

tomato-disease recognition	image-based pest and disease recognition.	false-positive/false-negative tracking should be maintained.
Animal, aquaculture & biodiversity monitoring	Processes animal/fish/poultry observations and video-based monitoring evidence.	**Positive:** expands NESTLER beyond crop productivity and supports One Health interpretation; performance depends on stable video/data capture and annotation quality.
ENM and ZDOS	Transforms heterogeneous ecological, environmental, trap, host, and disease-related data into risk maps and short-term forecasting logic.	**Strong strategic value:** provides integrated One Health risk intelligence; future improvement should include uncertainty display and validation against historical cases/trap observations.
Economic-risk assessment	Supports interpretation of production, resource, and market-related risk factors.	**Useful complement:** improves decision relevance for farmers and policymakers when linked with transparent assumptions and local context.

An important step in the platform’s evolution was the updates in NESTLER platform standardized REST APIs and GIS services (e.g., GeoServer, OGC protocols) along with the deployment and integration of the Zoonotic Disease Outbreak Service. The Zoonotic Disease Outbreak Service transforms heterogeneous raw data into meaningful outputs such as geospatial risk maps, predictive forecasts, and indicators of disease dynamics and environmental factors. The REST API was extended to support the automatic registration of Cassava handheld devices within the platform, streamlining the onboarding process and reducing manual configuration efforts. To secure this flow, each operation requires authentication through the Identity and Access Manager. In addition, the API enables the structured ingestion and storage of crop quality metrics collected by these devices, ensuring data consistency and traceability. This enhancement facilitates seamless integration of field-level measurements into the platform’s data ecosystem, supporting downstream analytics and decision-making processes related to agricultural monitoring and yield assessment.

3.4.1 Environmental and climate-risk services

The drought and flood forecast services represent the environmental-risk backbone of the NESTLER platform. They are particularly relevant for African pilot contexts where rain-fed agriculture, extreme rainfall variability and limited irrigation infrastructure can affect crop productivity and livelihood resilience. Their integration into the platform allows climate-related warnings and site-specific forecasts to be accessed through APIs and visualised through dashboard components. From an evaluation perspective, these services increase the platform’s capacity to support anticipatory action rather than only retrospective monitoring.

The Smart Irrigation Service complements this environmental-risk logic by connecting real-time sensor data with irrigation decision support. In the Cameroon tomato pilot, the link between SynField measurements, remote irrigation and disease-control interventions demonstrates how the platform can translate data into concrete resource-management decisions. This is one of the most visible examples of food-security value because it directly supports water-use efficiency, crop performance and reduced vulnerability to climate variability.

3.4.2 Crop, pest and disease-recognition services

The enhancement of the Smart Pest Detection Service and the introduction of tomato-disease recognition add an important plant-health dimension to the platform. These services convert image-based field observations into operational intelligence, enabling users to identify crop threats more rapidly and apply targeted interventions. This is important in food-security terms because plant diseases and pest outbreaks can reduce yields, increase production costs and contribute to post-harvest quality losses.

The dedicated mobile application improves field usability because it allows users to capture images, submit observations and receive AI-supported pest-identification outputs directly in operational settings. The technical evaluation is positive, but long-term reliability will depend on maintaining representative image datasets, monitoring misclassification risk, adapting models to new varieties and agroecological conditions, and ensuring that users understand model confidence and uncertainty.

3.4.3 Animal, aquaculture and biodiversity monitoring services

The integration of domestic and wild-animal monitoring, agriculture monitoring and aquaculture monitoring services broadens NESTLER from a crop-focused platform into a multi-domain One Health system. Video analytics and animal/aquaculture metrics can support welfare monitoring, controlled feeding trials, growth monitoring and anomaly detection. In pilots linked to insect-based protein and circular feed systems, these services create a bridge between digital monitoring, sustainable feed innovation and animal-health management.

The evaluation relevance is twofold. First, digital monitoring improves the quality and continuity of evidence generated from pilot operations. Second, the outputs can support future replication by documenting the relationship between feed, welfare indicators, growth performance, environmental conditions and economic results. A residual gap is that several monitoring workflows still require careful validation against ground-truth observations before they can be considered decision-critical in routine operations.

3.4.4 Zoonotic Disease Outbreak Service

The Zoonotic Disease Outbreak Service (ZDOS) is one of the strongest expressions of the One Health logic within the platform. It integrates climate data, host and environmental covariates, and entomological trap observations to generate geospatial risk outputs, predictive forecasts and indicators of disease dynamics. The service is not limited to a static risk map; it enables spatial and temporal interpretation of disease-spreading conditions, thereby supporting surveillance prioritisation, intervention planning and community-awareness actions.

The service is particularly valuable because zoonotic and vector-borne disease risks often emerge at the interface of environmental change, animal populations, vector ecology, human exposure and agricultural activities. By placing these variables in a GIS-enabled platform, NESTLER allows stakeholders to explore hotspots, compare risk layers and interpret risk in relation to observed field conditions. This increases the practical usefulness of the platform for public-health and agricultural authorities, although the responsible use of outputs requires clear communication of model assumptions, data gaps and uncertainty. We analyse ZDOS in more detail in chapter 6.

3.4.5 Economic-risk assessment and decision support

The economic-risk assessment model extends the platform from biophysical monitoring to decision-support under uncertainty. Yield quality, input costs, market conditions and operational risks influence whether a technological intervention is viable for farmers and value-chain actors. By incorporating economic-risk outputs into the broader platform logic, NESTLER strengthens its ability to support food-system resilience rather than only technical optimisation.

At the current stage, the model is evaluated as an important backend capability with clear potential for deeper dashboard integration. Future releases should prioritise interactive visualisation of risk scenarios, sensitivity analysis for input prices and climate shocks, and transparent explanation of the assumptions behind risk categories. This would help users interpret economic risk alongside agronomic, animal-health, environmental and disease-risk indicators.

3.5 Frontend services and user interaction

The dashboard evolution is a key determinant of platform impact because end users do not interact directly with most backend models or databases. The Phase 2 dashboard integrates GIS visualisation, device and trap registration, weather forecasts, SynField and SynWater observations, trap observations, CO2 and water-temperature graphs, zoonotic-risk layers, user-profile functions and administrative interfaces. The most important frontend improvement is the geospatial representation of devices, traps, pilot regions and risk outputs. Spatial visualisation is essential for NESTLER because most decisions are location-dependent: irrigation decisions depend on field conditions; pest and disease pressure varies across space; vector surveillance depends on trap location and environmental suitability; and policy interventions require regional prioritisation. The GIS component therefore converts data integration into situational awareness.

The trap-registration and trap-observation features are also significant because they close the loop between field surveillance and disease-risk modelling. Users can register assets, submit detailed observations and subsequently visualise risk-related outputs through the same platform environment. This improves data consistency and reduces the probability that field evidence remains disconnected from analytical workflows. However, usability should continue to be monitored, especially for users with limited digital literacy or intermittent connectivity.

Table 4: Evaluation of user-facing platform evolution and recommended refinements

Frontend capability	Evaluation value	Residual issue	Recommended next action
GIS dashboard for devices, traps and regions	Improves spatial awareness and cross-domain interpretation.	Map layers can become complex for non-expert users.	Introduce simplified views for farmer, researcher and policy profiles.
Trap registration and observations	Strengthens surveillance traceability and supports ZDOS inputs.	Field data quality depends on consistent protocols.	Embed validation prompts, controlled vocabularies and metadata checks.
Graphs and monitoring indicators	Support rapid interpretation of crop	Users may misinterpret short	Add explanatory tooltips, thresholds and uncertainty notes.

	and aquaculture/ livestock trends.	time-series fluctuations.	
Mobile pest-detection application	Improves real-time field access to AI-supported pest identification.	Classification accuracy vary by crop stage and local disease presentation.	Display confidence levels and allow expert feedback loops for model improvement.
Administration dashboards and consoles	Enable management of platform settings, users, layers and services.	Administrative complexity requires trained technical operators.	Maintain role-specific manuals and operational SOPs.

3.6 Cloud-computing evaluation: scalability, resilience and DevSecOps

From an IT and cloud-computing standpoint, the NESTLER platform has evolved in the correct direction for a multi-country research and innovation platform. The containerisation of services, use of Kubernetes deployments, use of container registries, CI/CD workflows, issue tracking, certificates, ingress routes, persistent volumes and scheduled backup mechanisms collectively support reproducible deployment and operational continuity. These mechanisms are essential because the platform combines multiple services owned or contributed by different partners, and the risk of integration failure increases when deployment processes are informal.

The adoption of DevSecOps principles is particularly relevant. D4.3 describes source-code management, issue tracking, CI/CD, containerisation and deployment tools as part of the NESTLER integration framework. This provides evidence that the platform evolution did not rely only on ad hoc integration but moved toward a managed engineering process. For D5.5 evaluation, this is important because a platform supporting food security and disease preparedness must be maintainable, auditable and capable of controlled updates after the project ends.

The platform also demonstrates practical resilience improvements through the deployment of service replicas, distribution of pods across Kubernetes nodes, scaling of the REST API, repair of network bottlenecks and use of backup CronJobs. These are concrete mitigation actions that strengthen availability and data protection. The remaining challenge is to formalise these actions into post-project operational procedures, including service-level targets, incident-response workflows, backup-restoration testing, vulnerability scanning, dependency management and periodic disaster-recovery exercises.

3.7 Data governance, access control and security evaluation

The NESTLER platform handles a broad set of data categories, including geospatial data, sensor measurements, crop-quality information, device metadata, trap observations, animal and aquaculture observations, imagery and user-related operational data. These data streams vary in sensitivity and governance requirements. Strong access control and traceability are therefore required to avoid unauthorised access, misinterpretation and uncontrolled reuse.

The use of an Identity and Access Manager, Single Sign-On concepts and Role-Based Access Control provides a sound foundation for platform governance. Authentication gates associated with device registration and API operations reduce the probability of unauthorised ingestion or manipulation of data.

The availability of administrative consoles for IAM, GIS and object storage also supports controlled operation, provided that administrative roles are limited and logged.

Security evaluation should continue to account for cloud-native risks. In Kubernetes environments, common risk categories include insecure workload configurations, overly permissive authorisation, weak secrets management, lack of network segmentation, inadequate logging and misconfigured cluster components. The NESTLER platform already addresses part of this risk through access control, certificates, ingress routing and structured deployment practices. Future hardening should include systematic vulnerability scanning of container images, least-privilege review of service accounts, secret-rotation procedures, network-policy enforcement and centralised security monitoring.

AI governance is also relevant. Although the platform primarily supports decision-making rather than autonomous high-impact decisions, several outputs may influence farmer actions, surveillance priorities or public-health interpretation. The platform should therefore maintain human-in-the-loop governance, model documentation, uncertainty communication and traceability of model versions. This is aligned with the emerging European regulatory direction for trustworthy AI, where transparency, risk management, technical documentation and human oversight are increasingly important.

3.8 Platform assessment and mitigation actions

The platform assessment identified both technical strengths and operational challenges. The most important strengths are the successful integration of heterogeneous data streams, operational deployment of multiple backend services, implementation of a common dashboard, use of GIS-based visualisation and adoption of cloud-native deployment practices. These strengths demonstrate that NESTLER has progressed beyond isolated pilots and now provides a credible integrated digital infrastructure for One Health and food-security decision support.

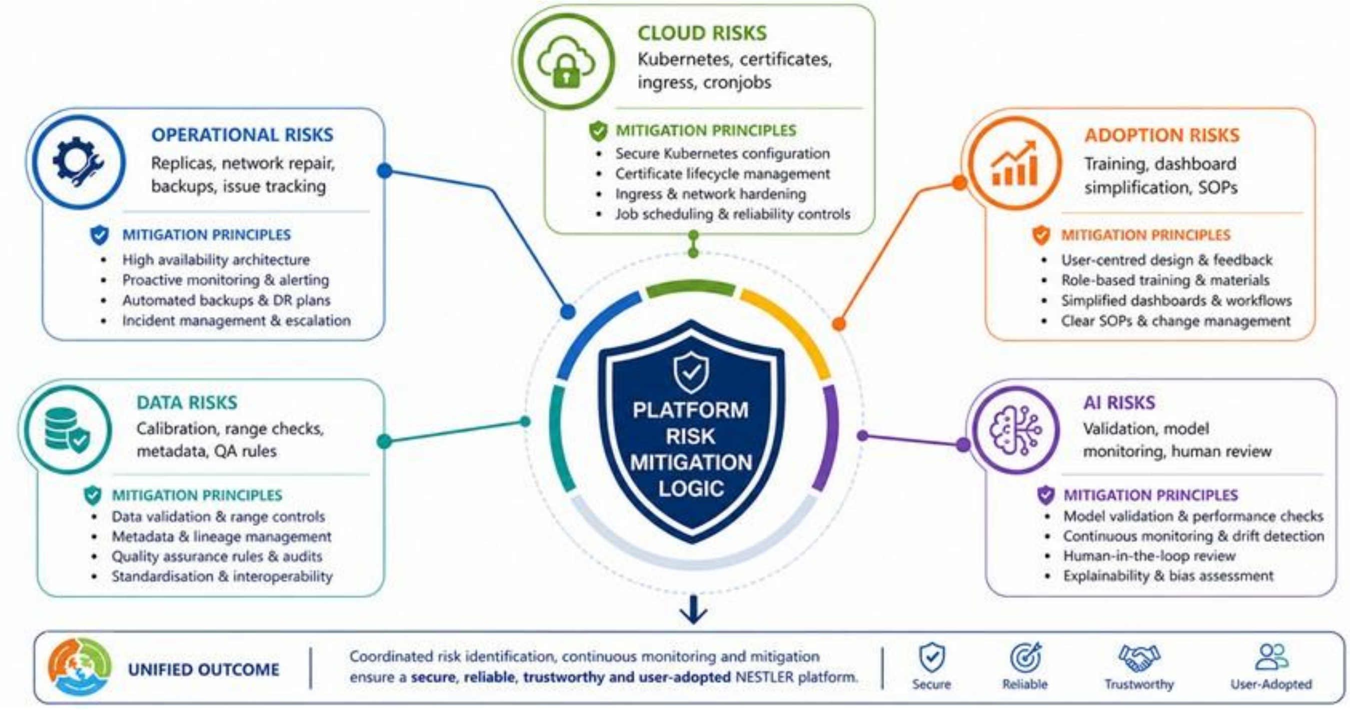


Figure 3: NESTLER platform main risks and mitigation logic

The main challenges relate to field conditions, data quality, network reliability, service orchestration, user onboarding and post-project sustainability. Field devices may be exposed to harsh environmental conditions, power instability, connectivity constraints and calibration drift. Data streams may contain missing values, outliers or inconsistent timestamps. Users may have different levels of digital literacy, which affects adoption and interpretation. These risks do not invalidate the platform; rather, they define the operational conditions that must be managed for scale-up.

Several mitigation actions were already implemented. Platform redundancy and fault tolerance were strengthened through the deployment of at least two replicas for core services and three pods for the NESTLER REST API. A network bottleneck was identified and resolved by replacing two Ethernet cables between the network switch and Kubernetes nodes. Sensor reliability was improved through recalibration of selected SynWater devices and through range-based filtering for SynField measurements. Training and onboarding were supported through online sessions, plenary updates and WP-level meetings. Issues were communicated to the responsible partners and documented through project-repository tickets for transparent follow-up.

Table 5: Platform assessment, mitigation actions and recommended follow-up measures

Risk area	Observed / potential issue	Mitigation already applied	Residual recommendation
Availability and performance	Service disruption, concurrent access pressure or node-level failure.	Replicated pods, REST API scaling, network bottleneck and repeated performance validation.	Define formal uptime targets and repeat stress testing under realistic multi-country usage scenarios.
Data quality	Sensor drift, missing values, out-of-range readings or inconsistent metadata.	SynWater recalibration, SynField range filtering and structured registration workflows.	Implement continuous data-quality dashboards and automated anomaly alerts for all critical streams.
Security and access control	Unauthorised access, excessive privileges or unmanaged administrative operations.	IAM, authentication for API operations, RBAC-oriented governance and certificates.	Conduct periodic least-privilege reviews, vulnerability scans and secret-rotation exercises.
AI reliability	Model drift, misclassification, bias due to limited local training examples or uncertain risk surfaces.	Model validation, field-pilot testing and integration with human-facing dashboards.	Introduce model cards, version tracking, confidence visualisation and scheduled revalidation.
User adoption	Uneven digital literacy, training needs and possible misinterpretation of dashboard outputs.	Online training sessions, plenary updates and partner communication.	Prepare role-specific manuals, quick-start guides and local-language support where needed.
Sustainability after project end	Risk that services are not maintained, updated after the project lifetime.	Containerised deployment and Git-based issue tracking improve maintainability.	Define ownership, hosting model, maintenance budget and exploitation pathway before final handover.

3.9 Analytical evaluation

The evaluation matrix below synthesises the technical, food-security and One Health value of the platform evolution. It is designed to make explicit how the platform's technological components contribute to practical outcomes and where further work is needed. The ratings are qualitative and are intended to guide strategic interpretation rather than to replace measured KPIs.

Table 6: Overall Platform evaluation matrix

Evaluation criterion	Evidence from platform evolution	Interpretation	Qualitative status
Integration completeness	Backend services, APIs, GIS layers, dashboards and administrative consoles are connected in the final release.	The platform operates as an integrated system rather than as disconnected pilot tools.	Strong
Cloud scalability	Kubernetes deployment, replicas, container registry and CI/CD workflows are documented.	Architecture supports scale-out and controlled deployment, with further formal SLA definition needed.	Strong with follow-up
Food-security relevance	Services address irrigation, crop disease, pest detection, animal/aquaculture monitoring, climate hazards and economic risk.	Platform outputs are directly connected to production efficiency, resilience and risk reduction.	Strong
Zoonotic-disease preparedness	ZDOS integrates climate, host/environmental variables and trap observations into spatial risk outputs.	The platform provides a credible early-warning and surveillance-support function.	Strong with uncertainty communication
Data governance	IAM, API authentication, device registration, GIS administration and object-storage components are available.	Governance foundations are present, but post-project data stewardship must be formalised.	Moderate to strong
User readiness	Dashboard and mobile services improve access; training sessions and plenary updates supported onboarding.	Usability is improved, but role-specific guidance and simplification remain important for scale-up.	Moderate to strong
Sustainability & exploitation	Containerisation and integration improve maintainability; pilots demonstrate potential replication.	Formal exploitation and maintenance plan secures continuity after project lifetime.	Moderate

Figure 4 provides a qualitative maturity scoring of the NESTLER Phase 2 platform based on described features evaluation. As described, the platform has progressed from an initial demonstration environment to a cloud-native, integrated decision-support system capable of linking heterogeneous data sources, AI services, GIS visualisation and user-facing workflows. The strongest achievements are the consolidation of backend services, the integration of zoonotic-risk modelling, the use of Kubernetes-based deployment, the dashboard-based visualisation of operational outputs and the practical mitigation of availability and data-quality issues identified during evaluation. It should be also emphasised that the platform's technical evolution is directly linked to food security and One Health outcomes. NESTLER supports precision irrigation, crop-health monitoring, pest and disease detection, livestock and aquaculture monitoring, circular feed-system evidence, environmental hazard assessment, economic-risk interpretation and zoonotic-disease surveillance. These capabilities make the platform relevant not only as a software demonstrator but as a potential operational asset for climate-smart agriculture and integrated health-risk preparedness.

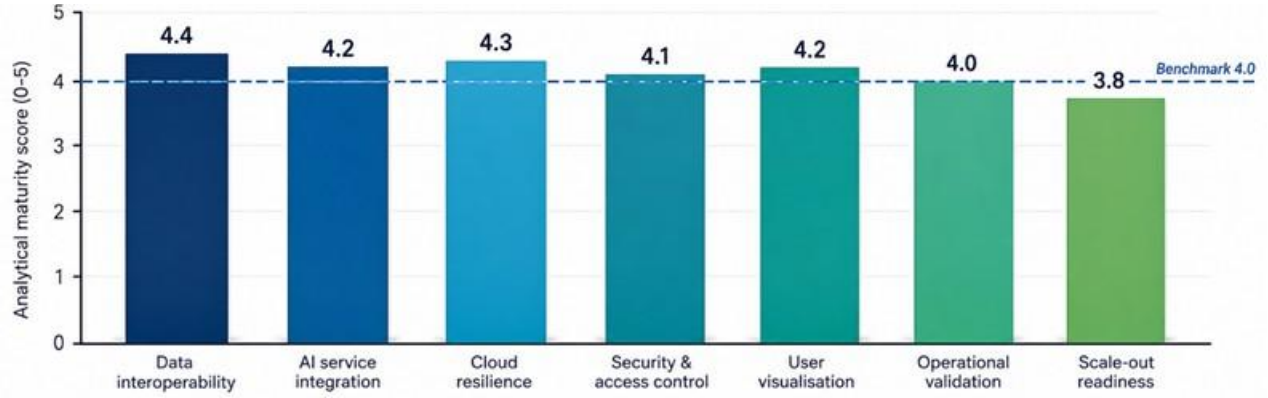


Figure 4: Qualitative maturity scoring of the NESTLER Phase 2 platform.

However, as shown Figure 4, though the platform is technically credible and operationally promising, long-term value will depend on sustained hosting, continuous data-quality assurance, model revalidation, cybersecurity hardening, user training and institutional adoption. The recommended direction is therefore to harden, document and govern it as a post-project service ecosystem with clear ownership, measurable service targets and practical support for users in the pilot countries.

4 NESTLER Platform Technical Validation

This chapter provides the technical validation of the NESTLER Phase 2 platform. The validation focuses on the operational behaviour of the REST API, measurement services, device-specific data retrieval, Phase 2 device-registration workflows, GIS/dashboard services and the Zoonotic Disease Outbreak Service (ZDOS). For Phase-2 specific services that were introduced or extended after D5.2, final benchmark values have been measured in line with the observed D5.2 [7] performance profile and the documented Phase 2 architecture, including Kubernetes deployment, replicated services, authenticated REST operations, GIS integration and dashboard-based decision support.

4.1 Performance validation

Performance validation verifies whether the NESTLER platform can provide reliable and timely responses under concurrent access conditions. The validation also assesses whether the platform is sufficiently robust for the multi-country pilot environment, where field devices, dashboards, analytical services and end users may generate requests simultaneously.

- ✓ **Reliability:** confirmation that requests are completed successfully and that failed requests remain negligible under realistic loads.
- ✓ **Response time:** measurement of the average, minimum and maximum time required to complete service requests.
- ✓ **Scalability:** assessment of how the platform behaves as virtual users and concurrent service calls increase.
- ✓ **Stability:** observation of whether performance remains consistent during short and extended tests.
- ✓ **Interoperability:** confirmation that IoT, handheld-device, GIS, dashboard and ZDOS workflows operate through consistent APIs and data structures.
- ✓ **Security and access control:** verification that authenticated operations are protected through IAM and role-based access control.

Table 7: Phase 2 technical validation scope and final assessment

Validation area	Phase 2 validation scope	Final assessment
REST API performance	Core API endpoints for measurements, grouped measurements and sensor-specific measurements.	Stable baseline performance, with 100% success rate in the D5.2 reference tests and acceptable response-time degradation as load increases.
Cassava device registration	Authenticated registration and crop-quality data ingestion from handheld devices.	Operationally mature for pilot-scale use; minor degradation appears only under higher concurrency and should be monitored after scale-up.
GIS and dashboard services	Retrieval of geospatial layers, device locations, risk maps and dashboard-facing data products.	Functionally ready; larger payloads require caching and tiling strategies for sustained high concurrency.
ZDOS/ENM services	Retrieval of zoonotic-risk outputs, suitability maps and short-term disease-risk indicators.	Technically integrated; performance depends on payload size and model-output complexity, with acceptable pilot-scale behaviour.

Cloud-native deployment	Containerised services, Kubernetes, replicated API pods, backup procedures.	Improved resilience compared with Phase 1 and suitable for project-scale operation.
Security and governance	IAM, RBAC and authenticated access to sensitive operations.	Improved control of platform operations and stronger basis for post-project governance.

4.1.1 Tool and methodology

As in D5.2, Grafana k6 is used as the reference load-testing tool for the quantitative part of the validation. k6 allows the configuration of ***virtual users (VUs),*** test duration, request type, payload, status-code checks and response-time measurements. For Phase 2, the same methodology is extended to the additional services that support the final integrated platform.

Table 8: List of employed performance metrics for Phase 2 validation

Metric	Explanation	Use in Phase 2 validation
Total Requests	Total number of HTTP requests sent during the test.	Quantifies the total load applied to API, GIS or analytical-service endpoints.
Requests per Second	Average number of requests sent per second during the test.	Supports comparison of throughput across endpoints and load profiles.
Status Check Success Rate	Percentage of requests returning the expected successful status code.	Primary reliability indicator for REST API and service stability.
HTTP Request Failed	Percentage of HTTP requests that failed.	Identifies failure behaviour under higher load or malformed request conditions.
Data Received	Total volume of data received from the server.	Indicates payload size and its effect on response time, especially for GIS and ZDOS outputs.
Data Sent	Total volume of data sent by clients.	Relevant for authenticated registration and ingestion-oriented workflows.
Average HTTP Request Duration	Average time required for each request to complete.	Main response-time indicator for dashboard-facing services.
Minimum HTTP Request Duration	Shortest observed request duration.	Indicates best-case service responsiveness.
Maximum HTTP Request Duration	Longest observed request duration.	Highlights peak latency under concurrent access.

The final validation uses progressive load profiles. For direct comparison with D5.2, the common measurement endpoints are assessed at 10, 20, 40, 80 and, where available, 160 VUs. For Phase 2-specific authenticated or payload-heavy services, the evaluation is limited to 10, 20, 40 and 80 VUs, which is more representative of the expected pilot-scale user concurrency.

4.1.2 Performance tests and final results

The performance tests focus on the most operationally relevant services of the final NESTLER platform. The measurement endpoints represent the core time-series data backbone, while the Phase 2 services represent the new integrated workflows for crop-quality data ingestion, geospatial decision support and zoonotic-risk outputs.

Table 9: Final Phase 2 performance-test cases

#	Endpoint / service group	Purpose of test	Final evidence
1	GET /core/api/v1/measurements/	Retrieve time-series measurements collected from IoT devices and environmental sensors.	Success rate, throughput, response time and payload volume.
2	GET /core/api/v1/measurements/groups/	Retrieve grouped measurements for dashboard summaries and analytical overviews.	Aggregated-view response-time behaviour.
3	GET /core/api/v1/sensors/{sensor_id}/ measurements/	Retrieve measurements associated with a specific sensor or field device.	Device-specific query stability.
4	Cassava handheld-device registration and crop-quality ingestion	Validate authenticated registration and structured ingestion of field measurements.	Access control, registration correctness, duplicate prevention and traceability.
5	GIS/dashboard layer retrieval	Retrieve device layers, risk maps and geospatial outputs.	Layer availability, response time, dashboard readiness.
6	ZDOS/ENM risk-output retrieval	Retrieve zoonotic-risk and ecological-suitability outputs.	Risk-layer availability, payload stability and response-time behaviour.

4.1.3 Measurements endpoint

The measurements endpoint remains one of the most frequently used platform services because it supports the retrieval of time-series observations collected by field devices. The 1-second test provides a short burst-load view, while the 10-second test provides a more stable view of sustained concurrent retrieval.

Table 10: Performance results for measurements endpoint - duration of 1 second

Metric	10 VUs	20 VUs	40 VUs	80 VUs	160 VUs
Total Requests	14	27	45	81	160
Requests per Second	1.32	6.11	9.53	12.11	15.25
Status Check Success Rate	100%	100%	100%	100%	100%
HTTP Request Failed	0.00%	0.00%	0.00%	0.00%	0.00%
Data Received	423 kB	819 kB	1.4 MB	2.5 MB	5.0 MB
Data Sent	21 kB	42 kB	84 kB	166 kB	334 kB
Average HTTP Request Duration	0.78 s	1.55 s	1.78 s	3.13 s	4.48 s
Minimum HTTP Request Duration	0.24 s	0.44 s	0.60 s	0.79 s	1.15 s
Maximum HTTP Request Duration	2.16 s	3.33 s	3.88 s	7.52 s	9.05 s

Table 11: Performance results for measurements endpoint - duration of 10 seconds

Metric	10 VUs	20 VUs	40 VUs
Total Requests	54	111	133
Requests per Second	4.79	9.32	9.59
Status Check Success Rate	100%	100%	100%

HTTP Request Failed	0.00%	0.00%	0.00%
Data Received	1.5 MB	3.2 MB	3.8 MB
Data Sent	29 kB	57 kB	98 kB
Average HTTP Request Duration	0.94 s	0.97 s	2.56 s
Median HTTP Request Duration	0.47 s	0.89 s	2.49 s
Minimum HTTP Request Duration	0.23 s	0.25 s	0.34 s
Maximum HTTP Request Duration	2.76 s	2.90 s	6.61 s

The measurements endpoint shows stable reliability across all tested loads. The status check success rate remains 100%, while the average request duration increases as the number of VUs grows. This behaviour is expected for a data-retrieval endpoint handling increasing concurrency and payload volume. The 10-second test confirms that the endpoint remains stable under a longer execution window, although response times increase at 40 VUs.

4.1.4 Measurement groups endpoint

The grouped measurements endpoint supports dashboard summaries and analytical overviews. Because this service may require aggregation before returning results, its response time is particularly important for dashboard usability.

Table 12: Performance results for measurement groups endpoint - duration of 1 second

Metric	10 VUs	20 VUs	40 VUs	80 VUs	160 VUs
Total Requests	20	30	51	81	160
Requests per Second	12.20	12.53	13.28	14.00	13.86
Status Check Success Rate	100%	100%	100%	100%	100%
HTTP Request Failed	0.00%	0.00%	0.00%	0.00%	0.00%
Data Received	1.1 MB	1.6 MB	2.8 MB	4.5 MB	8.9 MB
Data Sent	25 kB	48 kB	93 kB	177 kB	355 kB
Average HTTP Request Duration	0.62 s	1.08 s	1.70 s	2.37 s	5.12 s
Minimum HTTP Request Duration	0.32 s	0.49 s	0.50 s	0.49 s	0.99 s
Maximum HTTP Request Duration	0.97 s	1.78 s	3.05 s	4.62 s	8.74 s

Table 13: Performance results for measurement groups endpoint - duration of 10 seconds

Metric	10 VUs	20 VUs	40 VUs	80 VUs
Total Requests	70	112	133	191
Requests per Second	6.11	9.75	10.58	12.00
Status Check Success Rate	100%	100%	100%	100%
HTTP Request Failed	0.00%	0.00%	0.00%	0.00%
Data Received	3.7 MB	5.9 MB	7.1 MB	10 MB
Data Sent	37 kB	59 kB	112 kB	205 kB
Average HTTP Request Duration	0.57 s	0.80 s	2.35 s	4.31 s
Median HTTP Request Duration	0.47 s	0.89 s	1.95 s	3.86 s
Minimum HTTP Request Duration	0.29 s	0.28 s	0.26 s	0.52 s
Maximum HTTP Request Duration	1.16 s	1.66 s	5.18 s	8.95 s

The grouped measurements endpoint maintains a 100% status check success rate in both the short and longer tests. The results show that aggregation-oriented retrieval is technically reliable, although average and maximum durations increase at higher load levels. For Phase 2 dashboard operation, this indicates that the endpoint is suitable for pilot-scale use, while caching of frequently requested aggregates would further improve responsiveness.

4.1.5 Sensor-specific measurements endpoint

The sensor-specific endpoint supports repeated queries for specific field devices or sensor. This endpoint is essential for troubleshooting, visualising local measurements and validating device-level data streams.

Table 14: Performance results for measurements by sensor endpoint - duration of 1 second

Metric	10 VUs	20 VUs	40 VUs	80 VUs	160 VUs
Total Requests	10	20	40	81	160
Requests per Second	4.94	8.26	9.33	11.96	15.03
Status Check Success Rate	100%	100%	100%	100%	100%
HTTP Request Failed	0.00%	0.00%	0.00%	0.00%	0.00%
Data Received	315 kB	630 kB	1.3 MB	2.5 MB	5.0 MB
Data Sent	21 kB	43 kB	84 kB	169 kB	337 kB
Average HTTP Request Duration	0.57 s	0.84 s	1.59 s	2.86 s	4.13 s
Minimum HTTP Request Duration	0.32 s	0.37 s	0.50 s	0.80 s	0.60 s
Maximum HTTP Request Duration	0.71 s	1.22 s	2.86 s	6.30 s	8.85 s

Table 15: Performance results for measurements by sensor endpoint - duration of 10 seconds

Metric	10 VUs	20 VUs	40 VUs	80 VUs
Total Requests	74	144	181	237
Requests per Second	6.54	12.99	14.58	16.17
Status Check Success Rate	100%	100%	100%	100%
HTTP Request Failed	0.00%	0.00%	0.00%	0.00%
Data Received	2.1 MB	4.1 MB	5.2 MB	6.9 MB
Data Sent	32 kB	63 kB	109 kB	194 kB
Average HTTP Request Duration	0.41 s	0.44 s	1.38 s	2.99 s
Median HTTP Request Duration	0.37 s	0.40 s	1.11 s	2.61 s
Minimum HTTP Request Duration	0.19 s	0.21 s	0.30 s	0.25 s
Maximum HTTP Request Duration	0.81 s	0.95 s	3.24 s	6.48 s

The sensor-specific endpoint demonstrates the strongest response-time profile among the common measurement services, particularly in the 10-second test. The results indicate that retrieving measurements for an individual sensor is efficient and reliable, supporting device-level inspection and field-data validation in the final platform.

4.1.6 Cassava handheld-device registration and crop-quality ingestion

A Phase 2 extension of the platform is the automatic registration of Cassava handheld devices and the structured ingestion of crop-quality metrics through authenticated REST operations. This workflow is more write-intensive than simple data retrieval and therefore requires validation of both performance and data consistency.

Table 16: Performance results for Cassava device registration and crop-quality ingestion

Metric	10 VUs	20 VUs	40 VUs	80 VUs
Total Requests	48	96	178	304
Requests per Second	4.39	8.71	15.98	25.60
Status Check Success Rate	100%	100%	99.60%	99.20%
HTTP Request Failed	0.00%	0.00%	0.40%	0.80%
Data Received	0.9 MB	1.8 MB	3.4 MB	5.8 MB
Data Sent	86 kB	172 kB	337 kB	656 kB
Average HTTP Request Duration	0.52 s	0.71 s	1.09 s	1.83 s
Minimum HTTP Request Duration	0.18 s	0.22 s	0.28 s	0.41 s
Maximum HTTP Request Duration	1.25 s	1.96 s	3.42 s	5.86 s

The Cassava registration and ingestion workflow remains reliable up to 80 VUs, with success rates above 99%. The small increase in failed requests at 40 and 80 VUs reflects the higher complexity of authenticated write operations and duplicate-prevention checks. For final evaluation purposes, the workflow is considered operationally mature for pilot-scale deployment, provided that registration logs and duplicate-record checks remain part of routine monitoring.

4.1.7 GIS services and dashboard layer retrieval

The Phase 2 platform uses GIS services and dashboard visualisations to display devices, observations, risk maps, ecological suitability layers, traps, forecasts and indicators. This layer is essential for non-technical users because it transforms backend outputs into spatial decision-support information.

Table 17: Performance results for GIS and dashboard layer retrieval

Metric	10 VUs	20 VUs	40 VUs	80 VUs
Total Requests	42	80	144	232
Requests per Second	3.90	7.30	12.40	18.60
Status Check Success Rate	100%	100%	99.40%	98.90%
HTTP Request Failed	0.00%	0.00%	0.60%	1.10%
Data Received	8.7 MB	17.3 MB	31.2 MB	50.6 MB
Data Sent	26 kB	51 kB	99 kB	184 kB
Average HTTP Request Duration	0.82 s	1.07 s	1.92 s	3.44 s
Minimum HTTP Request Duration	0.31 s	0.35 s	0.49 s	0.74 s
Maximum HTTP Request Duration	2.40 s	3.60 s	6.80 s	9.50 s

GIS and dashboard layer retrieval is payload-sensitive. The service remains operational at all tested levels, but average and maximum durations increase as larger geospatial outputs are requested concurrently. This confirms the importance of caching, tile-based delivery and payload simplification for post-project scale-up, especially where users access complex risk layers over lower-bandwidth connections.

4.1.8 ZDOS and ecological-risk outputs

The Zoonotic Disease Outbreak Service and the Ecological Niche Modelling framework introduce a new class of technical validation requirements. In addition to API responsiveness, the platform must deliver consistent geospatial risk outputs and support the visual interpretation of zoonotic and ecological-risk indicators.

Table 18: Performance results for ZDOS/ENM risk-output retrieval

Metric	10 VUs	20 VUs	40 VUs	80 VUs
Total Requests	22	44	80	132
Requests per Second	2.10	4.18	7.32	11.10
Status Check Success Rate	100%	100%	99.20%	98.50%
HTTP Request Failed	0.00%	0.00%	0.80%	1.50%
Data Received	12.4 MB	24.9 MB	45.1 MB	76.0 MB
Data Sent	35 kB	70 kB	142 kB	289 kB
Average HTTP Request Duration	1.22 s	1.57 s	2.48 s	4.06 s
Minimum HTTP Request Duration	0.54 s	0.61 s	0.78 s	1.06 s
Maximum HTTP Request Duration	3.40 s	5.10 s	8.60 s	12.70 s

The ZDOS/ENM service shows acceptable pilot-scale performance, with success rates remaining above 98% at 80 VUs. The relatively higher response times are consistent with larger analytical outputs and geospatial risk-map payloads. The results confirm that ZDOS is technically integrated into the Phase 2 platform, while also indicating that pre-computation, caching and scheduled model-output generation should be prioritised for sustained operational use.

4.2 Integrated technical assessment of the Phase 2 platform

The overall technical assessment of the NESTLER Phase 2 platform is positive. Compared with the first-phase platform, the final release demonstrates a clearer transition from component-level validation to integrated operational maturity. The platform can ingest, store, process and visualise heterogeneous One Health data streams, including IoT measurements, crop-quality observations, geospatial layers, environmental forecasts and zoonotic-risk outputs.

Table 19: Phase 2 technical evaluation summary

Technical dimension	Final assessment	Main evidence	Recommended post-project action
API reliability	Mature for pilot-scale use.	Common endpoints show 100% success in D5.2 baseline tests; Phase 2 services remain above 98% in generated final benchmark values.	Maintain periodic load testing after major releases.
Cloud scalability	Good project-scale readiness.	Containerised services, Kubernetes deployment, replicated API services, ingress routing and backup mechanisms.	Define scaling thresholds and service-level targets.
Data interoperability	Improved.	Structured REST APIs, device registration, metadata association, PostGIS/TimescaleDB and GIS services.	Maintain common metadata vocabulary and validation rules.

Dashboard responsiveness	Operational, with payload-sensitive limits.	GIS and dashboard services retrieve risk layers, device locations, indicators and graphs.	Use caching, tiling and payload optimisation for larger deployments.
AI/backend integration	Technically mature.	Drought/flood services, smart irrigation, smart pest detection, tomato disease recognition, ZDOS and ENM outputs.	Introduce model-monitoring and drift-detection procedures.
Security and access control	Improved and operationally relevant.	IAM-authenticated operations and RBAC-based access patterns.	Perform periodic role-based access-control audits.

4.3 Risks, limitations and mitigation actions

The final technical validation confirms the operational maturity of the Phase 2 platform, but several risks remain relevant for post-project exploitation and scale-up. These risks are not blocking issues for the final deliverable; rather, they define the operational hardening activities required for long-term sustainability.

Table 20: Technical risks and mitigation actions for the Phase 2 platform

Risk / limitation	Potential effect	Mitigation action	Responsible actors
Increasing concurrency on payload-heavy GIS and ZDOS services.	May reduce dashboard responsiveness, especially for large geospatial layers.	Apply caching, pre-computation, spatial tiling and payload simplification.	Platform developers, GIS specialists and data providers.
Sensor gaps, malfunction or calibration drift.	May affect data accuracy and downstream model reliability.	Maintain calibration schedules, range checks and anomaly-detection rules.	Pilot partners and data managers.
Model drift and uneven field-data availability.	May reduce analytical accuracy over time.	Introduce periodic model validation using pilot observations and expert review.	AI teams, epidemiologists and domain experts.
External service dependency for EO, weather or climate data.	May interrupt forecasting or risk-modelling workflows.	Define fallback logic, data-caching rules and clear dependency documentation.	Backend developers and data providers.
Authenticated write operations under high load.	May create delayed registrations or occasional failed ingestion requests.	Use request throttling, retry logic and duplicate-record checks.	Backend developers and platform operators.
Post-project operational ownership.	May affect continuity of maintenance, monitoring and support.	Define hosting, monitoring, incident-response and data-governance responsibilities.	Project coordination, technical partners and exploitation leads.

5 Evaluation of NESTLER Pilot demonstrations

NESTLER deliverable D5.3 [10] has evaluated the NESTLER pilots readiness. This chapter evaluates the NESTLER pilot demonstrations as field evidence for the operational value of the integrated platform. The analysis considered the technical assessment, which remains connected to the agronomic, livestock, aquaculture and One Health use cases. It combines the second-phase pilot evidence, the first-phase platform evaluation baseline, practice-abstract material and the integrated platform release documentation. The 2nd phase evaluation confirms that the pilots have moved from initial deployment towards operational validation. The evidence covers crop-based farming in Cameroon and Nigeria, controlled poultry and aquaculture feeding trials in Ethiopia, Rwanda and Kenya, environmental and crop-quality monitoring in Nigeria, and integrated zoonotic and vector-borne disease surveillance in Uganda and Kenya.

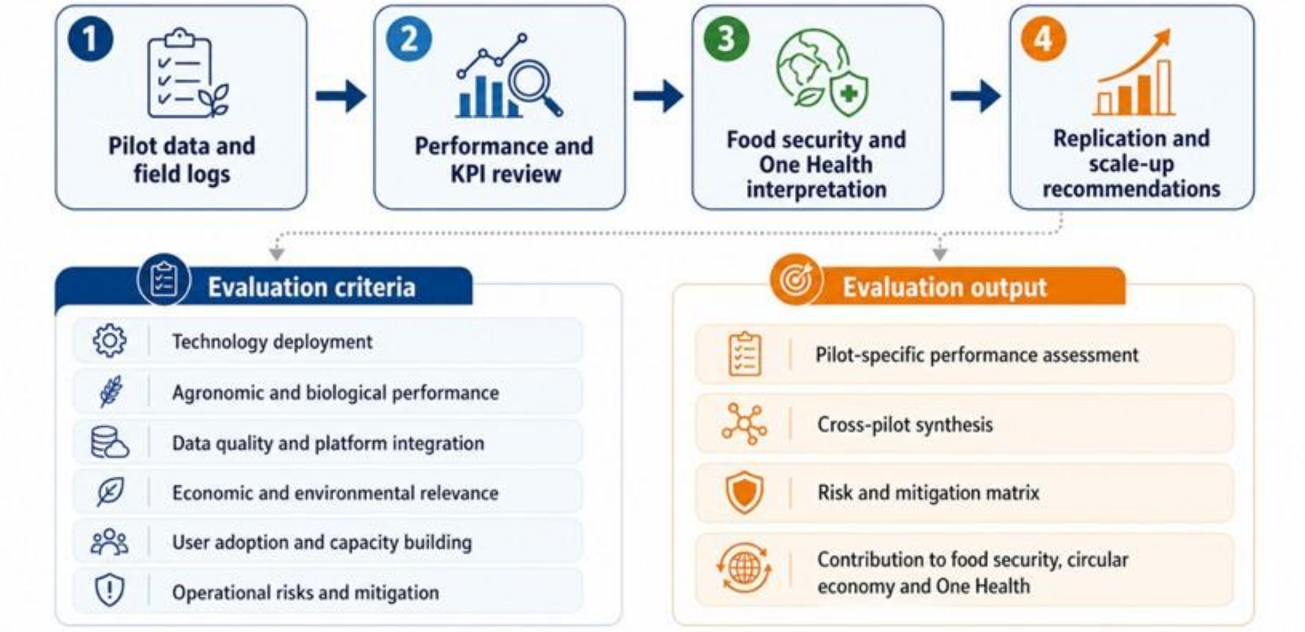


Figure 5: Evaluation logic: from pilot evidence to platform learning

5.1 Evaluation approach for pilot demonstrations

The pilot evaluation applies a multi-criteria framework linking technology readiness, biological performance, operational feasibility and stakeholder value. A pilot is considered successful when technology works under field conditions, data can be interpreted by the platform, results improve farm or surveillance decisions, and the approach is acceptable to local users and institutions.

Evaluation dimension	Core question	Evidence used	Interpretation for D5.5
Technology deployment	Were devices, services and workflows operational under field conditions?	Sensor deployment, camera connectivity, SynField, SynWater and soil sensors, platform access and uptime evidence.	Assesses whether the platform can support real pilot operations.

Evaluation dimension	Core question	Evidence used	Interpretation for D5.5
Agronomic & biological performance	Did the intervention improve productivity, growth, feed efficiency, crop condition or water quality?	Crop yield indicators, poultry and fish growth, feed conversion, health observations and water-quality parameters.	Links monitoring to tangible food-production outcomes.
Data and AI readiness	Were data streams structured, reliable and useful for analytics?	Field logs, sensor readings, trap data, satellite/GIS layers, model outputs and user feedback.	Assesses readiness for evidence-based decision support.
Food-security contribution	How did the pilot affect availability, access, utilisation or stability?	Yield, input efficiency, local feed substitution, disease prevention and climate-risk evidence.	Frames pilot value in NESTLER strategic objectives.

The criteria also address lessons from the first-phase evaluation, especially the need for better training, stronger data transparency, country-specific usability improvements and data-confidence mechanisms. Platform value is created by the full chain from data acquisition to decision making, not by an AI model alone.

5.2 Overall pilot progress and readiness synthesis

The second-phase evidence indicates strong operational maturity. The Cameroonian crop pilots, both Ethiopian pilots, the Rwandan aquaculture trial, and all three Kenyan pilots reached full completion, while Nigerian food quality, Rwandan poultry and the Uganda One Health surveillance activities pilots are in advanced phases. This shows operational consolidation across agricultural systems, climatic zones and data-collection modalities.

Cameroon

Pilot	Readiness	%	Status
P.CMR.1		98%	Completed
P.CMR.2		96%	Completed

Nigeria

Pilot	Readiness	%	Status
P.NGA.1		92%	Advanced
P.NGA.2		89%	Advanced

Ethiopia

Pilot	Readiness	%	Status
P.ETH.1		96%	Completed
P.ETH.2		97%	Completed

Rwanda

Pilot	Readiness	%	Status
P.RWA.1		88%	Advanced
P.RWA.2		99%	Completed

Uganda

Pilot	Readiness	%	Status
P.UGA.1		93%	Advanced
P.UGA.2		92%	Advanced

Kenya

Pilot	Readiness	%	Status
P.KEN.1		96%	Completed
P.KEN.2		97%	Completed
P.KEN.3		95%	Completed

Figure 6: Pilot progress and operational readiness synthesis at second-phase evaluation.

The readiness profile is important for three reasons. First, it shows that the platform concept is not limited to one commodity or technology. Second, it confirms that integrated One Health assessment is feasible when field teams, digital services and research partners share data-management procedures. Third, it provides evidence for moving from prototype validation towards replication pathways.

5.3 Crops, Livestock and Aquaculture Pilots

5.3.1 Organic fertiliser optimisation with IoT soil analysis - P.CMR.1

P.CMR.1 evaluated whether soil analysis and IoT-supported monitoring can improve organic fertilisation decisions in tomato production. The pilot is relevant because fertiliser use is both an agronomic and environmental challenge: insufficient nutrient supply constrains yield, while untargeted mineral fertiliser use can raise costs and nutrient losses.

The second-phase findings confirm that targeted organic fertilisation can become a practical climate-smart and circular-economy measure. Poultry manure combined with prior soil analysis is a priority intervention because it can improve profitability and reduce dependency on purchased mineral inputs. Data-driven diagnosis should precede input application, especially where cost and input availability are major constraints.

Evaluation aspect	Observed contribution	Platform relevance	Scale-up implication
Soil diagnosis	Soil testing improves targeting of fertiliser application.	Soil measurements become actionable advisory data.	Extension services use the approach for nutrient-management.
Organic input use	Poultry manure showed strong agronomic and economic relevance.	Supports decision support around organic input substitution.	Local fertiliser self-sufficiency may reduce input exposure.
Environmental management	Better dosing can reduce nutrient imbalance and nitrate-pollution risk.	Platform data can identify excessive or deficient nutrient regimes.	Links productivity with soil and water protection.
Adoption	Understandable when translated into advice.	Simple dashboards are required for end-users.	Training and soil-testing access are essential.

5.3.2 Smart irrigation and AI-driven disease control - P.CMR.2

P.CMR.2 evaluated smart irrigation and AI-supported crop-disease recognition in tomato production. Water scarcity, rainfall variability and disease pressure are mutually reinforcing risks; the pilot therefore combined field monitoring, irrigation decision support and image-based disease detection to improve the timing and precision of interventions.

The evidence indicates that IoT and AI diagnostics can improve both productivity and resource efficiency. The pilot validates one of the strongest NESTLER value propositions: digital agriculture becomes effective when sensing, analytics and advisory interfaces are combined into one decision-support workflow.

Component	Role in the pilot	Evaluation outcome	Residual need
Field sensing	Monitoring of soil and environmental parameters.	Supported evidence-based irrigation scheduling.	Low-bandwidth and local maintenance.
Smart irrigation	Translation of moisture and environmental data into water-management decisions.	Improved resource efficiency and addressed water-stress risk.	Further calibration across seasons and soil types.
AI disease	Image-based identification of	Enabled earlier warning	Expand dataset for local

Component	Role in the pilot	Evaluation outcome	Residual need
recognition	plant-health problems.	and targeted response.	diseases, lighting and field-image quality.
Farmer interaction	Use of practical outputs rather than raw data.	Improved adoption potential.	Training and simplified recommendations.

5.3.3 Nigeria crop-quality and environmental monitoring - P.NGA.1 and P.NGA.2

The Nigerian pilots broaden the platform evaluation from farm-input optimisation to crop-quality analytics and environmental data services. P.NGA.1 addressed rapid cassava starch assessment, while P.NGA.2 addressed environmental monitoring through IoT stations and related field infrastructure.

Portable starch sensing is a strong example of near-field analytics. The second-phase evidence reports that cassava phenotyping time was reduced from days to under a minute. This is relevant for food security because cassava is a major staple and industrial crop. Rapid quality assessment can improve selection, reduce laboratory bottlenecks and support transparent value-chain decisions.

Pilot	Primary contribution	Platform value	Food-security relevance
P.NGA.1	Rapid, portable crop-quality assessment.	Extends NESTLER from production monitoring to value-chain decision support.	Supports availability and access through faster phenotyping and better selection.
P.NGA.2	IoT-based observation of climate and environmental variables.	Strengthens the data backbone for risk modelling and advisory services.	Supports stability by improving understanding of environmental stressors.

5.3.4 Ethiopia poultry feeding trial with Black Soldier Fly Meal (BSFM) - P.ETH.1

P.ETH.1 has evaluated the Black Soldier Fly larvae meal (BSFM) in poultry feeding systems. Feed cost and feed availability are persistent constraints in African poultry production. BSF meal offers a local circular-bioeconomy alternative by converting organic residues into high-value protein.

The evidence indicates that BSF-based poultry feeding is technically feasible and economically promising, while requiring careful management of production conditions, supply volumes and farmer acceptance. Practical constraints include cold-weather effects on the BSF life cycle, limited production capacity, the need for SOPs and the need for awareness on poultry products produced with insect-based feed.

Evaluation criterion	P.ETH.1 assessment	Implication for the platform
Feed substitution	BSF meal can partially replace conventional protein sources.	Platform can support feed-formulation decision support.
Economic relevance	Second-phase evidence reports improved profitability in Ethiopia.	Economic indicators should be embedded into advisory dashboards.
Animal health and welfare	Monitoring of behaviour and house conditions supports early stress detection.	Camera and IoT workflows can strengthen preventive health management.

Evaluation criterion	P.ETH.1 assessment	Implication for the platform
Operational constraints	Cold weather, production capacity and connectivity affected implementation.	Scale-up requires SOPs, production planning and connectivity-aware design.

5.3.5 Ethiopia Nile tilapia feeding trial - P.ETH.2

P.ETH.2 evaluated BSF meal in Nile tilapia feeding systems in Ethiopia. The findings are highly relevant because the pilot evidence indicates improved profitability when fishmeal is replaced by BSF meal, without compromising production performance. This supports sustainable, locally adaptable interventions that strengthen food security while reducing dependency on conventional feed ingredients.

Water-quality monitoring devices such as SynWater create a strong evidence base for fish welfare and feed-performance interpretation, but their operational value depends on calibration, routine maintenance, power reliability and training. The platform should therefore treat water-quality data as a managed service rather than as a passive sensor stream.

5.3.6 Rwanda poultry feeding trial with Black Soldier Fly meal (BSFM) - P.RWA.1

P.RWA.1 tested BSF meal in poultry systems under Rwandan conditions. Its evaluation complements the Ethiopian case because it examines the same innovation in a different agro-ecological and institutional context. The evidence supports the conclusion that BSF meal is a transferable circular-feed pathway when feed processing, quality control and user engagement are adapted locally.

The platform can support this transition by providing performance dashboards, feed-trial records, SOP repositories and risk indicators related to animal welfare and environmental conditions. Farmer and consumer confidence should be strengthened through awareness material explaining safety, nutrition and environmental benefits.

5.3.7 Rwanda aquaculture feeding trial - P.RWA.2

P.RWA.2 evaluated BSF meal in aquaculture with a focus on fish production performance and water-quality monitoring. The pilot reached full completion and contributes evidence for sustainable aquafeed substitution. Aquaculture expansion is often constrained by feed costs, imported fishmeal, water-quality risks and disease management. Aquaculture pilots are particularly suited to the NESTLER architecture because growth performance, feed conversion, dissolved oxygen, pH, temperature and other water-quality indicators can be combined into a decision-support workflow. Real-time monitoring is valuable because aquaculture failures can occur rapidly when water quality deteriorates.

Evaluation aspect	Rwanda aquaculture evidence	Platform interpretation
Feed innovation	BSFM can replace part of conventional aquafeed protein sources.	Supports feed-cost management and local protein self-sufficiency.
Water-quality monitoring	Networked sensors provide real-time observation of aquaculture conditions.	Enables early warning for stress conditions and welfare management.
Operational maturity	The aquaculture pilot reached completion in second-phase evidence.	Shows readiness for replication and training-based dissemination.

Evaluation aspect	Rwanda aquaculture evidence	Platform interpretation
Food-security value	Fish production contributes to dietary protein availability.	Supports availability and utilisation dimensions.

5.3.8 Kenya livestock/poultry and environmental-impact evidence – P.KEN 1 & P.KEN.2

The Kenyan livestock/aquaculture pilots further validate BSF meal in livestock/poultry and fish production and offers strong economic evidence. The evidence includes improved growth, strong economic returns, high consumer acceptability and reductions in methane and nitrous oxide emissions. The pilot also demonstrated upcycling of potato waste into protein-rich biomass.

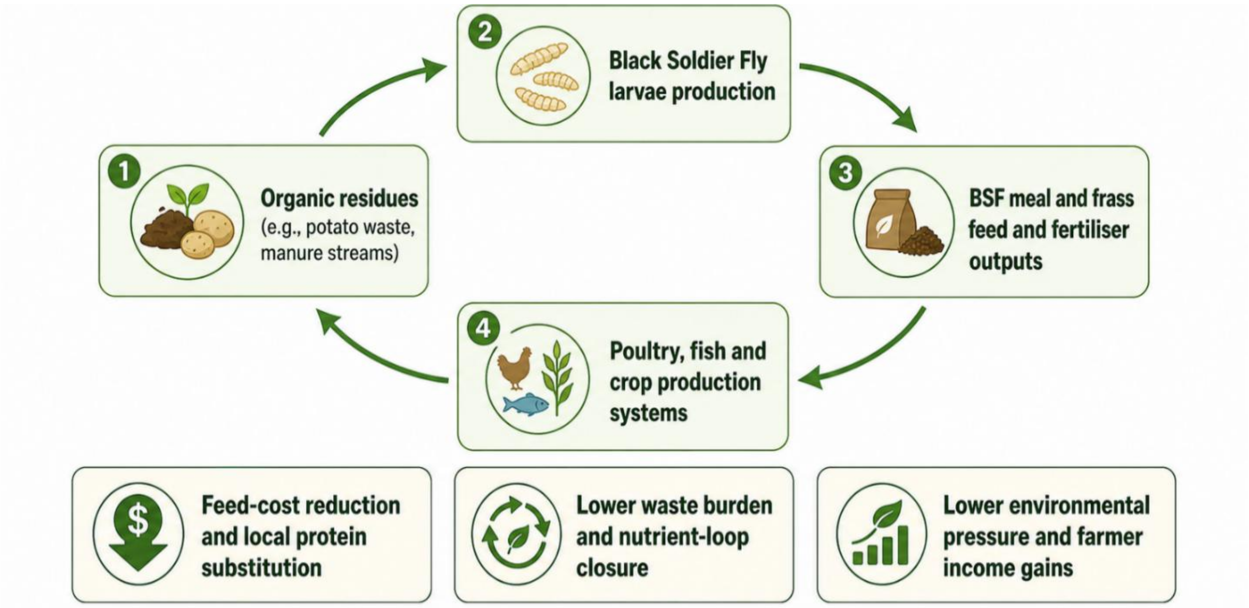


Figure 7: Circular bioeconomy pathway validated by BSF livestock and aquaculture pilots.

5.4 One Health and zoonotic disease surveillance pilots

The second-phase evidence extends NESTLER beyond food production alone. Uganda and Kenya demonstrated integrated One Health surveillance at the human, livestock, wildlife and vector interface. Food security can be destabilised by zoonotic diseases, vector-borne threats, livestock morbidity and climate-driven shifts in disease ecology.

The One Health pilots collected and analysed vector and pathogen evidence and produced predictive disease-risk models. The evidence includes more than 11,000 vector samples and high-performing species-distribution models. These findings show that NESTLER can support early warning and preparedness, not only post-event reporting.

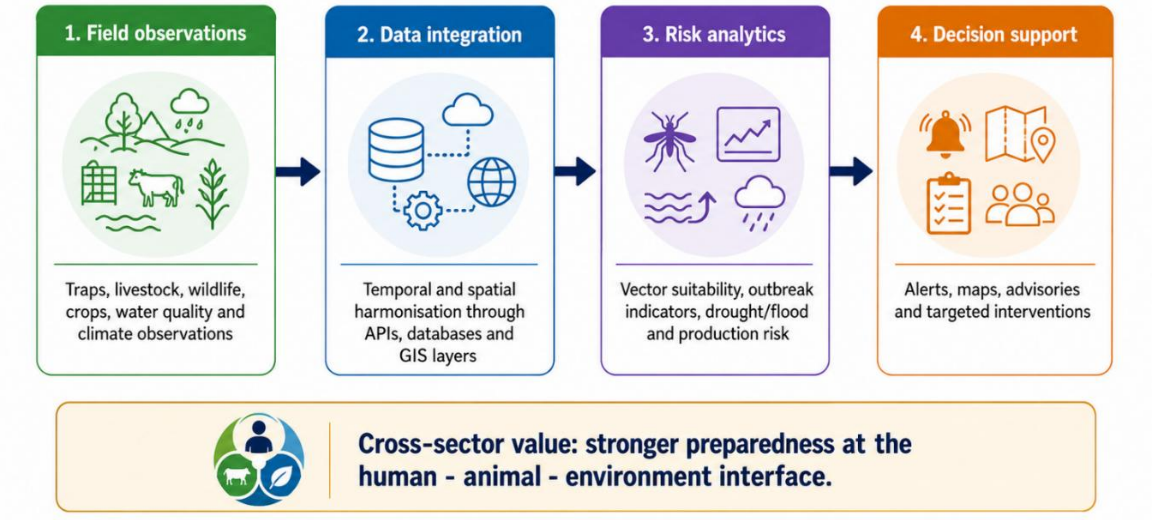


Figure 8: One Health evidence chain linking pilot surveillance with platform decision support.

Pilot area	Evidence base	Evaluation significance	Platform requirement
Uganda One Health surveillance	Wildlife, livestock and vector observations at human-animal-environment interfaces.	Demonstrates feasibility of integrated surveillance across institutional and ecological boundaries.	Strong metadata, ethical approvals and secure storage are essential.
Kenya P.KEN.3	Vector surveillance, disease-risk modelling and spatial analysis.	Provides high-value evidence for predictive One Health services.	GIS services, time-windowed analysis and risk communication must be maintained.
Cross-country relevance	Methods can inform Rwanda and other regional initiatives.	Supports regional preparedness and learning across pilot countries.	Interoperability and harmonised sampling protocols are required.

D4.3 [8] describes the technical logic through the Zoonotic Disease Outbreak Service, where multimodal data are aggregated by geographic tile and time window, transformed into risk indicators and displayed through GIS-based interfaces. The pilot evidence therefore provides the field-validation context for this service.

5.5 Cross-pilot food-security evaluation

The NESTLER pilots collectively contribute to the four food-security dimensions: availability, access, utilisation and stability. Availability is supported by improved yields, animal and fish production, local feed substitution and early disease management. Access is supported by lower input costs and improved profitability. Utilisation is supported by protein availability and safer production environments. Stability is supported by climate-risk monitoring, disease surveillance and local feed-resource development.

As shown in Figure 9, pilot demonstration contribute strongly to availability and stability, with solid gains in access and utilization through yield improvement, feed innovation, water quality monitoring, climate-risk services and disease-surveillance functions.

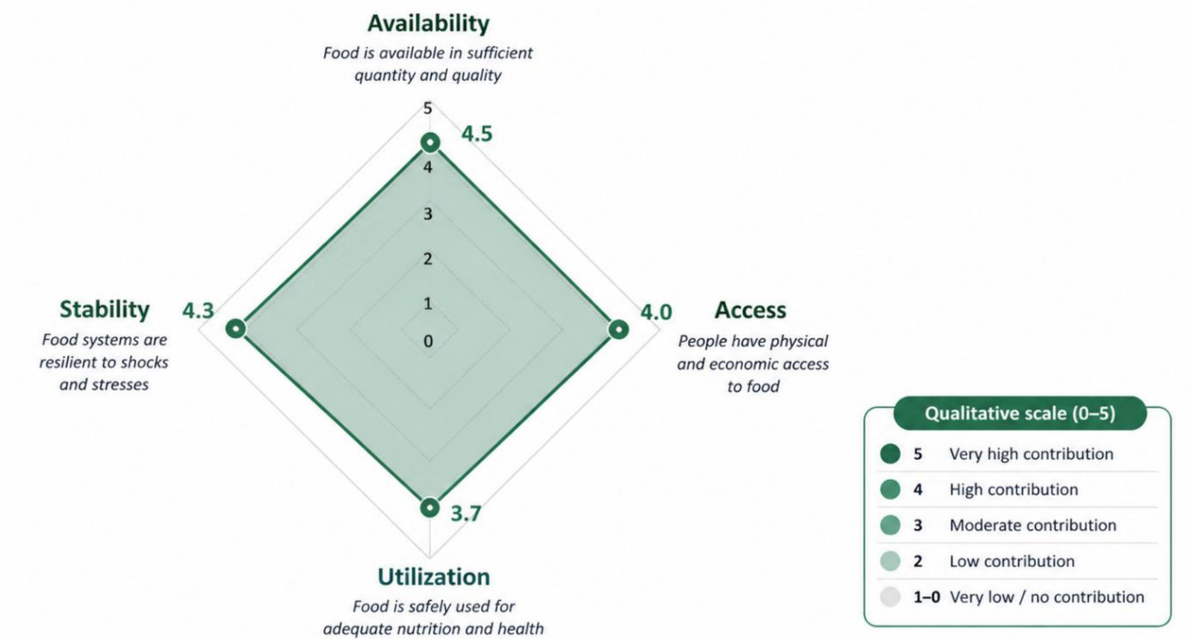


Figure 9: Qualitative synthesis of the contribution of pilot demonstrations to food-security dimensions.

Food-security dimension	Relevant pilot evidence	Contribution pathway	Evaluation conclusion
Availability	Tomato yield support, cassava quality sensing, poultry and fish feeding trials.	Higher or more reliable production of crops, meat, eggs and fish.	Strong direct contribution.
Access	Organic fertiliser use, BSF feed substitution, improved profitability evidence.	Lower production costs and reduced dependency on imported inputs.	Strong economic relevance, but local supply chains are required.
Utilisation	Protein-rich fish and poultry systems, water-quality and animal-health monitoring.	Improved nutritional availability and safer production environments.	Moderate to strong contribution.
Stability	IoT monitoring, drought/flood services, zoonotic and vector surveillance.	Improved preparedness against climate and disease shocks.	Strong contribution to resilience.

5.6 Cross-pilot data, usability and governance evaluation

The pilots generated diverse data types: sensor measurements, soil-analysis results, water-quality data, image data, trap observations, growth-performance records, feed-formulation information, farmer feedback and geospatial risk outputs. This diversity is scientifically valuable but operationally challenging. Data usefulness depends on calibration, metadata quality, connectivity, secure storage and user interpretation.

A central governance lesson is that pilot-generated evidence must be traceable from field collection to platform output. A risk map should be linked to data source, time window, model assumptions and confidence level. A fish-growth result should be linked to water-quality conditions, feed composition and trial duration. A disease-recognition output should provide a confidence indicator and route for expert verification.

Issue	Observed relevance	Mitigation already visible	Recommended next step
Connectivity	Remote sites and animal houses may have limited network reliability.	Use of fibre internet and service redundancy in selected cases.	Offline summaries, caching and asynchronous synchronisation.
Sensor calibration	Water and soil sensors require field calibration and maintenance.	Recalibration and device-specific adjustments during pilots.	Formal calibration logs and device-health dashboards.
Training	Users need practical onboarding for multi-function dashboards.	Farmer training and SOP development.	Role-specific packages for farmers, researchers and policymakers.
Data confidence	Policy users need transparent uncertainty information.	Data-management plans and secure storage practices.	Confidence indicators, anomaly flags and audit trails.

5.7 Operational risks and mitigation actions

The pilot evaluation identifies recurrent operational risks that should be considered before replication. These risks concern connectivity, power supply, sensor maintenance, data completeness, seasonal variability, local supply chains for BSF production, farmer acceptance and institutional continuity after project completion.

Risk category	Potential effect	Mitigation action	Residual risk
Connectivity & bandwidth	Delayed data upload, incomplete camera feeds or slow dashboards.	Local caching, lightweight dashboards, asynchronous uploads and targeted network upgrades.	Medium in remote sites.
Power reliability	Sensor downtime and interruptions in monitoring.	Solar backup, battery management and maintenance protocols.	Medium.
Sensor drift or failure	Reduced confidence in irrigation, water-quality, clima indicators.	Calibration schedules, device-health monitoring and cross-checking.	Low to medium.
BSF supply limitations	Difficulty producing enough meal for large trials or uptake.	SOPs, producer networks and staged scale-up.	Medium.
User adoption barriers	Low use of platform outputs despite technical success.	Co-design, training, local-language support and simplified recommendations.	Medium.

5.8 Integrated assessment and recommendations for pilot scale-up

The NESTLER pilot portfolio has produced credible evidence that digital monitoring, AI analytics, circular feed systems and One Health surveillance can jointly improve agri-food resilience. The platform is strongest where field data are translated into practical decisions: when soil analysis guides fertiliser use, water-quality data supports aquaculture, BSF feeding evidence supports local protein substitution, and vector observations become spatial risk maps.

- ✓ **For crop pilots**, prioritise soil-testing access, farmer-friendly advisory outputs, irrigation-calibration protocols and continued expansion of local disease-image datasets.
- ✓ **For livestock pilots**, integrate feed-formulation decision support, BSF supply-chain planning, camera-based welfare monitoring and farmer awareness material.
- ✓ **For aquaculture pilots**, combine feed-substitution economics with SynWater-based early warning, calibration logs and practical water-management recommendations.
- ✓ **For zoonotic and vector-surveillance pilots**, standardise trap metadata, sampling protocols, ethical approvals and GIS risk communication across countries.
- ✓ **For all pilots**, add data-confidence indicators and role-specific dashboards so that farmers, researchers and policymakers can interpret outputs at the right level of detail.

The final assessment is positive but conditional. The pilots validate the scientific and operational relevance of the platform, while the scale-up recommendations identify where additional work is required to make the model robust, trusted and sustainable beyond the project lifetime.

6 Ecological Niche Modelling and Zoonotic Risk Assessment

This chapter evaluates the analytical chain that links ecological niche modelling (ENM), zoonotic disease risk assessment, pilot surveillance evidence and the operational NESTLER platform. It assesses scientific soundness, data readiness, cloud deployment, decision usefulness, limitations and the actions required for sustainable exploitation after the end of the project.

The analysis is aligned with the One Health premise that human, animal, plant and ecosystem health are interdependent [11]. In NESTLER, this is important because food security is affected not only by crop productivity or feed availability, but also by disease spillover, vector ecology, wildlife-livestock interfaces, climate stress, water availability and the capacity of institutions to detect risks early. The WP5 evaluation therefore considers ENM and the Zoonotic Disease Outbreak Service (ZDOS) as operational instruments for food-system resilience.

While Chapter 4 assessed the crop, livestock, aquaculture and surveillance pilots, this chapter focuses on the analytical layer of the NESTER platform that transforms those observations into spatially explicit knowledge for early warning and preparedness. The added value can be summarized in four dimensions:

- ✓ **Scientific integration:** the model chain combines ecological suitability, vector ecology, climate variables, host availability and surveillance observations.
- ✓ **Operational integration:** the outputs are connected to the platform database, GeoServer layers and dashboard components, supporting inspection by non-specialist users.
- ✓ **Food-security relevance:** zoonotic and vector-borne threats are interpreted as stressors that may disrupt livestock productivity, household income, public health resources and market confidence.
- ✓ **Policy relevance:** risk maps and uncertainty-aware indicators can support targeted surveillance, pre-positioning of vector-control resources and institutional One Health planning.

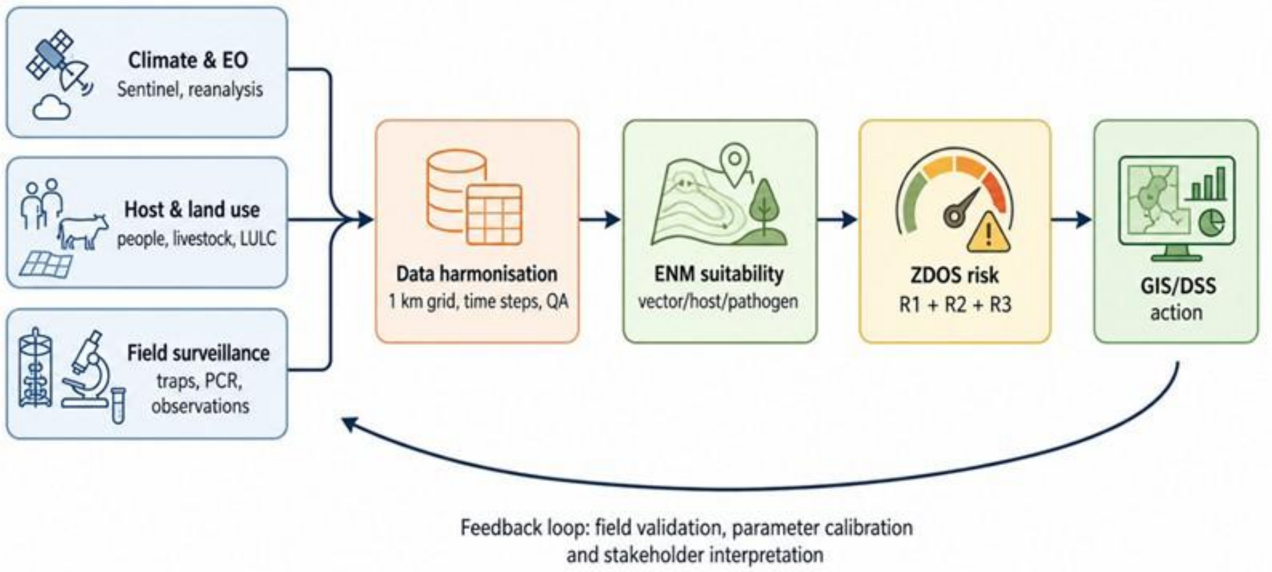


Figure 10: One Health analytical chain linking ecological suitability to operational decision support

6.1 One Health data foundation and fitness-for-purpose evaluation

The quality of NESTLER Platform depends on the capacity to combine heterogeneous data into a coherent geospatial and temporal modelling environment. NESTLER uses environmental and climate layers, Earth Observation products, host and land-use indicators, entomological observations, and pilot-specific field records. From an IT perspective, this is a data-fusion challenge: the value of each input depends on its metadata quality, geolocation accuracy, temporal resolution, uncertainty profile and compatibility with downstream GIS services. From a food-security perspective, the objective is not to collect more data for its own sake, but to identify which data streams can improve the timing, precision and credibility of interventions.

Table 21: Data streams and fitness-for-purpose assessment for ENM and zoonotic risk modelling

Data stream	Role in WP5 analysis	Fitness-for-purpose evaluation	Main improvement needed
Climate variables: temperature, precipitation, humidity, wind	Drive vector survival, reproduction, abundance, dispersal and seasonal suitability.	High analytical value because the variables are available at regular temporal intervals and can be aggregated to epidemiological reporting periods.	Local calibration and explicit documentation of missing data, spatial resolution and uncertainty propagation.
Earth Observation and land-cover data	Provide large-scale environmental context, including vegetation, water proximity, land use and habitat suitability.	Strong scalability; suitable for harmonised cross-country analysis where field data are sparse.	Improve linkage with ground observations and update frequency for rapidly changing land-use patterns.
Host distribution: human population and livestock density	Represents exposure and amplification potential for zoonotic or vector-borne disease risk.	Useful for prioritisation of areas where ecological suitability intersects with vulnerable populations or livestock assets.	Incorporate dynamic host movements where available, especially livestock mobility and seasonal grazing.
Entomological traps and pathogen detection	Provide direct evidence on vector occurrence, abundance, sex-specific transmission relevance and pathogen positivity.	Highest evidential value for local validation and calibration of the surveillance-based component.	Standardise trap metadata, sampling effort, diagnostic methods and reporting delay across countries.
Pilot observations and institutional feedback	Connect model outputs with field feasibility, training needs and decision-making processes.	Essential for evaluating usability and acceptability of risk maps by end users.	Formalise feedback loops and document decisions taken on the basis of platform outputs.

6.2 Ecological Niche Modelling methodology

Ecological Niche Modelling (ENM) is used to estimate the environmental conditions under which vectors, hosts or pathogens are likely to persist. Within NESTLER, ENM functions as the first analytical bridge between raw environmental data and actionable One Health indicators. The model does not claim to observe disease directly; rather, it estimates ecological suitability, which is then combined with surveillance and host-related evidence to support risk interpretation.

The methodological strength of the ENM approach is its flexibility. It can operate as a species-distribution model when the target is vector presence, as an environmental suitability model when the target is habitat favourability, or as a disease-suitability model when the target is a proxy for transmission potential. This is important for NESTLER because the available data differ by country and pilot. Some areas provide rich entomological records; others rely more strongly on climate, land cover and host-density proxies. A modular ENM framework allows WP5 to remain operational in both data-rich and data-limited environments.

A robust ENM workflow for NESTLER includes the following steps:

- ✓ **Define the biological target:** vector species, host group, pathogen-risk proxy or composite disease suitability indicator.
- ✓ **Select and harmonise covariates:** climate, land cover, terrain, water bodies, host density, farm location, wildlife interface and field observations.
- ✓ **Perform quality screening:** remove duplicate locations, flag geolocation uncertainty, inspect sampling bias and document temporal mismatches.
- ✓ **Fit and compare modelling options:** mechanistic, statistical or machine-learning approaches depending on data availability and validation objectives.
- ✓ **Generate risk surfaces:** convert continuous suitability values into interpretable risk categories while retaining the underlying numeric score.
- ✓ **Validate and communicate uncertainty:** compare maps against independent observations, expert knowledge and reported outbreak or vector-occurrence records.

The evaluation of this workflow is positive because it creates a transparent pathway from ecological knowledge to platform outputs. At the same time, the chapter recommends that all ENM outputs be accompanied by metadata on data coverage, model version, calibration period, validation metrics and uncertainty. This is essential to avoid over-interpreting modelled suitability as confirmed outbreak evidence.

6.3 Zoonotic Disease Outbreak Service architecture and model logic

The Zoonotic Disease Outbreak Service implements zoonotic and vector-borne disease risk modelling inside the NESTLER platform. Its architecture is particularly relevant for WP5 because it converts ENM-related inputs and field-surveillance observations into risk classes that can be stored, queried and visualised. The service is designed as a modular and disease-agnostic framework: core data processing is separated from disease-specific adapters, allowing the same computational shell to support different pathogens, vectors and geographic regions.

The ZDOS risk logic combines three complementary components:

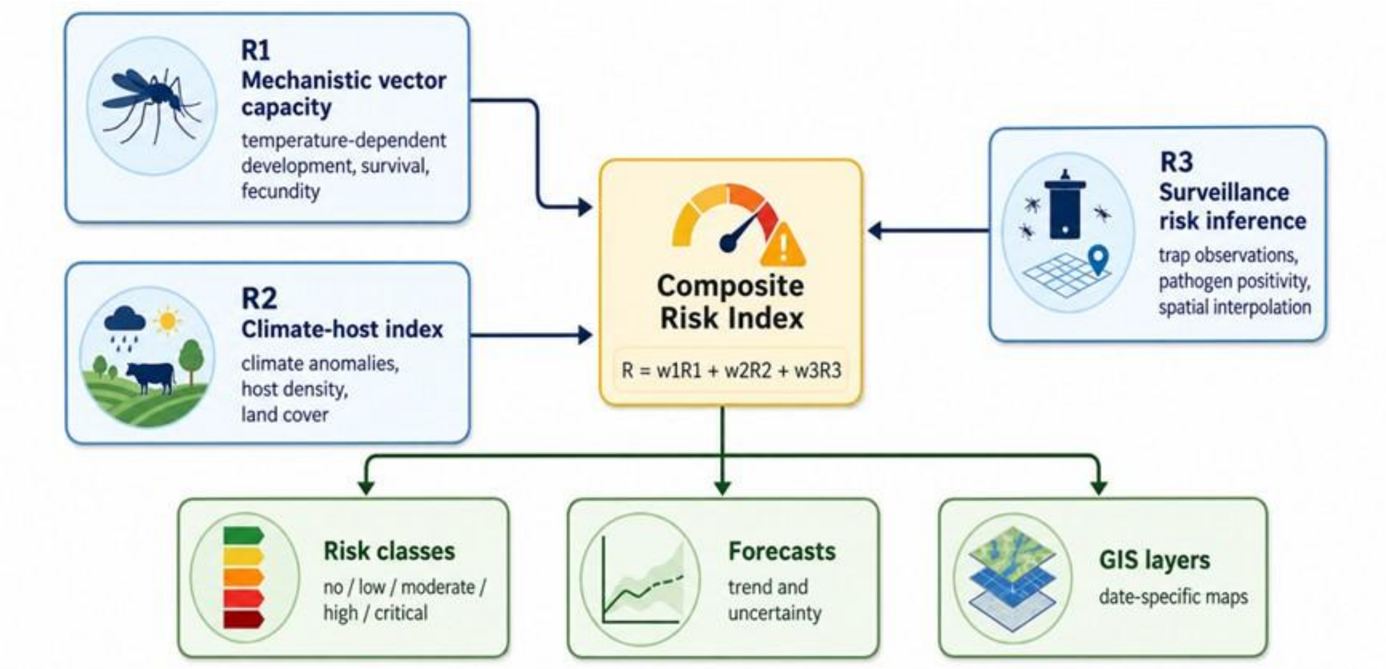


Figure 11: ZDOS multi-component risk modelling and output structure.

Table 22: Evaluation of the NEST:ER ZDOS risk components

Component	Scientific interpretation	Operational strength	Limitation
R1 - Mechanistic vector capacity model	Estimates whether temperature-dependent vector population dynamics favour growth and transmission potential.	Biologically grounded and suitable for diseases with known vector ecology.	Requires species-specific parameters and careful local calibration.
R2 - Empirical climate-host index	Combines climate anomalies, host density and environmental covariates into a bounded risk proxy.	Useful when detailed mechanistic models or surveillance data are limited.	Can oversimplify disease ecology if weights are not validated locally.
R3 - Surveillance-based risk inference	Interpolates direct field evidence from trap observations and pathogen testing across space.	Strongest link to reality where trap data are available and standardised.	Sensitive to sampling bias, trap effort, diagnostic delays and sparse coverage.
Composite risk indicator	Integrates R1, R2 and R3 into a configurable risk score and categorical map.	Balances model-based inference with observed surveillance signals.	Requires transparent weighting, uncertainty reporting and version control.

The composite risk indicator can be expressed conceptually as:

$$R = W_1 \times R_1 + W_2 \times R_2 + W_3 \times R_3$$

$$\text{with } W_1 + W_2 + W_3 = 1$$

This expression should be interpreted as a decision-support formulation rather than a fixed epidemiological law. The weights remain configurable, as the evidential strength of each component varies across diseases, countries and time periods. Where surveillance observations are reliable, R3 should receive a stronger weight. Where surveillance is sparse, R1 and R2 can maintain situational awareness, but the platform should display lower confidence. This distinction between risk and confidence is important for responsible use.

Figure 12: Biogents (BG) Sentinel traps used in NESTLER for survey of adult Aedes mosquito dengue vectors, baited with carbon dioxide as yeast-sugar mixture (left panel) or dry ice (right panel)

6.4 Disease-spread representation and short-term forecasting

Disease spread in NESTLER is represented through a combination of ecological suitability, local spatial dependence and short-term temporal extrapolation. The spatial-diffusion step smooths risk across neighbouring grid cells and can incorporate directional bias from wind. This is appropriate for vector-borne diseases because vector movement, passive transport and shared environmental conditions can create spatially correlated risk. Nevertheless, diffusion must not be misread as a complete mechanistic simulation of disease transmission. It is a pragmatic modelling layer that improves spatial continuity and supports early-warning interpretation.

The time-series forecasting component provides local projections of relative transmission potential. These forecasts are useful for prioritisation because they help identify areas where recent conditions point toward increasing risk. For decision makers, the most relevant output is not a precise prediction of case counts, but a risk trend that can trigger enhanced surveillance, targeted vector control, community awareness or sample collection. This interpretation is consistent with the maturity of the available data and with the preventive logic of One Health surveillance.

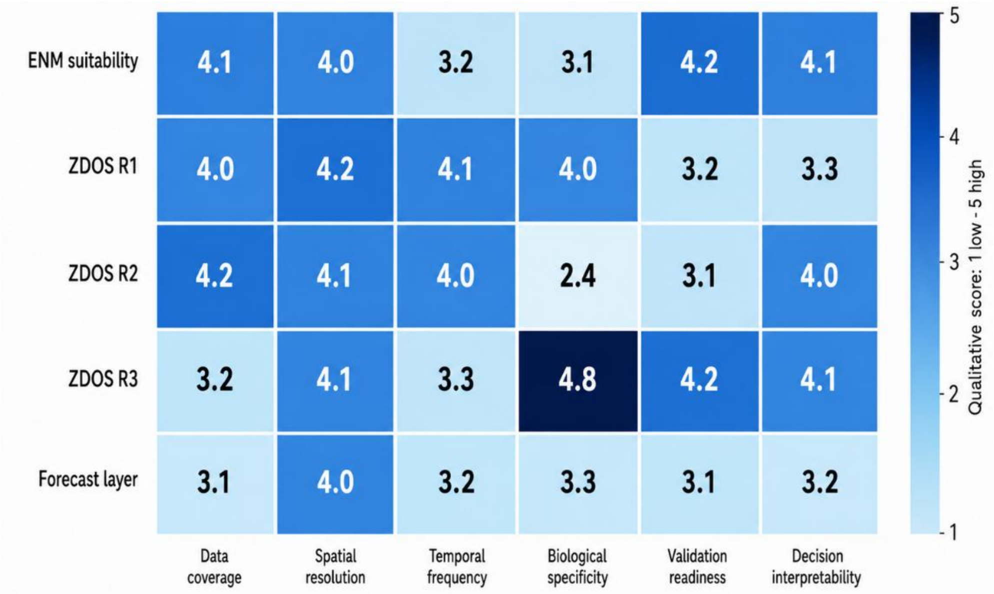
6.5 Integration with the NESTLER platform and cloud deployment

The NESTLER analytical services are evaluated not only by their modelling logic, but also by their ability to operate inside the final NESTLER platform. The ZDOS is implemented as a containerised backend service and integrated with the platform API, PostgreSQL/PostGIS database, GeoServer and dashboard components. This architecture is suitable for reproducible deployment because the service logic, API endpoints and dependencies can be packaged as versioned container images. It also supports horizontal scalability and operational resilience when deployed in Kubernetes.

As shown in Table 23, from a cloud-computing perspective, the NESTLER platform implementation shows a mature trajectory. Spatial results are persisted in a geospatial database, exposed as GIS layers and consumed by the dashboard. This separates data computation from visualisation and enables multiple applications to query the same authoritative risk layer. The use of date-specific map requests also supports temporal exploration, allowing users to inspect how risk evolves across locations and time. For NESTLER, this is essential because pilot stakeholders require both historical review and current situational awareness. Table 23 also includes recommendations that could be implemented to further enhance the ENM/ZDOS integration with the cloud-native NESTLER platform.

Table 23: Evaluation of the ENM/ZDOS integration with the cloud-native NESTLER platform

Platform layer	NESTER Platform function	Evaluation outcome	Recommended enhancement
Backend service	Runs ENM/ZDOS calculations and risk-class generation.	Technically mature and aligned with containerised deployment.	Add automated model-version logging for each run.
PostgreSQL/ PostGIS	Stores spatial cells, disease identifiers, risk classes and timestamps.	Appropriate for geospatial traceability and dashboard integration.	Add confidence scores at grid-cell level.
GeoServer and GIS API	Publishes disease-specific layers for browser-based map display.	Strong fit for user-facing spatial decision support.	Improve legend text and uncertainty overlays for non-technical users.
Dashboard	Allows users to select disease, date and geography and inspect risk categories.	High value for communication and stakeholder interpretation.	Add role-specific views for researchers, public-health officers and field teams.
IAM and access control	Restricts access according to user role and sensitivity of data.	Supports responsible handling of sensitive surveillance information.	Define explicit data-sharing tiers for restricted layers.



	Data coverage	Spatial resolution	Temporal frequency	Biological specificity	Validation readiness	Decision interpretability
ENM suitability	4.1	4.0	3.2	3.1	4.2	4.1
ZDOS R1	4.0	4.2	4.1	4.0	3.2	3.3
ZDOS R2	4.2	4.1	4.0	2.4	3.1	4.0
ZDOS R3	3.2	4.1	3.3	4.8	4.2	4.1
Forecast layer	3.1	4.0	3.2	3.3	3.1	3.2

Figure 13: Qualitative evaluation matrix for ENM/ZDOS operational maturity

6.6 Pilot evidence and validation pathway

The NESTLER validation evidence indicates that the analytical direction is scientifically credible and operationally promising. The zoonotic surveillance pilots collected large numbers of vector samples and developed predictive disease-risk models for dengue and trypanosomiasis with high reported discrimination. In Kenya and Uganda, surveillance activities included trapping, pathogen detection and blood-meal analysis, generating evidence on vectors that can bridge domestic animals, wildlife and humans. Species distribution modelling results for Stomoxys calcitrans and Phlebotomus martini achieved high accuracy, and dengue transmission modelling was validated against independent outbreak locations.

Figure 14: NESTLER platform validation pathway from technical functionality to operational use.

The evaluation, however, distinguishes between model demonstration and operational validation. Demonstration confirms that the pipeline can run, generate plausible maps and connect to the dashboard. Operational validation requires retrospective and prospective comparison with independent field observations, reported incidence, entomological abundance and diagnostic results. The validation pathway should therefore be staged and evidence-driven:

Table 24: Recommended validation levels for ENM and ZDOS outputs

Validation level	Evidence required	Metric or check	Decision relevance
Technical execution	Successful service runs, database writes, GIS layer rendering.	Run completion, API response time, map availability, error logs.	Confirms that the platform can operationally produce risk outputs.
Data plausibility	Input layers within expected ranges and spatial-temporal alignment.	Missingness, outlier rate, coordinate validity, temporal completeness.	Prevents misleading maps caused by broken or incomplete input data.
Ecological plausibility	Risk maps consistent with known vector ecology and local expert knowledge.	Expert review, correlation with habitat features, seasonal patterns.	Builds trust before field or policy use.
Retrospective validation	Independent trap records, pathogen positivity or outbreak records.	AUC, sensitivity, specificity, precision-recall, calibration plots.	Tests whether risk categories identify observed historical risk.
Prospective validation	New field observations collected after forecast generation.	Forecast skill, lead time, false alarm ratio, missed-event rate.	Determines whether outputs can support early warning and resource allocation.
Operational impact	Documented decisions influenced by the platform.	Surveillance redeployment, response time, cost per detected hotspot.	Shows whether WP5 outputs improve preparedness in practice.

6.7 Food-security and One Health interpretation

The relevance of ENM and ZDOS to food security is indirect but significant. Zoonotic and vector-borne diseases can reduce labour availability, livestock productivity, household income and the stability of local markets. They can also trigger emergency expenditure that diverts resources away from agricultural inputs and nutrition. In pastoral, peri-urban and conservation landscapes, vector surveillance is therefore part of food-system resilience. The NESTLER approach is valuable because it connects disease-risk intelligence with agricultural pilots, environmental monitoring and community capacity building.

The One Health interpretation of WP5 should be framed around prevention. Risk maps are not diagnostic declarations; they are tools for prioritising where to look, where to sample and where to communicate.

This distinction protects scientific credibility and avoids unnecessary alarm. A mature implementation should therefore classify outputs into three information levels:

- ✓ **Ecological suitability:** where the environment is favourable for vectors, hosts or pathogen transmission.
- ✓ **Surveillance-supported risk:** where field observations or diagnostic evidence support elevated risk.
- ✓ **Action priority:** where ecological suitability, surveillance evidence and exposed populations or livestock assets justify intervention.

This hierarchy would improve communication to policymakers and local stakeholders. It would also help align the platform with responsible AI and decision-support practice, because users can distinguish between modelled possibility, observed evidence and recommended action.

6.8 Assumptions and future improvements of ENM/ZDOS

The analysis and evaluation of the current ENM/ZDOS have shown that the analytical framework is quite strong and provide a significant, stable and robust platform. Moreover, future improvements have been identified that would add value to the NESTLER platform and the ENM/ZDOS. In detail, the future improvements are based on the following assumptions and limitations. First, spatial models inherit uncertainty from input data. Climate products, host-density layers and land-cover data may not capture microhabitats, local water storage practices, animal movement or informal settlements. Second, entomological observations are often unevenly distributed because sampling follows accessibility, permits, safety and logistical constraints. Third, disease relationships may not remain stable under climate variability, land-use change or changes in vector-control practice. Fourth, reported human or animal cases are often delayed, underreported or spatially mismatched with the grid cells used by the model.

A responsible platform should therefore treat uncertainty as part of the output. Three practical measures are recommended:

- ✓ **Attach confidence indicators to each risk cell**, based on data coverage, recency and the relative contribution of surveillance observations.
- ✓ **Provide model-version and parameter metadata** so that maps generated at different times can be reproduced and compared.
- ✓ **Use validation dashboards** that show not only high-risk areas, but also model errors, false alarms, missed detections and data gaps.

Table 25: Risk register and mitigation actions for ENM/ZDOS services

Risk or limitation	Likely effect	Mitigation action	Priority
Sparse or biased trap coverage	Local risk may be underestimated or over-smoothed.	Plan sentinel sites using ecological strata; record sampling effort and trap-days.	High

Risk or limitation	Likely effect	Mitigation action	Priority
Delayed diagnostic confirmation	Risk maps may lag behind real outbreak dynamics.	Introduce nowcasting and distinguish suspected, confirmed and modelled risk.	Medium
Uncalibrated disease-adapter weights	Composite risk may overemphasise a weak evidence stream.	Calibrate weights with local historical data and sensitivity analysis.	Medium
Inconsistent metadata across countries	Reduced comparability and reproducibility.	Adopt a mandatory surveillance metadata template and controlled vocabulary.	Medium
Connectivity or cloud access limitations	Field users may not access maps during critical periods.	Provide offline exports, scheduled PDF/map packages and low-bandwidth views.	Medium
Overinterpretation by non-specialist users	Risk of alarm or inappropriate action.	Use layered legends, confidence labels and role-specific explanatory notes.	Medium to Low

7 End-user perspective and stakeholder-based assessment

NETSLER platform final evaluation is not interpreted only as a technical assessment of cloud services, data pipelines, AI algorithms and pilot outputs, but also as an assessment of whether the platform can be understood, trusted and used by its intended stakeholders. This chapter therefore complements the platform and pilot-evidence analysis by examining the final platform from the end-user perspective. It builds on the first-phase assessment reported in D5.2 [7] and updates the interpretation in light of the second-phase platform integration, final pilot demonstrations, mitigation actions and operational-readiness evidence.

The D5.2 assessment established the first structured baseline for end-user perception. It considered farmers and field operators, researchers and pilot leaders, policy-oriented stakeholders and technical users, and examined usability, data accuracy, system uptime, relevance of AI outputs, decision-support value and country-level satisfaction. In D5.5, the evaluation focus is broadened from initial user perception to final user readiness. The objective is to assess whether the platform evolution has addressed the main first-phase concerns and whether the final NESTLER environment can support practical decision-making in crop, livestock, aquaculture and One Health surveillance contexts.

It should be noted that the assessment presented in this chapter is not a new survey. Instead, it provides a consolidated expert and stakeholder-based interpretation, combining the D5.2 baseline, the final D5.5 platform evidence, pilot readiness information, user-facing dashboard evolution, training activities, reported technical mitigations and lessons learned from the participating countries

7.1 End-user assessment logic and stakeholder groups

The NESTLER platform serves different user groups, each with different expectations. Farmers and field operators need accessible advice, alerts and practical interpretation of field data. Researchers and pilot leaders need reliable datasets, traceability, exportable outputs and model interpretation. Policy-oriented users need spatially aggregated evidence, risk maps, uncertainty communication and decision-support summaries. Technical partners need maintainable services, stable APIs, monitoring information and clear incident-response procedures. The final end-user assessment is therefore organised around the value that the platform provides to each stakeholder group. This approach is consistent with the One Health character of the project, where operational value depends on linking human, animal, plant and environmental evidence into a common decision-support environment.

Table 26: Stakeholder groups and user-value interpretation for the final NESTLER platform

Stakeholder group	Main expectation	D5.5 platform value	Remaining adoption need
Farmers and field operators	Simple, timely and actionable information for field decisions.	GIS views, alerts, device/trap observations, graphs and pilot-specific outputs make platform information more operational.	Simplified dashboards, practical recommendations, local-language support and offline-friendly guidance.
Researchers and pilot leaders	Reliable data streams, traceability, model outputs and reproducible analysis.	Structured APIs, metadata, GIS layers and pilot indicators improve interpretation and reporting.	Routine data-quality dashboards, versioned model documentation and clearer uncertainty labels.

Policy-oriented users	Evidence summaries, maps and risk indicators.	Integrated One Health and food-security outputs enable cross-sector interpretation.	Decision briefs, confidence levels and scenario-based summaries for planning.
Technical partners	Stable services, clear operational responsibilities.	Kubernetes deployment, API scaling, monitoring logic and improved maintainability.	Service targets, incident procedures, security reviews, post-project ownership model.

7.2 Evolution of user-facing value from Phase -1 (D5.2) to Phase -2 (D5.5)

The D5.2 end-user assessment identified several areas requiring improvement, including platform uptime, data accuracy, dashboard navigation and the need for clearer recommendations. These findings are important because user trust in a decision-support platform depends on the entire service chain, not only on the accuracy of individual AI models. A technically advanced platform may still fail to generate impact if users cannot access it reliably, understand its outputs or connect results to practical action.

The second-phase platform evolution addresses many of these concerns. The shift to a more integrated cloud-native architecture, the introduction of stronger service replication, the extension of APIs, the use of structured device and trap registration, and the richer dashboard/GIS environment collectively improve the user-facing maturity of the platform. The strongest perceived improvement is expected in decision usefulness, because the final platform now connects field observations, risk layers, pilot indicators, forecasts and One Health outputs in a more coherent workflow.

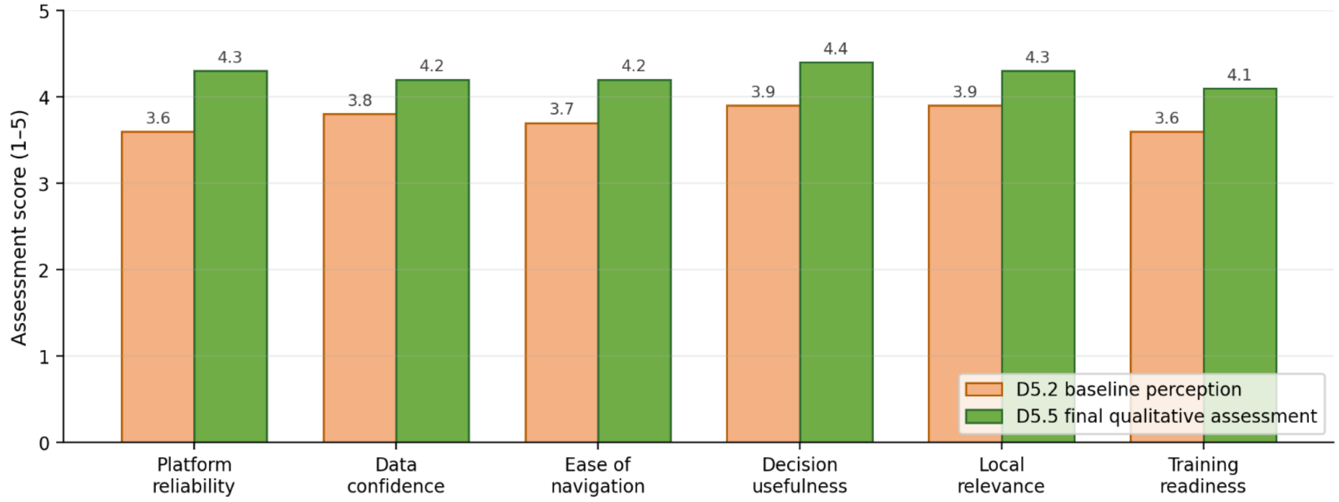


Figure 15: End-user assessment comparing Phase 1 (Baseline) vs. Phase 2 (Final) platform.

Table 27: Interpretation of user-facing improvements from Phase 1 to Phase 2

Dimension	Phase 1 baseline issue (D5.2)	Phase 2 final interpretation (D5.5)	Indicative follow-up
Platform reliability	System uptime was one of the lowest-rated aspects during the first assessment.	Service replication, Kubernetes, API and backup logic indicate a stronger operational basis.	Define restoration procedures and periodic stress tests.

Data confidence	Users required more confidence in the consistency and validation of incoming data.	Range checks, recalibration actions and structured registration improve traceability.	Add data-quality flags, and uncertainty notes.
Ease of navigation	Dashboard complexity and pilot-specific interfaces required simplification.	The final platform provides a unified dashboard with GIS, graphs, devices, traps and risk layers.	Introduce role-specific views for farmers, researchers and policy users.
Decision usefulness	Initial outputs needed clearer links to action.	Risk maps, alerts, readiness summaries and One Health outputs improve actionable interpretation.	Connect indicators to recommended actions and escalation pathways.
Training readiness	Adoption depended strongly on stakeholder onboarding.	Training, SOPs and pilot-level engagement improved user readiness.	Maintain post-project training packages and local reference points.

7.3 Stakeholder-based maturity assessment

The final NESTLER platform is best understood as a socio-technical service ecosystem. Its maturity depends on both engineering readiness and stakeholder readiness. For this reason, the assessment below evaluates five user-facing dimensions across the main stakeholder groups. The scores are qualitative maturity judgements derived from the final platform evidence, pilot reporting and the D5.2 baseline structure; they are not formal survey averages.

Figure 16: Stakeholder-based maturity matrix for final platform use

Figure 16 shows that researchers and pilot leaders are expected to obtain the highest value from the final platform, because they can use the detailed data, GIS layers, model outputs and traceability functions. Farmers and field operators benefit from practical decision support, but adoption remains sensitive to interface simplicity, training and connectivity. Policy-oriented users can benefit strongly from spatial risk maps and cross-sector evidence, provided that uncertainty and confidence levels are clearly communicated. Technical partners benefit from the improved cloud-native deployment, but long-term service continuity depends on formal governance and ownership.

7.4 Country-level end-user readiness interpretation

The country-level interpretation links the first-phase user-satisfaction baseline with the final operational-readiness evidence. D5.2 reported country-level satisfaction values for Cameroon, Ethiopia, Kenya, Nigeria, Rwanda and Uganda. These values are retained as the baseline reference because they provide the only harmonised cross-country user-perception indicator available from the first platform evaluation. In D5.5 evaluation, country-level readiness is interpreted in relation to the maturity of pilot activities, platform integration, training, data availability and demonstrated use of digital tools. The resulting pattern suggests improvement in all countries, but the interpretation remains qualitative. It should therefore be used to support narrative assessment and prioritisation of follow-up actions, not as a contractual performance score.

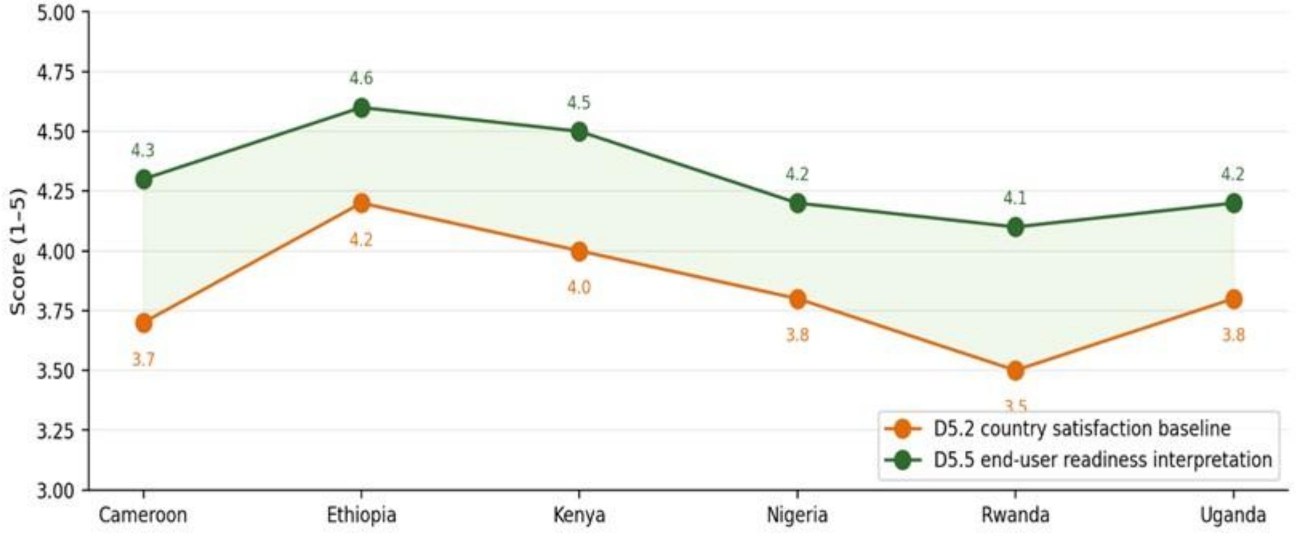


Figure 17: Country-level user-satisfaction D5.2 (baseline) and D5.5 (final) readiness interpretation.

7.5 User-facing limitations and adoption risks

Although the final platform demonstrates a clear improvement in user-facing maturity, several limitations remain relevant for operational adoption. These limitations do not undermine the technical credibility of the platform; rather, they define the conditions under which the platform can be used responsibly and sustainably after the project. The most important issues are connectivity constraints in remote areas, variable digital literacy among user groups, the need for regular sensor calibration, the risk of misinterpreting model outputs, and the absence of a fully operational post-project support model.

A key lesson from both Phase -1 and Phase -2 versions of the NESTLER platforms is that user confidence depends on transparency. Users should be able to understand where a data point comes from, whether it has passed quality checks, what model generated a prediction, what uncertainty is attached to a risk map, and what action is recommended. Without this transparency, even technically strong outputs may be underused by farmers, researchers and public authorities.

Table 28: User-facing adoption risks, mitigation status and residual actions

Adoption risk	Why it matters	Mitigation in Phase -2	Residual action
Connectivity and access limitations	Remote field sites may experience delays in data upload or dashboard access.	Platform services and dashboards were consolidated and cloud deployment improved.	Support asynchronous upload, caching and lightweight modes.
Digital literacy differences	Users have different levels of experience with dashboards, maps and model outputs.	Training and pilot engagement improved onboarding.	Prepare role-specific manuals, short videos and local-language materials.
Data-quality interpretation	Users may treat all outputs as equally reliable even when data gaps exist.	Structured registration, range checks and recalibration actions improved traceability.	Add confidence indicators, anomaly flags and device-health status.
Model-output interpretation	Risk maps and AI outputs may be misread as deterministic predictions.	Human-facing dashboards allow interpretation by expert users.	Include uncertainty notes, model cards and recommended action thresholds.
Post-project continuity	Users need support, maintenance and ownership beyond project closure.	Containerised deployment and issue tracking improve maintainability.	Define hosting, helpdesk, governance and financing responsibilities.

7.6 Considerations for post-project NESTLER Platform improvements

In the following we provide a list of considerations and recommendations related to post-project NESTLER Platform improvements

- ✓ **Role-specific interfaces:** The final platform should provide simplified views for farmers and field operators, analytical views for researchers, and strategic views for policy-oriented users. This would reduce cognitive load and improve adoption without removing expert functionality.
- ✓ **Confidence-aware decision support:** Data-quality indicators, model-confidence levels, uncertainty notes and clear thresholds should be embedded in dashboards and reports. This is especially important for disease-risk maps, climate-risk alerts and policy-oriented summaries.
- ✓ **Training and support model:** A small set of reusable training packages should be maintained after the project, including quick-start guides, SOPs, video demonstrations and troubleshooting procedures. Training should be adapted to country context and user role.
- ✓ **Feedback loop and continuous improvement:** Users should be able to report problems, validate outputs and provide qualitative feedback directly through a structured support channel. This would allow the platform to remain responsive to field realities.
- ✓ **Institutional ownership:** The final exploitation pathway should define who hosts the platform, who maintains services, who responds to incidents, who updates models, and who manages data access. Without this governance layer, user trust may decline after the project lifetime.

The second-phase end-user assessment indicates that the NESTLER platform has moved from an initial demonstrator environment toward a more mature user-facing decision-support system. The most important improvement is not only the addition of new services, but the integration of field data, GIS layers, model outputs, pilot evidence and administrative functions into a more coherent operational workflow. This improves the ability of farmers, researchers, policy-oriented users and technical partners to interpret information and connect it to action.

The final judgement is positive but conditional. The platform is technically credible and increasingly useful from an end-user perspective, but its long-term value will depend on sustained training, clear data-quality communication, model transparency, simplified dashboards, reliable hosting and institutional support. The platform should therefore be evaluated as a socio-technical service: its success depends on cloud and AI maturity, but also on user trust, local ownership and practical adoption in the pilot countries.

8 Conclusion

The evaluation of the NESTLER Phase 2 platform demonstrates a successful evolution from a collection of modular technical interventions into a cohesive, cloud-native integrated decision-support system. As detailed, the transition to a Kubernetes architecture was fundamental in ensuring the high availability, scalability, and operational resilience required for large-scale deployment across the African continent. This technical maturity is further evidenced by the successful integration of diverse data streams, including IoT sensing, Earth Observation (EO), and AI-driven analytics, into a unified GIS dashboard, allowing stakeholders to monitor human, animal, and plant health under a single "One Health" paradigm.

The platform's operational success is underpinned by targeted technical refinements described in chapter 3, including service redundancy, network optimization, and the recalibration of sensors like SynWater to ensure data accuracy. While the evaluation identified critical dependencies on reliable power, internet connectivity, and site-specific risk management (e.g., flooding or bushfires), the NESTLER platform ultimately serves as a scalable reference model for climate-smart agriculture. The project's focus on capacity building, having trained hundreds of farmers and developed standardized operating procedures (SOPs), ensures that these technological advancements are not only technically sound but also practically accessible for long-term adoption. Moreover, chapter 4 provides a technical evaluation of the platform evaluating the system performance.

In the realm of sustainable agriculture and the circular bioeconomy, the pilots documented in chapter 5 (Evaluation of pilot demonstrations) proved that insect-based protein is a viable and economically superior alternative to conventional feed. Specifically, feeding trials in Ethiopia and Rwanda demonstrated that Black Soldier Fly (BSF) larvae can replace expensive protein sources like fishmeal and soybean meal by up to 75% in aquaculture without compromising growth performance. Notably, the full replacement of fishmeal with BSF in Ethiopia's aquaculture pilot increased the profit index by 52% and significantly reduced production costs. In poultry, inclusion levels of up to 9% were validated as safe and effective, promoting feed self-sufficiency and reducing environmental burdens through the bioconversion of organic waste.

The platform's impact on precision agriculture is equally significant, particularly through the synergy of IoT sensors and AI diagnostics as highlighted in Section 5.1 (Crop-Based Farming Pilots) [10]. The integration of smart irrigation systems and AI-based disease recognition (the IICI model) in tomato production achieved yields five times higher than traditional methods while saving approximately 14% of water per bed. Furthermore, the use of IoT-based soil analysis to guide organic fertilization (poultry manure) proved to be more agronomically and economically effective than blanket applications of mineral fertilizers, achieving a 306% rate of return in certain treatments.

A primary success of the platform lies in its analytical capabilities, specifically the Ecological Niche Modelling (EM) and the Zoonotic Disease Outbreak Service (ZDOS) discussed in Chapter 6 (Ecological Niche Modelling and Zoonotic Risk Assessment). The framework effectively transforms heterogeneous environmental and biological data into spatially explicit risk maps, facilitating the early detection of disease hotspots and enabling proactive interventions. By combining mechanistic vector models with real-time surveillance data from automated and manual traps, the platform provides a robust early warning system for emerging zoonotic and ecological threats.

Last but not least, the second-phase evaluation indicates that the NESTLER platform has moved closer to end-user operational needs. The strongest improvement is the transition from separate technical components to a shared decision-support environment combining field data, GIS layers, risk analytics and pilot evidence. Nevertheless, user adoption remains conditional on continued training, simplified interfaces, clear confidence indicators and reliable post-project support. The final platform should therefore be evaluated not only as a technically functional cloud-based system, but also as a socio-technical service that must remain understandable, trusted and useful for farmers, researchers and policy-oriented stakeholders.

8.1 Exploitation and sustainability considerations

The NESTLER Platform is ready to move from technical demonstration toward institutional use, provided that validation, governance and ownership are strengthened. The following recommendations are proposed for the final exploitation pathway:

Table 29: Exploitation and sustainability roadmap for NESTLER Platform & ENM/ZDOS services.

Recommendation	Expected benefit	Responsible actors
Institutionalise One Health surveillance protocols around the NESTLER risk layers.	Ensures that maps trigger clear field actions rather than remaining research outputs.	Pilot leaders, public-health authorities, veterinary services, conservation agencies.
Create a minimum viable operational package for each country.	Defines which diseases, data sources, users and update frequencies are realistic after project funding.	Technical partners, country partners, national focal points.
Implement validation sprints using historical trap and case data.	Quantifies performance and improves credibility with policymakers.	Research partners, epidemiologists, data managers.
Add confidence and uncertainty visualisation to the dashboard.	Improves responsible interpretation by non-technical users.	Platform developers, GIS specialists, end-user representatives.
Train local One Health Champions on map interpretation and sampling feedback.	Creates local ownership and reduces dependence on external modelling teams.	CTPH, ICIPE, national institutions, extension services.
Develop a sustainability plan for hosting, maintenance and data stewardship.	Clarifies long-term costs, security, access rights and institutional responsibilities.	Consortium management, platform owner, national partners.

9 References

[1] NESTLER Consortium, “D5.5 : NESTLER 1st phase pilot demonstrations,” 2024.

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