VANUATU
DATA SCIENCE
AND CLIMATE
CHANGE

Pacific
Community
Communauté
du Pacifique

Vanuatu Data Science Driving Innovation in Climate Change and Natural Disasters

Vanuatu Data Science Driving Innovation in Climate Change and Natural Disasters

Pacific Community
Communauté du Pacifique

Nouméa, New Caledonia
October 2025

Original text: English

Authors: Andy Calo, Hugo Pigott

Cover photo: Flickr, David T Rruddock

Layout: Gaëlle Le Gall

Prepared for publication at SPC’s headquarters,

B.P. D5, 98848 Noumea Cedex, New Caledonia, 2025

www.spc.int| spc@spc.int

Contents

Abbreviations

DEP	Digital Earth Pacific
EO	Earth Observation
MIS	Management Information System
ML	Machine learning
NDMO	National Disaster Management Office
PDNAs	Post-Disaster Needs Assessments
RAP	reproducible analytical pipeline
STAC	Spatiotemporal Asset Catalog
VBoS	Vanuatu Bureau of Statistics

Executive Summary

Vanuatu, the most disaster-prone country in the world, faces acute risks from cyclones, earthquakes, volcanic eruptions, droughts, and floods. Despite substantial investments by both government and development partners, the country lacks a comprehensive system to collect and analyse quality data to support targeted and timely responses to climate change and natural disasters. This project, "Vanuatu Data Science Driving Innovation in Climate Change and Natural Disasters," launched to address this critical gap by building an integrated, data-driven decision support system. Spanning 24 months, the project is structured in three strategic phases:

- Phase 1 focused on co-creation and design, establishing governance structures, and conducting provincial consultations to ensure the system reflected local needs.
- Phase 2 developed key tools: a reproducible analytical pipeline (RAP) to estimate the damage from a cyclone and resources needed for response & recovery, a machine learning (ML) training programme for climate monitoring using satellite data, and a Management Information System (MIS).
- Phase 3 centered on implementation, including disaster simulation exercises, tool validation, and sustainability planning to embed the innovations within national systems.

Through the integration of cutting-edge technology, strong local governance, and inclusive design, the project lays the foundation for evidence-based planning, faster response, and more effective recovery, ultimately strengthening the country's adaptive capacity to climate change and natural disasters.

Summary Highlights

Key Outcomes	Description
Enhanced Disaster Resilience and Climate Response	Vanuatu possesses a functional, data-driven framework that enables rapid estimation of disaster impacts and informed planning for climate-related challenges. This supports faster, more targeted responses and improves preparedness at all levels.
Institutionalised Use of Data Science in Public Decision-Making	Data science tools such as ML and RAPs are embedded within the national statistical system. This institutionalisation enhances the relevance, efficiency, and agility of government decision-making.
Strengthened Coordination Across Sectors and Stakeholders	Creation of inclusive governance structures and the integration of data systems into a centralised MIS enables whole-of-government coordination across climate change, disaster management, and public service delivery sectors.
Improved Statistical Quality and Innovation	Project elevated the standards of statistical methods used by the Vanuatu Bureau of Statistics (VBoS), resulting in more timely, accurate, and policy-relevant data.
Increased Efficiency in Data Management and Service Delivery	Automating analytical workflows and digitising data collection increases the speed and efficiency of statistical operations, improving VBoS ability to produce, manage, and disseminate high-quality data.
Local Capacity and Ownership for Sustainability	Through mentoring and hands-on training, the project has built local expertise in geospatial analysis, machine learning, and data pipeline development, ensuring the innovations can be maintained, scaled, and adapted beyond the project timeline.
Reproducible Analytical Pipelines	Automate workflows developed to estimate disaster damage and calculate the required resources for response and recovery, using area council-level socio-economic profiles made from census, administrative and earth observation data.

Key Outcomes	Description
Machine Learning Models and Training	ML models were built to analyse satellite imagery and generate real-time maps of key environmental indicators. Government of Vanuatu staff were trained in ML development and deployment using open-source tools.
Management Information System	A centralized, secure digital platform that integrates RAP outputs, ML data, and census & admin inputs to provide visual, spatially disaggregated dashboards for disaster and climate planning.
Governance Structures	The Steering Committee and Disaster Statistics Technical Committee provide technical and strategic guidance throughout the project and beyond.
Community Vulnerability Profiles	Area-specific datasets compiled from census and administrative data, forming the foundation for RAP-based damage and needs estimation.
Key Policy Evaluation Using ML	Machine learning models used to evaluate the effectiveness and impact of priority policies from the Ministry of Climate Change and Adaptation
Sustainability Plan and Final Evaluation	A strategic plan to ensure the innovations are maintained, updated, and institutionalised, and a comprehensive evaluation of performance and outcomes.

1. Introduction

- Problem Statement:

  i. The Republic of Vanuatu is the world's most at-risk country for natural disasters in the form of seismic and volcanic activity, cyclones, drought, and flooding. Huge financial sums have been spent by both government and development partners to collect the necessary data to effectively mobilize resources. However, the Government of Vanuatu currently lacks a system for the collection of quality data that targets action needed to help people cope with climate shocks.

- Research Questions:

  i. What is the potential for using data innovations to improve data related to climate change?

  ii. Are Reproducible Analytical Pipelines able to automatically quantify the damage from a disaster, resources needed for immediate response, and a post-disaster needs assessment?

  iii. Does a management information system enhance the efficiency of data collection and improve the delivery of public services related to climate change and natural disasters?

The experimental components of this initiative involve an integrated set of innovations aimed at strengthening disaster preparedness and climate change monitoring in Vanuatu. Automating the analysis of socio-economic and asset data through a Reproducible Analytical Pipeline (RAP) can rapidly estimate disaster impacts and resource needs. Integrating machine learning with earth observation data further enhances the ability to monitor agricultural productivity, coastal changes, and climate indicators in real time. Leveraging platforms like Digital Earth Pacific strengthens the regional application of these tools.

Collectively, these innovations consolidated through a centralised Management Information System will enable faster, evidence-based decision-making and more targeted delivery of public services in the face of climate risks.

2. Methodology

2.1. Phase I: Co-creation and Design

A co-creation and participatory design process, ensuring that the development of data-driven tools was representative of local needs, technically robust, and institutionally sustainable.

A central feature of this process was the establishment and active engagement of two core governance bodies: the Steering Committee and the Disaster Statistics Technical Committee.

Steering Committee:

i. Provide strategic oversight throughout the grant period. It ensures that all project activities are aligned with Vanuatu's national policies, development strategies, and climate and disaster risk priorities.

ii. The Committee reviewed progress against project milestones, assessed implementation effectiveness, and recommended adjustments to maximise impact. It also advised on institutional arrangements to sustain innovations beyond the life of the project and played a vital role in identifying and mitigating key delivery risks—including logistical, financial, and operational challenges.

iii. Importantly, the Steering Committee helped foster cross-sectoral collaboration by facilitating coordination among ministries, technical teams, and development partners, and securing the stakeholder buy-in necessary for long-term success.

Disaster Statistics Technical Committee

i. Led the technical design and implementation of the project's key innovations. Composed of experts from across government and partner institutions, the Committee provided hands-on guidance in the design of RAPs, ML models and MIS.

Provincial-level assessments

i. Carried out by the Vanuatu Bureau of Statistics and the Technical Committee. These assessments aimed to ensure that the national MIS was responsive to local needs and realities.

ii. Participatory workshops and SWOT analyses were conducted across four Provinces.

2.2. Phase II: Innovation Development

2.2.1. Machine Learning – Slow Moving Impacts of Climate Change

Machine learning capacity building plan designed to build technical and institutional capacity to develop, apply, and integrate ML models using satellite imagery for climate monitoring, disaster risk reduction, and environmental management.

Integration with Digital Earth Pacific (DEP): provides access to harmonised satellite data, cloud-based computing, and regional benchmarking capabilities. This integration enhances scalability, ensures consistency across Pacific island nations, and reduces infrastructure costs by providing platform-as-a-service tools.

Month 1: staff are introduced to Earth Observation (EO) concepts, including how to access imagery through the Spatiotemporal Asset Catalog (STAC) and work with cloud platforms.

Months 2–3: training continues with ML image segmentation techniques using existing models. Use cases include classifying land types using Sentinel-2 data, detecting flood zones through Sentinel-1 and Sentinel-2 imagery, and identifying roads from high-resolution Planet NICFI imagery.

Month 4: the team focuses on integrating these outputs into the MIS, including formatting outputs, adding metadata, and aligning results to MIS using QGIS.

Month 5: decision tree methods such as XGBoost are used to develop supervised learning models for monitoring soil health and water retention. These models classify soil conditions and model the landscape's filtration capacity using Sentinel-2, Planet NICFI, DEM, and vegetation data.

Months 6–8: focus on modelling coastal environmental change, including coastal elevation mapping, coastal erosion detection (using Sentinel-2), sea level rise tracking (using SWOT and Sentinel-2), and coral reef health assessment (using Sentinel-2, Planetscope, and ICESat-2).

Months 9–10: rainfall accumulation is modelled using rain gauge data; drought areas are classified using vegetation and thermal indices; and surface temperature trends are derived from ERA5 reanalysis and CMIP6 projections. Outputs across this phase include raster maps of soil and temperature conditions, coastline vectors, and classified environmental indicators.

Phase	Indicator	Dataset	Output
Remote Sensing	Satellite familiarity	Sentinel, STAC	Imagery downloads and processing
Image Segmentation	Land Cover Flooding Roads	Sentinel-2, NICFI	Pixel segmentation & polygons
MIS Integration	All outputs	Vector formats + QGIS	Metadata assignment + dashboard-ready layers
Agriculture	Soil Health Water Retention	Sentinel, NICFI	Classed raster outputs
Coastal	Coral Reefs Sea Level Rise Coral Reef Health	DEM, LiDAR, Altimetry	Erosion maps, reef degradation indexes
Climate	Rainfall Surface Temp Trends	ERA5, CMIP6	Drought pixels, anomaly trends

2.2.2. Reproducible Analytical Pipelines – Estimating impact of Cyclone, and Resources Needed for Response & Recovery

Collaborative approach was adopted, integrating stakeholder consultation, systematic data collection, and technical tool development.

The process began with extensive engagement across government ministries, cluster leads, and provincial disaster committees. Through participatory workshops and SWOT analyses, stakeholders identified key sectoral data needs, institutional capacities, and existing information gaps.

Baseline data was collected from across the Vanuatu Statistical System (VSS), including census data, administrative records, and geospatial datasets. These datasets were cleaned, standardised, and geocoded to form the foundation of the RAP.

Indicators were organised into four core analytical components across each cluster: (1) baseline estimation to capture pre-disaster conditions, (2) damage prediction based on hazard exposure and vulnerability, (3) estimation of resources required for immediate response, and (4) financial recovery modelling to quantify losses and inform funding.

The RAP was built using Quarto to automate the processing, modelling, and reporting tasks.

Hazard data such as cyclone wind intensity were overlaid with infrastructure and agricultural exposure data to model physical damage. Expert-derived coefficients were applied to estimate the extent of damage to various assets, which were then linked to the emergency resources needed and the financial value of those losses.

A practical case study to illustrate how the RAP operates in real disaster scenarios:

i. In this example, a simulated Category 4 cyclone impacted South-East Santo, while a Category 3 affected East Santo.

ii. Baseline agricultural production data showed that South-East Santo produced 380,000 kg of Fiji Taro and 420,000 kg of Kumala, while East Santo produced 320,000 kg and 88,000 kg, respectively.

iii. After consulting sector experts, damage estimates were applied based on cyclone intensity: 70% loss for Fiji Taro in South-East Santo (Category 4) and 25% in East Santo (Category 3). This resulted in 266,000 kg of Fiji Taro lost in South-East Santo and 80,000 kg in East Santo.

iv. The number of affected households engaged in crop production was used to estimate immediate response needs, such as seed kits or planting materials. For example, over 1,000 households in each area grew Fiji Taro and would require inputs to restart farming. These figures were matched with sector guidance to determine the appropriate relief packages.

v. For financial recovery, market prices were used to calculate the value of lost crops—800 Vatu per kg of Fiji Taro—translating to 212.8 million Vatu in damages in South-East Santo and 64 million Vatu in East Santo.

Cluster	Indicator Type	Indicator	Attributes
Education	Baseline	▪ Number of schools ▪ Number of students ▪ Number of teachers	▪ Early Childhood Care and Education; Primary; Secondary
	Prediction	▪ Damage	▪ Roof; Building; Rain Tank; Gas Tank; Water Supply
	Immediate Response	▪ Resources	▪ Tents; Solar lamp; Food; Water
	Financial Recovery	▪ Assets	▪ Roof; Building; Rain Tank; Gas Tank; Learning Materials
Emergency Telecommunications	Baseline	▪ Tower Cell	
	Prediction	▪ Damage	
	Financial Recovery	▪ Assets	
Energy	Baseline	▪ Household electricity ▪ Household cooking ▪ Infrastructure	▪ Battery lamp; Generator; Main grid; No access; Solar system ▪ Bottle gas; Open fire; Solar Power; Electricity ▪ Electricity poles; Hydroelectricity; Solar grids
	Prediction	▪ Damage	▪ Electricity poles; Solar grids; Battery lamp; Solar system
	Immediate Response	▪ Resources	▪ Electricity poles; Electricity wiring; Solar grids; Kerosene
	Financial Recovery	▪ Assets	▪ Electricity poles; Electricity wiring; Solar grids; Solar systems
Food Security	Baseline	▪ Stable crop production (kg) ▪ Number of households engaged in stable crops ▪ Cash crop production (kg) ▪ Value of timber (vatu) ▪ Number of households engaged in forestry ▪ Number of households engaged in fishing	▪ Island cabbage; Banana; Taro; Kumala; Manioc; Yam ▪ Kava; Coconut; Cocoa; Coffee; Vanilla; Tahitian Lime; Pepper; Noni ▪ Kauri; Mahogany; Sandalwood; Natapoa; Whitewood; Pine; Nangae; Koyu/Natora ▪ Inshore Fishing; Offshore Fishing; Fresh Water; Mangroves; Lagoon; Coastal

Cluster	**Indicator Type**	**Indicator**	**Attributes**
		▪ Fish production (kg)	Reefs; Outer Reefs; Pelagic/Open Ocean
	Prediction	▪ Damage to stable crops (no. of plants) ▪ Damage to cash crops (no. of plants) ▪ Damage to trees (no. of plants) ▪ Damage to fisheries	▪ Island cabbage; Banana; Taro; Kumala; Manioc; Yam ▪ Kava; Coconut; Cocoa; Coffee; Vanilla; Tahitian Lime; Pepper; Noni ▪ Kauri; Mahogany; Sandalwood; Natapoa; Whitewood; Pine; Nangae; Koyu/Natora ▪ Boat with motor; Boat without motor; Bamboo raft
	Immediate Response	▪ Resources for stable crops	▪ Island cabbage; Banana; Taro; Kumala; Manioc; Yam
	Financial Recovery	▪ Value of cash crop (vatu) ▪ Value of stable crops (vatu) ▪ Value of timber (vatu) ▪ Transport (fishing) ▪ Loss to fishing income (vatu)	▪ Island cabbage; Banana; Taro; Kumala; Manioc; Yam ▪ Kava; Coconut; Cocoa; Coffee; Vanilla; Tahitian Lime; Pepper; Noni ▪ Kauri; Mahogany; Sandalwood; Natapoa; Whitewood; Pine; Nangae; Koyu/Natora ▪ Inshore Fishing; Offshore Fishing; Fresh Water; Mangroves; Lagoon; Coastal Reefs; Outer Reefs; Pelagic/Open Ocean
Gender & Protection	Baseline	▪ Population ▪ Martial status ▪ Household size ▪ Difficulties ▪ Employment status	▪ Sex; Age ▪ Defacto; Married; Never Married; Seperated; Widowed ▪ 1 to 3; 4 to 7; 8 and above ▪ Communication; Hearing; Remembering; Seeing; Selfcare; Walking ▪ Government; Private; Employer; Self-employed; Voluntary; Unpaid; Producing goods for own consumption
Health & Nutrition	Baseline	▪ Number of health facilities ▪ Number of health professionals ▪ Number of inpatient beds	▪ Health centre; Dispensary; Aidpost ▪ Doctor; Midwife; Nurse aid; Nurse practioner; Registered nurse ▪ Dispensary; Health centre
	Prediction	▪ Damage	▪ Roof; Building; Bed

Cluster	Indicator Type	Indicator	Attributes
	Immediate Response	▪ Resources	▪ Medicines; Equipment; Mosquito nets; Number of health professionals; Tents
	Financial Recovery	▪ Assets	▪ Roof; Building; Bed
Logistics	Baseline	▪ Transportation infrastructure ▪ Number of Domestic carriers ▪ Number of transportation (land vehicle) ▪ Storage infrastructure	▪ Number of wharfs; Number of airports; Asphalt road (km); Concrete road (km); Gravel road (km); Number of bridges ▪ Ships; Planes; Boats ▪ Government; Private; Warehouses (for storing goods); Distribution hub (potential areas for distributing goods)
	Prediction	▪ Damaged carriers ▪ Damaged warehouse	▪ Ships; Planes; Boats ▪ Building; Roof
	Immediate Response	▪ Transport hire ▪ Building hire	▪ Private planes hire; Domestic ship hire; Boats (fibre glass) hire; Private truck ▪ Schools; Lodges; Community centres
	Financial Recovery	▪ Assets	▪ Ships; Planes; Boats
Shelter	Baseline	▪ Number of households ▪ Household size ▪ Number of appliances in working condition	▪ Private households; Institutions ▪ Below 6 members; 6 or more members ▪ TV; Freezer; Radio; Refrigerator
	Prediction	▪ Damaged households ▪ Damaged appliances	▪ Wall (permanent, semi-permanent, traditional); Roof ▪ TV; Freezer; Radio; Refrigerator
	Immediate Response	▪ Resources	▪ Tents/tarpaulin; Mosquito nets; Solar light/lanterns; Kitchen set; Jerrycan 10L; Hygiene kit; Sleeping mats; Blanket
	Financial Recovery	▪ Value (vatu)	▪ Household building (cost of permanent, semi-permanent, traditional) ▪ TV; Freezer; Radio; Refrigerator
Water, Sanitation & Hygiene	Baseline	▪ Household drinking water ▪ Household Toilet type ▪ Household water source	▪ Piped; Well; Tank ▪ Pit latrine; VIP; Flush; Water sealed ▪ Surface water (including springs); Groundwater

Cluster	Indicator Type	Indicator	Attributes
			(Boreholes & Wells); Rainwater Tank
	Prediction	▪ Damaged Drinking water ▪ Damaged Toilet type ▪ Damaged Toilet type ▪ Damaged water source	▪ Piped; Well; Tank ▪ Pit latrine; VIP; Flush; Water sealed ▪ Surface water (including springs); Groundwater (Boreholes & Wells); Rainwater Tank
	Immediate Response	▪ Resources	▪ Bottled water ▪ Tank
	Financial Recovery	▪ Value (vatu)	▪ Piped; Well; Tank ▪ Pit latrine; VIP; Flush; Water sealed; Rainwater Tank
Business Houses	Baseline	▪ Type of business ▪ Number of employees ▪ Total revenue	▪ Wholesale and retail trade; Accommodation and food services; Administration and support services; Agriculture, forestry and fishing; Construction; Real estate activities; Transport and storage; Electricity, gas, steam and air condition; Financial and insurance activities; Public administration and defence
	Prediction	▪ Damage	▪ Building; Stock or resources; Loss of operating days; Number of Disrupted employees
	Financial Recovery	▪ Value (vatu)	▪ Building; Resources; Business revenue (stimulus package); Wages
International Trade	Baseline	▪ Imports ▪ Exports	▪ Construction materials; Fuel; Rice; Noodles; Tined fish; Biscuits ▪ Cocoa; Copra; Fish: Tuna; Kava; Wood

2.2.3. *Management Information System- Integration & Visualisation of Project Outputs*

This MIS centralised platform for the collection, integration, analysis, and dissemination of critical data related to climate change and natural disasters, enabling more effective decision-making and resource allocation.

a) *Centralised Data Management:* consolidates data from various sources, including formats such as csv, json & shapefile.
b) *Dashboard:* visualisation tools within the MIS to support data driven decision-making.

c) *Integration and Interoperability*: ensure that the MIS integrates seamlessly with existing government systems and can exchange data with external systems and platforms through standardized APIs.

d) *Capacity Building and Sustainability:* build capacity of local government staff to use, maintain and adapt the MIS.

e) *Assessment & Co-creation:* engage with key stakeholders including VBoS, Disaster Statistics Technical Committee, Office of the Government Chief Information Officer among others, to ensure that the MIS design is responsive to the needs of all relevant parties.

f) *System Design:* develop a detailed system blueprint that outlines the architecture, data flows, user interfaces, and security protocols. Ensure that the design accommodates integration with existing systems, databases, and external data sources.

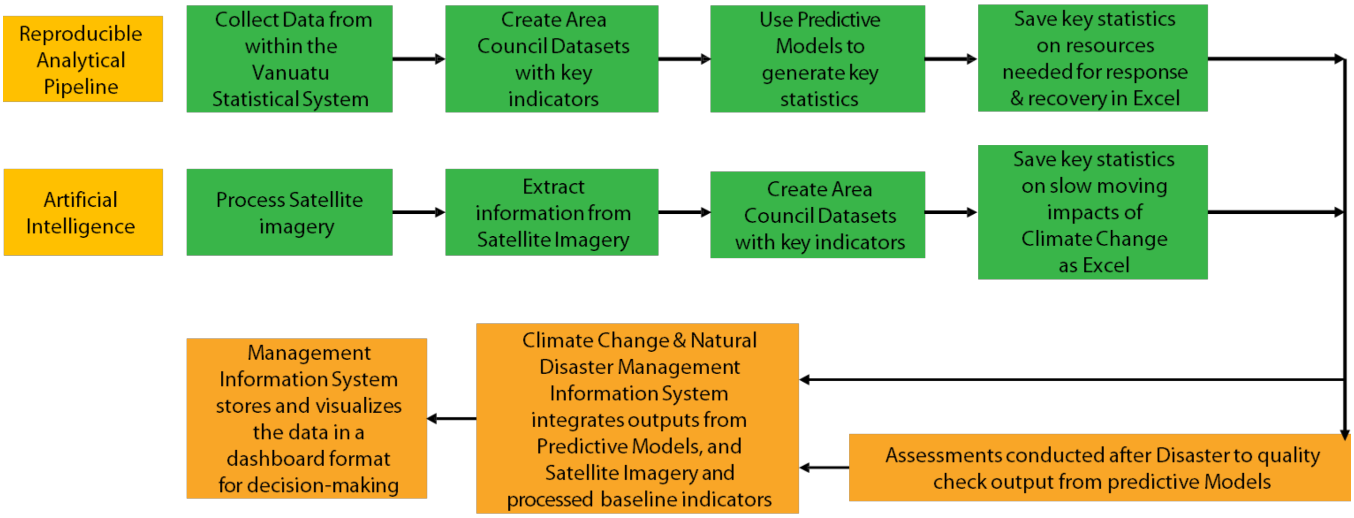
g) *System Development:* build the MIS according to the approved design, ensuring scalability, reliability, and user-friendliness. Integrate various data sources, including real-time and historical data related to climate change and natural disasters.

h) *User Training:* develop and deliver a comprehensive training programme for government staff and other key users of the MIS. Provide ongoing support and mentorship to ensure users can effectively use, maintain, and adapt the system. Develop manual that has all necessary information to use, maintain, and adapt the system.

i) *System Testing and Pilot Testing:* conduct rigorous system testing to identify and resolve any issues before full-scale deployment. Implement a pilot testing phase to evaluate the system's performance in real-world scenarios.

j) *System Improvement:* based on feedback from the pilot testing phase, make necessary adjustments and improvements to the system. Ensure the final system is fully operational and meets the project's objectives.

Figure 1: Climate Change & Natural Disaster System Flow Diagram (Outputs & Outcomes)



3. Results

3.1. Governance

The project has made significant progress, with five Steering Committee meetings and seven Disaster Statistics Technical Committee meetings successfully completed. The initiative has received strong support from key stakeholders, including the Minister of Climate Change, the Director General of Climate Change, who also serves as Chair of the Steering Committee as well as development partners and high commissions.

The Technical Committee has worked collaboratively within their respective departments, contributing valuable insights to the design and implementation of the project. Several key technical recommendations were put forward by the Committee and have been formally endorsed by the Steering Committee. These include:

i. The integration of all household disaster response cluster questionnaires into a single unified tool to reduce the burden on families after disasters

ii. A decision for the VBoS to partner with the National Disaster Management Office (NDMO) to conduct disaster assessments in affected areas

iii. The development of a formal policy to guide the establishment and implementation of the MIS, with ownership residing with the Ministry of Climate Change Adaptation.

iv. Additionally, the Steering Committee endorsed a recommendation to seek further funding to build on the project's success, including support for an application to the Government Investment Programme, backed by a Council of Ministers' decision.

3.2. Needs Assessment

The provincial assessment adopted a whole-of-Vanuatu approach, engaging ministries, development partners, community representatives, and the private sector to ensure the design of the innovations inclusive and responsive to the needs of all stakeholders. The consultations achieved strong representation across key provinces, with 88 participants in Shefa, 53 in Tafea, 31 in Sanma, and 42 in Malampa, reflecting a broad and diverse set of perspectives.

Through participatory workshops and SWOT analyses, the assessments identified sector-specific strengths, gaps, and opportunities across agriculture, gender and protection, health and WASH, logistics, shelter, education, communications, and local disaster committees.

Key strengths included strong community networks, existing emergency structures, and pre-established data systems like Vanuatu Education Management Information System. However, critical weaknesses emerged, including insufficient transport and funding, outdated or fragmented data systems, inadequate coordination, and limited technical capacity—particularly at the community level.

Opportunities lie in formalising logistics frameworks, upgrading infrastructure, enhancing training and communication systems, and expanding support for farmers.

Threats such as political interference, delayed responses, and information gaps underline the need for resilient, well-coordinated systems.

The analysis of the assessments helped inform key design principles for the MIS. Interoperability emerged as a core requirement to ensure the system can integrate seamlessly with existing data platforms and government systems.

User-centric design was emphasised to guarantee that the MIS is intuitive and accessible for all end-users, regardless of technical background.

Strong data security protocols were identified as essential to protect sensitive information, while also allowing for an open public-facing portal with tiered access to secure data requiring clearance.

The MIS will be developed using open-source software, enabling flexibility, cost-efficiency, and ease of future enhancements. Finally, the MIS will include advanced analytical tools, such as interactive dashboards, and automated reporting functions, to support evidence-based decision-making across all levels of government and partner agencies.

3.3. Machine Learning – Slow Moving Impacts of Climate Change

As part of the project's ML integration, several key programmes and partnerships have successfully advanced the use of artificial intelligence and Earth observation for climate and environmental monitoring in Vanuatu.

A flagship initiative to develop a machine learning model for land classification using over 2,000 georeferenced observations from the national Forest Inventory. The resulting model achieved an accuracy of 82%, enabling high-confidence mapping of land cover types to support land accounting and policy decision-making.

A 12-month ML training programme led by Development Seed began in November 2024, featuring intensive two-hour sessions every fortnight.

A stakeholder workshop helped define a standardised set of climate change indicators. Modules include an introduction to satellite remote sensing, land and water classification (including flood and road mapping), agricultural productivity monitoring (focused on soil health and water retention), coastal environmental monitoring (such as erosion, sea level rise, and coral reef health), and climate trend analysis (including accumulated rainfall, drought, and land/sea surface temperature). The outputs are directly linked to the Management Information System (MIS) for real-time visualisation in platforms like QGIS and structured data tables.

To support regional sustainability, a strategic partnership was also established with Digital Earth Pacific (DEP), allowing the integration of all training content and ML models into the DEP and VBoS GitHub repositories for open access. DEP's analytical tool connects to free, continuously updated historical satellite imagery at 10m resolution and allows real-time geospatial analysis similar to the RAP system.

All machine learning activities were conducted using open-source Python workbooks, ensuring transparency, adaptability, and replicability. These workbooks were developed in alignment with international best practices and tailored to Vanuatu's context using freely available satellite imagery and locally validated training data. The notebooks are designed to be modular and user-friendly, enabling easy adaptation for other Pacific Island countries.

As part of the regional knowledge-sharing strategy, all code, documentation, and training materials will be made publicly available through the Vanuatu Bureau of Statistics and the Pacific Community (SPC) GitHub repositories. This approach supports regional capacity building and allows other Pacific national statistics offices to adopt and localise similar methodologies for land classification, climate monitoring, and disaster risk analysis.

Indicator	**Potential Impact**
Land Cover	Measuring land cover enables better land-use planning, environmental monitoring, and resource allocation by identifying patterns of deforestation, urban expansion, and agricultural activity
Flooding	Mapping flood extent in near real-time supports rapid emergency response, infrastructure planning, and risk mitigation, helping protect vulnerable communities and allocate relief resources more effectively.
Roads	Identifying and mapping road networks ensures up-to-date transport infrastructure data, supporting logistics planning, disaster response, and maintenance prioritization for remote and underserved areas.
Soil Health	Monitoring soil health informs sustainable agricultural practices by identifying areas of erosion, degradation, or fertility loss, enabling targeted interventions to improve food security and rural livelihoods.
Water Retention	Understanding landscape water retention capacity helps in planning for flood control, irrigation, and ecosystem services, improving resilience in agriculture and water resource management.
Coral Reefs	Tracking changes in coral reef extent and condition supports marine conservation, sustainable fisheries, and coastal tourism strategies, helping protect biodiversity and livelihoods dependent on reef ecosystems.
Sea Level Rise	Monitoring shoreline changes and sea level rise provides essential evidence for climate adaptation planning, including relocation strategies, infrastructure protection, and coastal zone management.
Coral Reef Health	Measuring coral reef health enables early detection of bleaching and degradation, supporting timely restoration efforts and the long-term sustainability of marine ecosystems.
Rainfall	Satellite-based rainfall estimates improve drought and flood preparedness, agricultural planning, and water resource management by filling gaps in ground-based monitoring networks.
Surface Temperature Trends	Tracking land and sea surface temperature trends enables governments to detect climate change impacts over time, guiding policy in sectors like health, energy, agriculture, and urban planning.

3.4. Reproducible Analytical Pipelines – Estimating impact of Cyclone, and Resources Needed for Response & Recovery

Significant progress has been achieved in building RAPs to support disaster preparedness and response in Vanuatu. As part of the data collection and preparation process, eleven geospatial datasets were gathered, processed, and mapped, with population density used as the base reference layer to assess vulnerability and exposure. In parallel, fourteen administrative datasets, population & agricultural data from the 2020 Population

Census and the 2022 Agricultural Census, were cleaned and processed—resulting in over 46,000 rows of baseline indicators covering key development and disaster response metrics.

To enable predictive analysis, baseline data was projected into future years using population growth rates and agricultural trends. Sector specialists collaborated to define multiplying factors—specific decimal values reflecting expected damage levels from different disaster intensities (e.g., Category 3, 4, or 5 cyclones or volcanic eruptions).

These were grounded in historical experience and used to estimate the expected damage to critical assets such as crop yields or household structures. These factors were embedded in the RAP code to generate rapid, evidence-based estimates of disaster impact.

A dedicated component is being incorporated into the upcoming revision of the National Accounts framework to assess the macroeconomic impact of disasters—positioning Vanuatu to become the first Pacific Island country to embed disaster shock analysis into its national accounts system.

Each sectoral disaster cluster—ranging from education, emergency telecommunications, food security and agriculture, to newer additions like business houses and international trade—is addressed in the report. Every cluster contains baseline data, damage prediction logic, response resource calculation, and recovery cost estimates.

To enhance quality and reproducibility, an international consultant was hired to develop the report using Quarto, an open-source publishing framework that builds on RMarkdown to produce high-quality, interactive, and version-controlled outputs. The consultant is working closely with VBoS staff to strengthen in-house capacity to use Quarto, with skills transferable to other official statistical products.

The RAP-based report is scheduled for completion in July 2025, representing a significant innovation in how Vanuatu integrates real-time data and predictive modelling into national disaster risk management.

Cluster	Potential Impact
Education	Admin data from Ministry of Education to map school infrastructure, teacher numbers, and student enrolment by ECCE, Primary, and Secondary levels. Predicts damage to roofs, buildings, and water/gas systems using cyclone data, and estimates emergency needs like tents, lamps, food, and water. Financial modelling calculates the cost of damaged assets to support recovery planning. Outputs guide rapid assessments, logistics, and budget forecasting, and are integrated into the MIS for cross-sector coordination.
Emergency Telecommunications	Admin data from Digicel & Vodafone to map tower locations and structures Predict damage using hazard data, and estimates emergency equipment needs. Calculate recovery costs to support funding and ensure communication continuity for disaster coordination. Outputs are integrated into the MIS and aligned with NDMO and Emergency Operations Centres.
Energy	Admin data from Utilities Regulation Authority and 2020 Population and Housing Census (estimation 2025) Map household energy access and critical infrastructure. It forecasts damage from wind hazards and estimates immediate restoration needs. The pipeline also models recovery costs, prioritizing emergency lighting and cold storage.
Food Security	Data from 2022 Agricultural Census, baseline data maps crop, fishery, and timber activity. RAP predicts cyclone-related damage to crops and gear, estimates emergency inputs (e.g., planting kits), and models economic losses for financial support. Coordination includes Agriculture, FAO, and Fisheries departments, with outputs linked to Nutrition and WASH clusters in the MIS
Gender & Protection	Data from the 2020 National Population & Housing Census, focuses on pre-disaster sociodemographic mapping, identifying vulnerable groups (e.g., women, disabled, elderly) and support needs.

Cluster	Potential Impact
	While it does not model physical damage, it guides social protection interventions and informs gender-inclusive services. Coordination spans Protection, Shelter, and WASH clusters, feeding into MIS dashboards.
Health & Nutrition	Data from Ministry of Health, maps health facilities and staffing, predicts damage to buildings and infrastructure, and estimates immediate supply needs. It models replacement costs to inform PDNAs and health budgets. Outputs support Ministry of Health, WHO, and aid partners, with MIS integration for service disruption tracking.
Logistics	Data from 2020 National Population & Housing Census, and administrative data from Department of Ports & Harbours. Maps transport and storage infrastructure and predicts disruptions using hazard overlays. It estimates transport hire needs and models asset recovery costs.
Shelter	Data from 2020 National Population & Housing Census. Estimates housing types and shelter demand, predicts damage to structures and appliances, and calculates emergency supply needs.
WASH	Data from 2020 National Population & Housing Census, baseline data maps water sources and sanitation. Forecasts damage and contamination risks, estimates emergency supply needs, and models recovery investments.
Business Houses	Data from Business Registry, administrative data from Department of Customs and Inland Revenue Maps business activity by sector and size, predicts disruptions, and estimates lost operating time and workforce impacts.
International Merchandise Trade	Administrative data from Department of Customs uses trade and customs data to establish baselines and predict port disruptions. It models import delays and export shortfalls and estimates revenue losses.

3.5. Management Information System – Integration of Project Outputs

Software and Hardware Preferences	**Technology Stack:** open-source software to ensure cost-effectiveness, flexibility, and ease of customisation. **Hardware**: system operate efficiently within the existing hardware infrastructure of the government, with provisions for scalability
Database Design	**Optimized Data Storage and Indexing:** efficient database structures with proper indexing to allow for rapid retrieval of data. **Efficient Data Querying:** Optimize queries and ensure that data is pre-aggregated or cached when possible, reducing the need for real-time computations during dashboard loading. **Scalable Infrastructure:** scalable infrastructure, to handle varying loads and ensure fast access times regardless of the number of concurrent users.
Data Requirements	**Data Formats:** capable of handling multiple data formats, including but not limited to: CSV (Comma-Separated Values) for structured data; Shapefiles for geographical and spatial data; JSON (JavaScript Object Notation) for data interchange and integration with web services.
Integration	**System Integration:** integrate seamlessly with existing government systems, databases, and third-party APIs. **APIs:** enable data exchange between the MIS and other relevant systems such as maps, ensuring interoperability and efficient data management.

Dashboard	**One-Page Layout (No Scrolling):** entire dashboard displayed on a single page to ensure users can view and interact with all elements without the need to scroll. **Filter Panel:** dedicated filter panel to dynamically adjust the data displayed on the dashboard. Filters include options such as date ranges, geographic areas, and specific indicators, enabling tailored views of the data. **Central Map:** A large, interactive map support zooming and panning for detailed exploration. Hovering over specific areas on the map trigger tooltips displaying key indicators related to that area. Clicking on an area bring up more in-depth tables and additional information. **Charts and Graphs:** several bar charts and line graphs display key indicators in a visually compelling manner. The charts update automatically based on the selected filters and the area chosen on the map. **In-Depth Tables:** displaying detailed interactive tables with in-depth data, allowing users to sort, filter, and explore data directly within the dashboard. **Intuitive and User-Centric Design:** ensure that it is accessible to a broad range of users, including non-technical staff. The dashboard should be intuitive, with clear navigation and minimal training required for effective use.
Security Requirements	**Security:** Given the sensitivity of some data and the critical nature of the MIS in disaster response and management, the system must adhere to the highest security standards. **Access Control:** Different levels of access must be granted based on user roles, with access managed through secure passwords and other authentication methods.
Sustainability Training	**System Architecture and Integration:** train staff on the overall architecture of the MIS. Provide guidance on maintaining and adapting the open-source software stack, ensuring compatibility with the government's server infrastructure. **Database Management and Optimization:** educate staff on efficient database design, including data storage, indexing, and query optimization to ensure fast data retrieval.

4. Discussion

Project has demonstrated that strong governance, inclusive consultation processes, and innovative data science methodologies can significantly improve the way Vanuatu prepares for and responds to natural disasters and climate change.

Convening of Steering Committee and Technical Committee meetings ensured that the design and implementation of the project remained anchored in national priorities and informed by a wide cross-section of stakeholders.

Endorsement of key policy and operational recommendations such as the unification of disaster assessment tools and the integration of the VBoS into field assessments marks a critical shift toward institutionalising data-driven disaster response through a centralised MIS.

Nationwide needs assessment process further affirmed the importance of a whole-of-country approach. The high participation rates across provinces and sectors underscored the broad demand for a system that is interoperable, user-friendly, secure, and open source.

Findings from participatory assessments provided a nuanced understanding of local strengths and weaknesses, which were directly translated into the MIS design principles. These include enabling seamless integration with existing platforms, applying strict data security protocols, and incorporating analytical tools that support decision-making across ministries and disaster clusters.

Major innovation of this project lies in its application of machine learning and earth observation data to monitor slow onset impacts of climate change. The development of an 82% accurate land classification model using national forest inventory data showcases the potential of AI to provide reliable, granular, and scalable environmental intelligence.

Capacity-building partnership with Development Seed, coupled with the integration of training content into DEP and open GitHub repositories, not only strengthened local technical capacity but also contributed to regional knowledge sharing. These open-source machine learning workbooks ensure that tools developed in Vanuatu can be replicated and adapted by other Pacific Island countries.

Machine learning outputs ranging from flooding and road mapping to soil health and coral reef monitoring, offer critical insights for climate adaptation and disaster resilience. Importantly, these indicators have direct operational value; for example, satellite-based flood extent mapping can guide the allocation of relief resources, while surface temperature trends support long-term planning in health, agriculture, and infrastructure.

Embedding these outputs into the MIS, the system becomes a powerful tool not only for response, but also for early warning and long-range planning.

The development of RAPs represents a transformative step in Vanuatu's disaster risk management capacity. Automating the estimation of disaster impacts using sector-specific multiplying factors, these pipelines can generate rapid assessments of damage and recovery needs, drastically reducing the time between a disaster event and the mobilisation of response efforts.

The RAPs are grounded in rich geospatial and administrative datasets—over 46,000 baseline indicators were processed—and calibrated using the 2020 Population and 2022 Agricultural Census data. This approach ensures that projections are tailored to Vanuatu's context and aligned with national development planning.

The planned integration of disaster impact modelling into the national accounts system also represents a pioneering move in the Pacific region, enabling governments to quantify the macroeconomic consequences of disasters and advocate for better-targeted investments and aid.

Finally, the integration of all project components into a unified, secure, and user-friendly MIS will institutionalise the gains achieved. The dashboard design prioritises accessibility, with features such as a single-page layout, dynamic filtering, and interactive maps and charts, ensuring that information is readily available to decision-makers.

Ongoing training and sustainability planning will ensure that government staff are equipped to maintain and evolve the system beyond the life of the project.

5. Conclusion

Combining participatory governance, state-of-the-art data science methods, and system-wide integration has demonstrated that small island states can harness advanced technologies to strengthen resilience and improve public service delivery.

The project's success was anchored in strong institutional leadership, with cross-sectoral collaboration facilitated through the Steering and Technical Committees.

The development of a centralised, open-source MIS stands as a key outcome of the project. Built on principles of interoperability, user-centred design, and robust security, the MIS will enable faster and more coordinated responses to disasters, while also serving as a planning tool for climate adaptation.

The integration of ML models and satellite imagery has added new capabilities to Vanuatu's toolkit, ranging from real-time mapping of environmental changes to predictive modelling of disaster impacts.

The creation of RAPs has operationalised these data innovations, allowing for rapid damage assessments, estimation of recovery needs, and uniquely economic impact analysis within the national accounts framework. These innovations are not only relevant for Vanuatu but have regional significance, with open-source tools and training materials designed to be adopted by other Pacific Island countries.

The project has already demonstrated that through inclusive design and technological innovation, Vanuatu is setting a new benchmark for how small island developing states can lead in disaster preparedness, climate monitoring, and evidence-based decision-making.

6. Recommendations

a) Institutionalise the MIS within Government Structures

i. Formalise the MIS under the leadership of the Ministry of Climate Change Adaptation, ensuring clear ownership, governance, and sustainability.

ii. Develop a comprehensive MIS policy and standard operating procedures to guide its use across all relevant ministries and disaster clusters.

iii. Embed MIS operations into national planning, budgeting, and disaster response protocols to ensure long-term adoption and relevance.

b) Strengthen National Capacity for ML and Satellite Analytics

i. Continue investment in hands-on training for VBoS staff and sectoral stakeholders in open-source tools such as Python, QGIS, and DEP.

ii. Establish a permanent data science and remote sensing unit within VBoS to institutionalise expertise and support the government's broader digital transformation.

iii. Collaborate with regional partners to update training materials, facilitate peer learning, and ensure ongoing access to technical assistance.

c) Expand and Maintain RAPs

i. Scale up the RAP system to cover all key disaster clusters, including business houses and international trade, with regular updates based on new census, administrative, and geospatial data.

ii. Develop a structured maintenance plan for RAPs, including regular data refresh schedules, version control, and quality assurance.

iii. Integrate RAP outputs into emergency response protocols and post-disaster needs assessments (PDNAs) to reduce response time and enhance decision-making.

d) Regionalise and Share Tools Across Pacific Island Countries

i. Publish all machine learning models, training data, RAP code, and documentation on VBoS and SPC GitHub repositories.

ii. Organise regional workshops and South-South exchanges to help other Pacific NSOs adopt, localise, and expand on Vanuatu's methodologies.

iii. Advocate for regional donor support to sustain and scale open-source satellite analytics tools, building on the proven success of the DEP partnership.

e) Invest in System Integration and Data Governance

i. Ensure full interoperability between the MIS and other national platforms (e.g., education, health, agriculture, disaster management) through the development of secure, well-documented APIs.

ii. Establish data sharing agreements and access protocols that define responsibilities, ensure privacy and security, and promote timely data flows between agencies.

iii. Promote open data where feasible, while maintaining layered access for sensitive datasets, to foster transparency and wider data use by communities and partners.

f) Improve Use of Climate Indicators for Policy and Planning

i. Formalise the use of the project's climate indicators (e.g., land cover, flooding, coral reef health, soil moisture, rainfall) in national monitoring frameworks and climate adaptation policies.

ii. Align these indicators with national and regional climate strategies, including NDCs (Nationally Determined Contributions) and the Sendai Framework for Disaster Risk Reduction.

iii. Use these indicators in sectoral policy dialogues such as agriculture, infrastructure, tourism, and health to mainstream climate resilience into national development.

g) Ensure Sustainability through Continued Investment and Local Ownership

i. Mobilise additional resources through the Government Investment Programme (GIP), Green Climate Fund, and other climate finance channels to sustain and expand the system.

ii. Encourage leadership from government Ministers, Director Generals, Directors and senior managers to champion the use of data in policy and emergency response.

iii. Create a roadmap for transferring ownership of technical systems and processes to local institutions by the end of the project lifecycle, supported by ongoing mentoring and knowledge transfer.

7. Lessons Learned

Activity	Challenge	Lesson
Cross-Ministerial Coordination Requires Ongoing Engagement and Political Backing	Coordinating activities across ministries, clusters, and technical stakeholders initially faced delays due to competing priorities, unclear mandates, and institutional silos.	Strong political leadership, particularly from the Director General of Climate Change as Chair of the Steering Committee was critical to aligning stakeholders and maintaining momentum. Early and continuous engagement of key ministries ensured ownership and sustained participation.
Building Technical Capacity Requires Time, Mentorship, and Practical Application	Limited local experience with machine learning, remote sensing, and open-source programming tools slowed the uptake of advanced methods.	Partnering with global technical organisations like Development Seed provided essential hands-on training. Staggered training programmes, localised case studies, and integration into real projects (e.g., land classification, disaster impact prediction) significantly improved learning outcomes and built confidence among staff.
Data Fragmentation and Legacy Systems Can Undermine Integration	Baseline data was scattered across different formats, institutions, and systems, many of which were outdated or not interoperable.	The adoption of interoperable, open-source standards from the outset, along with extensive data cleaning and harmonisation efforts, was crucial to building a centralised MIS.
Open-Source Tools Are Powerful but Require Dedicated Support for Sustainability	While open-source tools like Quarto, R, Python, and QGIS provide flexibility and cost savings, they also require ongoing internal expertise to maintain and adapt.	Investments in reproducible workflows (e.g., RAPs), clear documentation, and GitHub repositories helped ensure sustainability. Hiring external consultants to mentor local teams during the development process was an effective bridge until in-house capacity was fully established.
Complex Technical Outputs Need Simple, User-Friendly Interfaces	While the MIS contained powerful analytical tools, users with limited technical backgrounds initially found it difficult to navigate and interpret results.	Co-designing dashboard features with non-technical users such as provincial planners and disaster response teams ensure that visualisations, filter panels, and summary tables are intuitive and actionable. User testing and iterative refinement of dashboard design was key.
Disaster Response Is Time-Sensitive Automated Tools Must Be Tested Ahead of Time	Manual disaster assessments were time-consuming and resource-intensive, making rapid response difficult during actual emergencies.	Developing and testing automated estimation tools (like RAPs) in advance, including mock simulations (e.g., cyclone impact on taro and kumala production), demonstrate their potential to speed up decision-making. Pre-defining sector-specific multiplying factors and linking them to census and geospatial data essential for this success.

Activity	Challenge	Lesson
Regional Impact Depends on Sharing, Not Just Building	Tools developed in-country often remain underutilised regionally due to lack of visibility or local customisation barriers.	Publishing all models, training material, and code through open platforms (VBoS and Digital Earth Pacific GitHub) ensured accessibility. Aligning training content with regional priorities (e.g., land use, climate indicators) and maintaining open communication with SPC, UNESCAP, and Pacific NSOs enhanced regional relevance and scalability.
Institutionalising Innovation Requires Long-Term Vision and Funding	Innovations often face the risk of being one-off pilots unless anchored in national systems with long-term funding.	Embedding the MIS within Ministry of Climate Change and Adaptation, securing Steering Committee endorsement, and applying to the Government Investment Programme (GIP) were vital steps toward institutionalisation. Future donor engagement should be aligned with these national frameworks to ensure continuity and scale.