ORAL PRESENTATIONS

Research Presentations by Thematic Stream

The oral presentation collection is organized across five RCSS 2026 research streams.

- **A** Agriculture & Food Systems
- **B** Climate Data & Monitoring Systems
- **C** Urbanization, Infrastructure & Energy
- **D** Nature-Based Solutions & Ecosystems
- **E** Health–Climate Nexus



AGRICULTURE & FOOD SYSTEMS

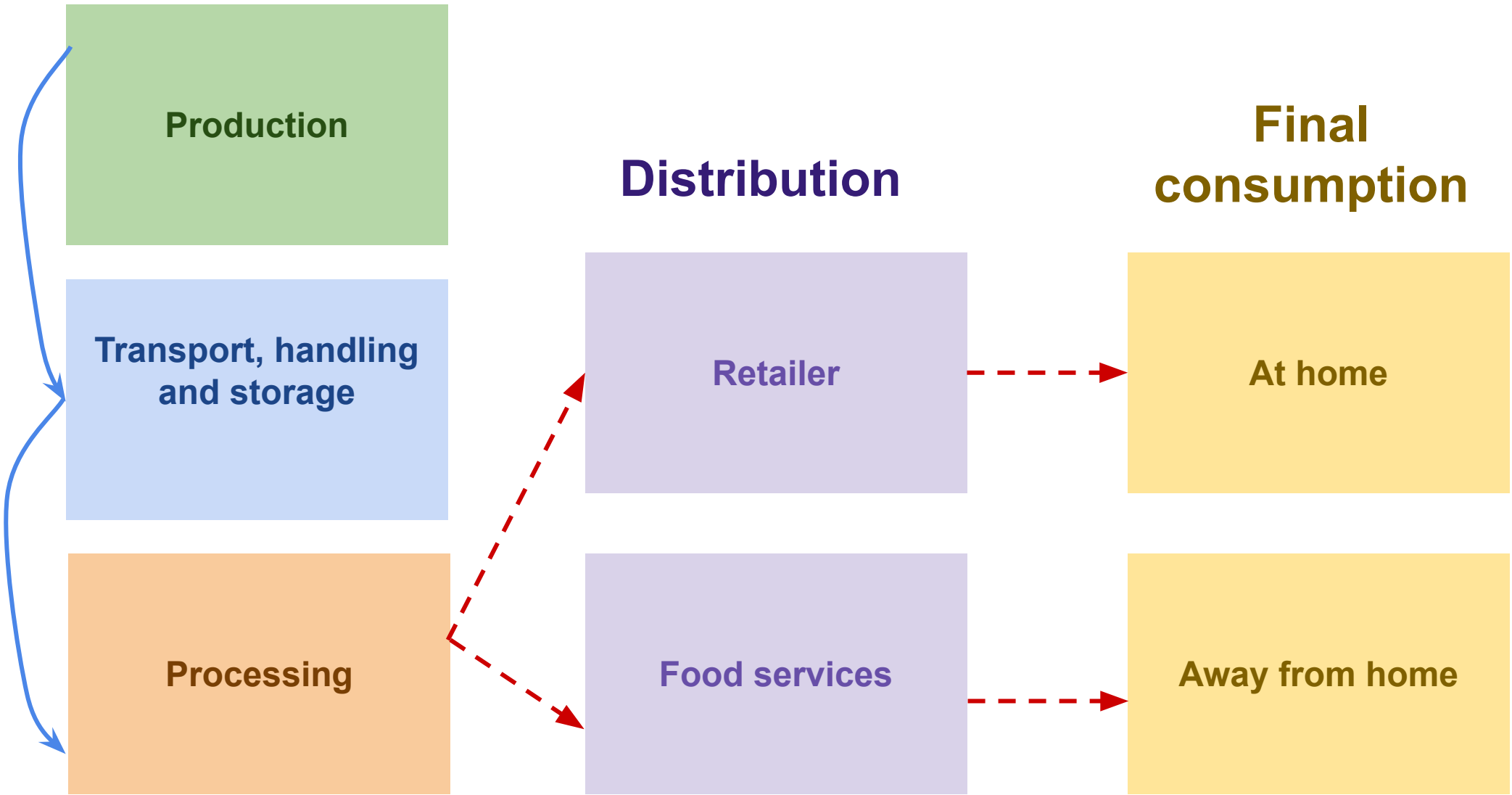
A Progressive Approach Towards Postharvest Loss Reduction

Audrey Demafo
PhD candidate

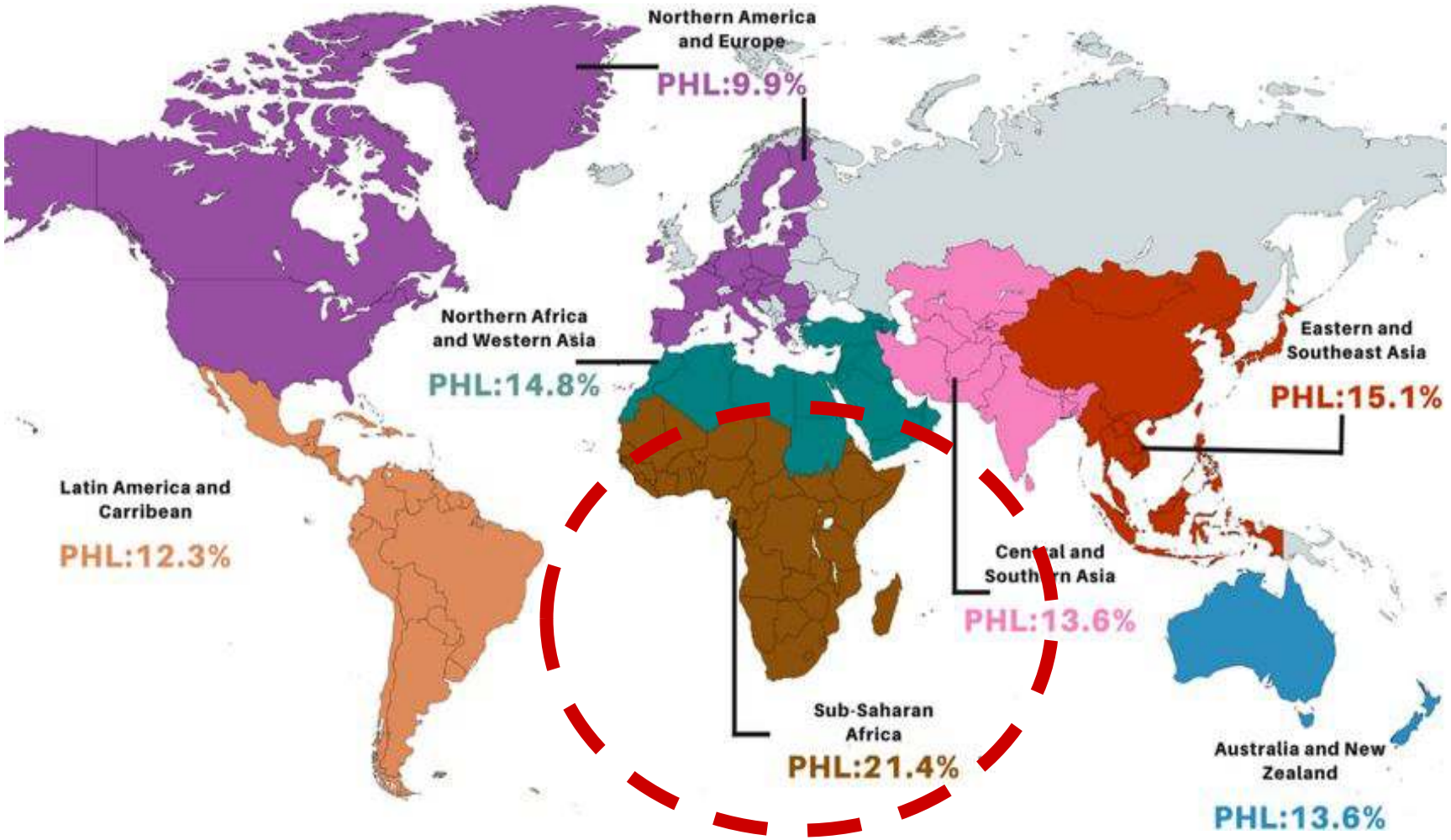
University of Rwanda / AIMS-Rwanda

DAAD Deutscher Akademischer Austauschdienst German Academic Exchange Service
AIMS African Institute for Mathematical Sciences RWANDA
Alexander von Humboldt Stiftung/Foundation
Federal Ministry of Education and Research

Food Supply Chain



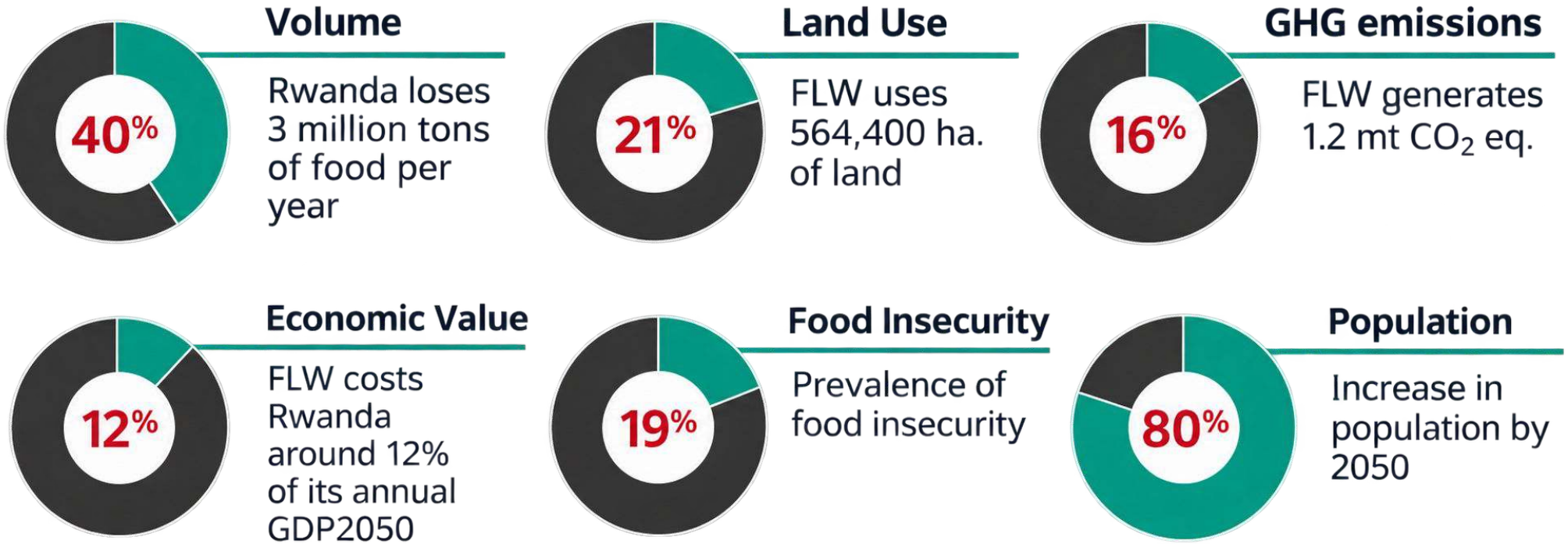
PHL per region



- Nearly 30% of global food production is lost or wasted between production and consumption.
- Postharvest loss is higher in sub-Saharan Africa compared to other regions on the globe.
- Losses in developing countries are prominent at pre-consumption stages.

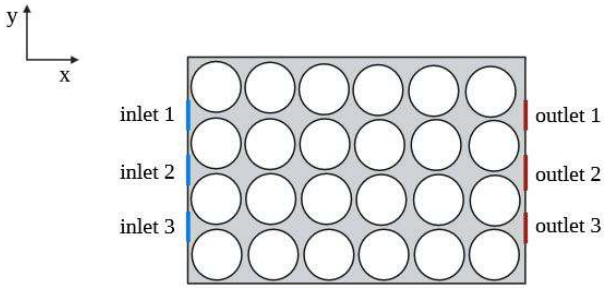
Figure 1: Postharvest loss percentage per region in the globe [1]

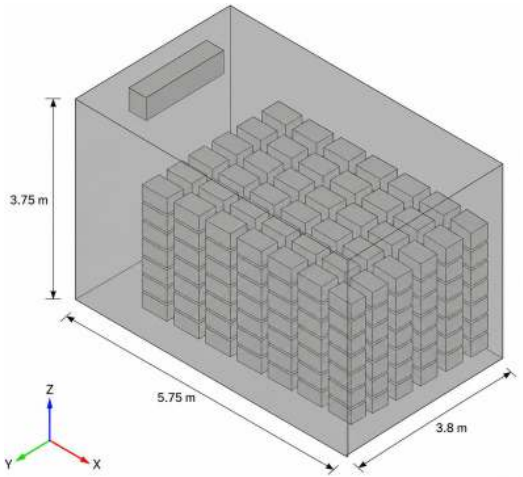
The Rwandan Context

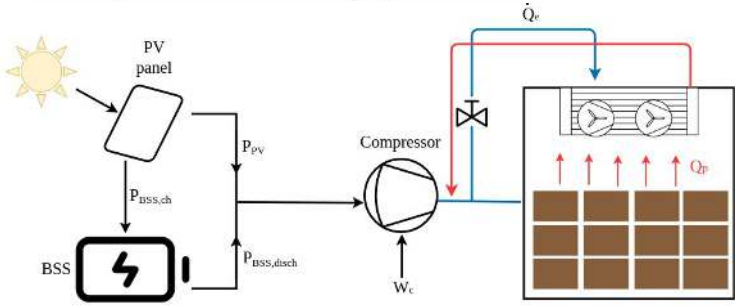


Sources: USAID 2018; World Bank Open Data; WRI CAIT Climate Data Explorer; World Food Program, 2018; UN Population Prospects; and WB calculations

The progressive approach







1 Crate design

- Proposed two crate configurations with different ventilation scenarios.
- Conducted numerical experiments to analyse cooling rate in each venting scenario across the two configurations.

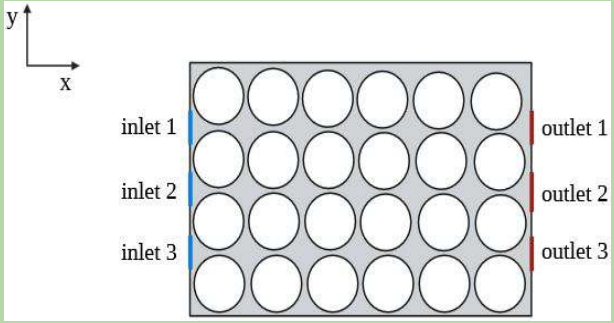
2 Cold room configuration

- Studied the effect aisle location in a cold room relative to a wall-mounted evaporator
- Analyse the effect of the proposed configurations on cooling uniformity.

3 System optimization (ongoing)

Design an optimal energy management system for a solar-powered cold room while preserving produce quality

Methodology



Model variables

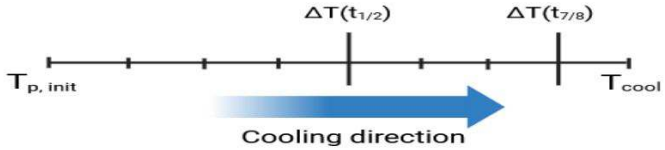
- Crate air temperature T_a(℃)
- Local air velocity u (m/s)
- Produce temperature T_p(℃)

1. Half-cooling time (HCT): corresponds to the time when the temperature difference between the products and the cooling medium reaches half of its initial value:

$$\Delta T(t_{1/2}) = \frac{1}{2}(T_{p,init} - T_{cool}).$$

2. Seven-eights cooling time (SECT): corresponds to the time when the temperature difference between the products and the cooling medium reaches $1/8^{th}$ of its initial value:

$$\Delta T(t_{1/8}) = \frac{1}{8}(T_{p,init} - T_{cool}).$$



- Airflow pattern is modeled using the continuity equation and the Navier Stokes equations:

$$\begin{cases} \dfrac{\partial \rho_a}{\partial t} + \mathrm{div}(\rho_a \boldsymbol{u}) = 0, \\ \rho_a \dfrac{\partial \boldsymbol{u}}{\partial t} + \rho_a(\boldsymbol{u} \cdot \nabla \boldsymbol{u}) = -\nabla \boldsymbol{p} + \nabla \cdot [\mu_a(\nabla \boldsymbol{u}) + (\nabla \boldsymbol{u})^T] \\ \qquad\qquad +\text{Boundary Conditions} \end{cases}$$

- Air and produce temperature are modeled as follows:

$$\begin{cases} \rho_a c_{p,a} \dfrac{\partial T_a}{\partial t} + \rho_a c_{p,a}(\boldsymbol{u} \cdot \nabla T_a) = \nabla \cdot (k_a \Delta T_a), \\ \rho_p c_{p,p} \dfrac{\partial T_p}{\partial t} = \nabla \cdot (k_p \Delta T_p), \\ \qquad\qquad +\text{Boundary Conditions} \end{cases}$$

Key results … Airflow and temperature distribution

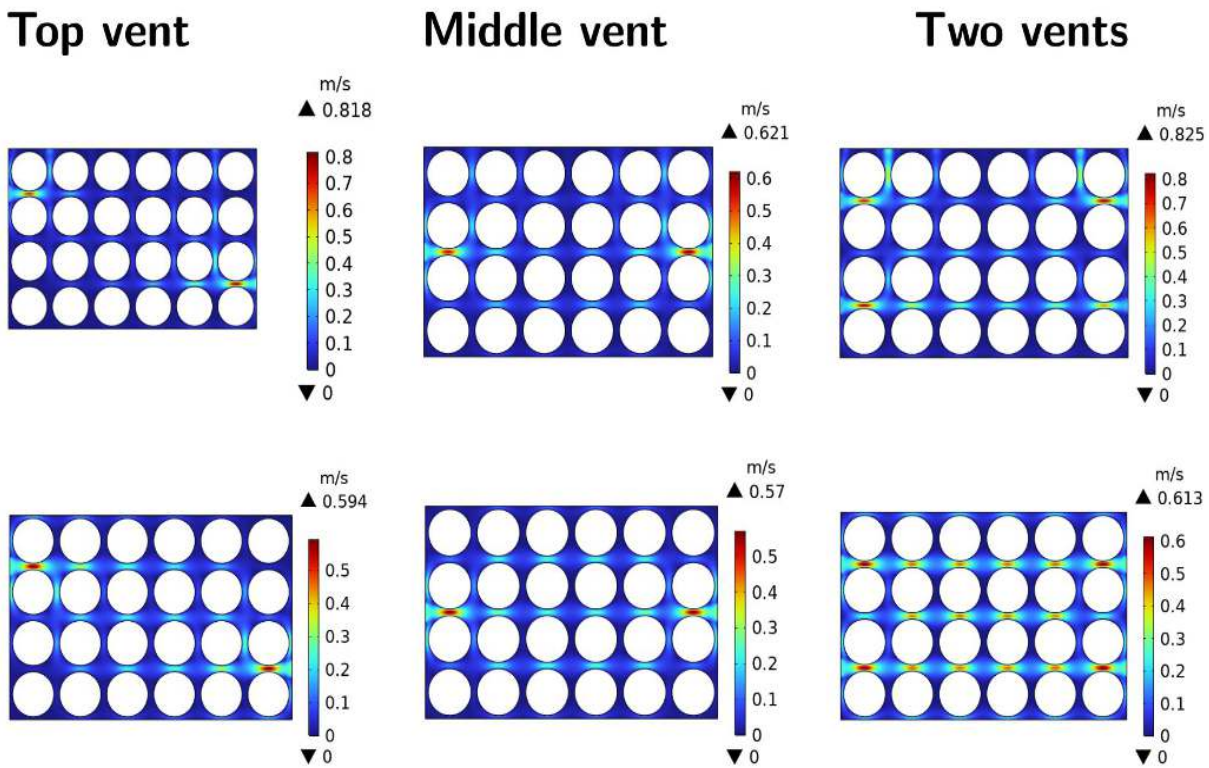


Figure 2: Airflow distribution across the two package design: first row (open top); second row (insulated top)

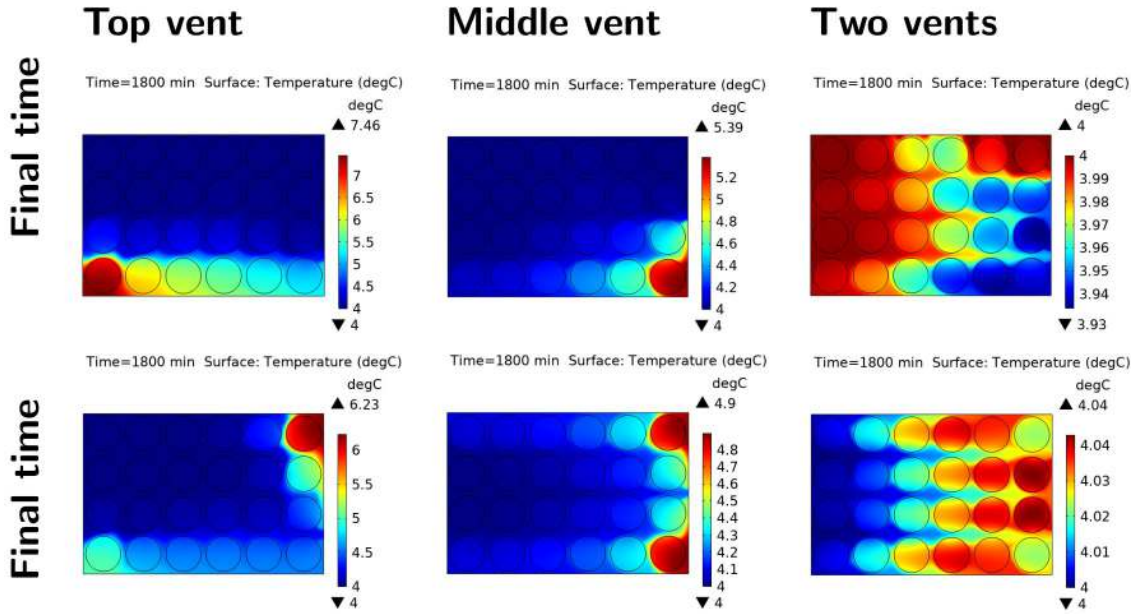


Figure 3: Temperature distribution across the two package designs: first row (open top); second row (insulated top)

Key results … cooling metrics

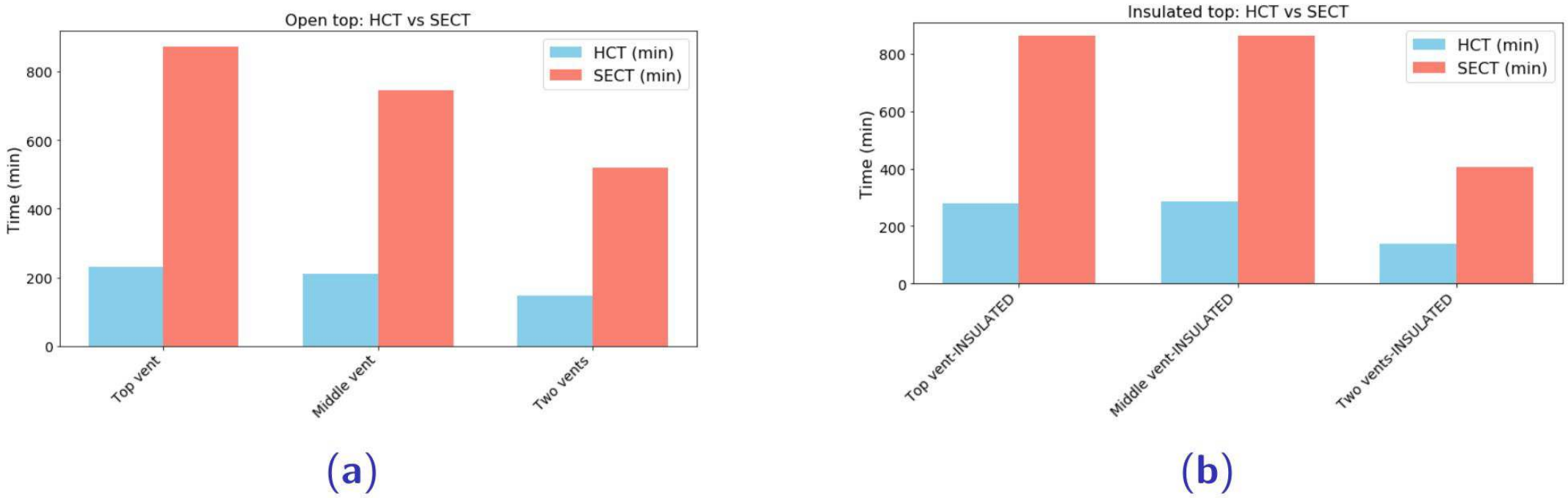
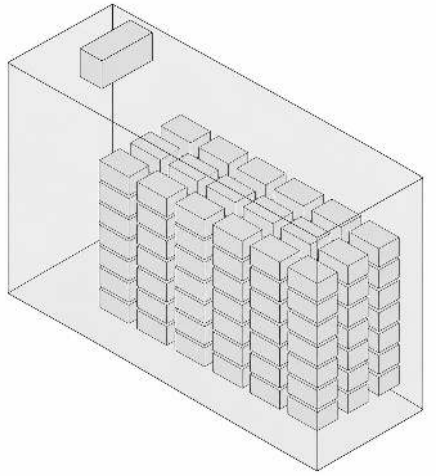


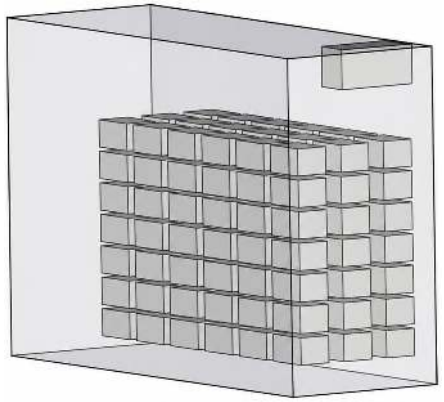
Figure 4: Half cooling time and seven-eighths cooling time for all package~configurations.

Study scope

1



2



3

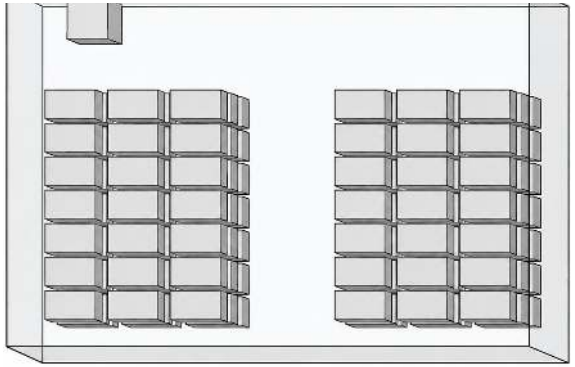


Figure 5: Half cooling time and seven-eighths cooling time for all package~configurations.

- **Objective:** study the effect of the position of the loading aisle relative to a wall-mounted evaporator on the cooling performance of stored apples in a medium-sized cold room.
- **Proposed configurations:** three discrete configurations (1) evaporator and aisle on the same wall (baseline), (2) evaporator on the wall opposite the aisle, (3) evaporator at one end with the aisle centrally located, splitting the crates into two banks.
- **Variables of interest:** velocity and temperature fields, per-crate cooling curves, the distribution of final crate temperatures (histograms), and a temperature heterogeneity index (standard deviation of crate temperatures across the load) evaluated over time.
- **Key finding:** the aisle-evaporator configuration has a limited effect on the *average* cooling rate but a substantial effect on cooling *uniformity* — the central-aisle configuration achieved the most uniform cooling, reducing final heterogeneity by ~39% relative to the baseline.

Key results

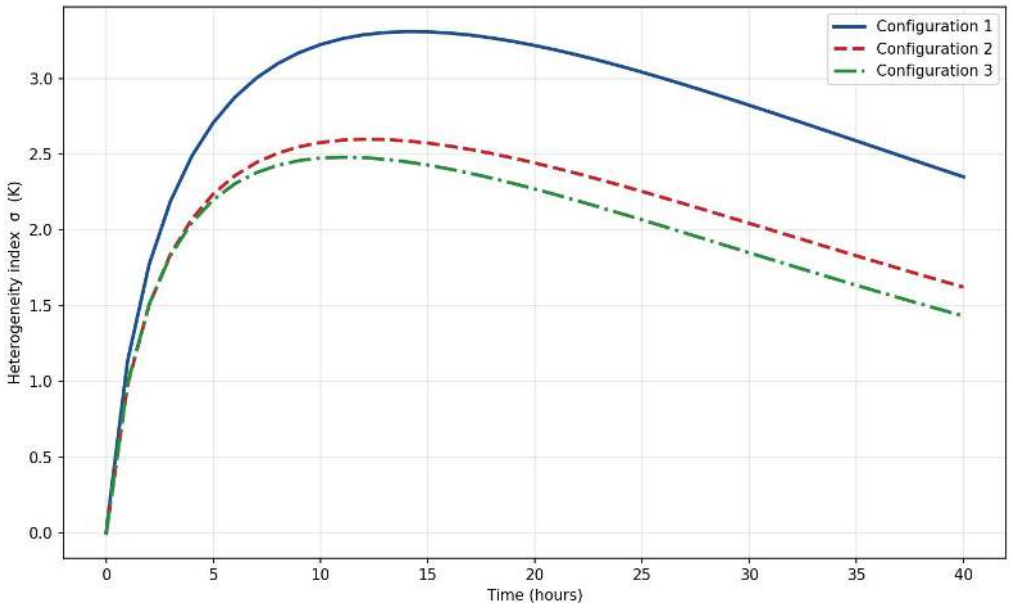


Figure 6: Heterogeneity index across all three configurations

Configurations	initial heterogeneity	final heterogeneity
conf 1	3.3℃	2.35℃
conf 2	2.6℃	1.62℃
conf 3	2.5℃	1.43℃

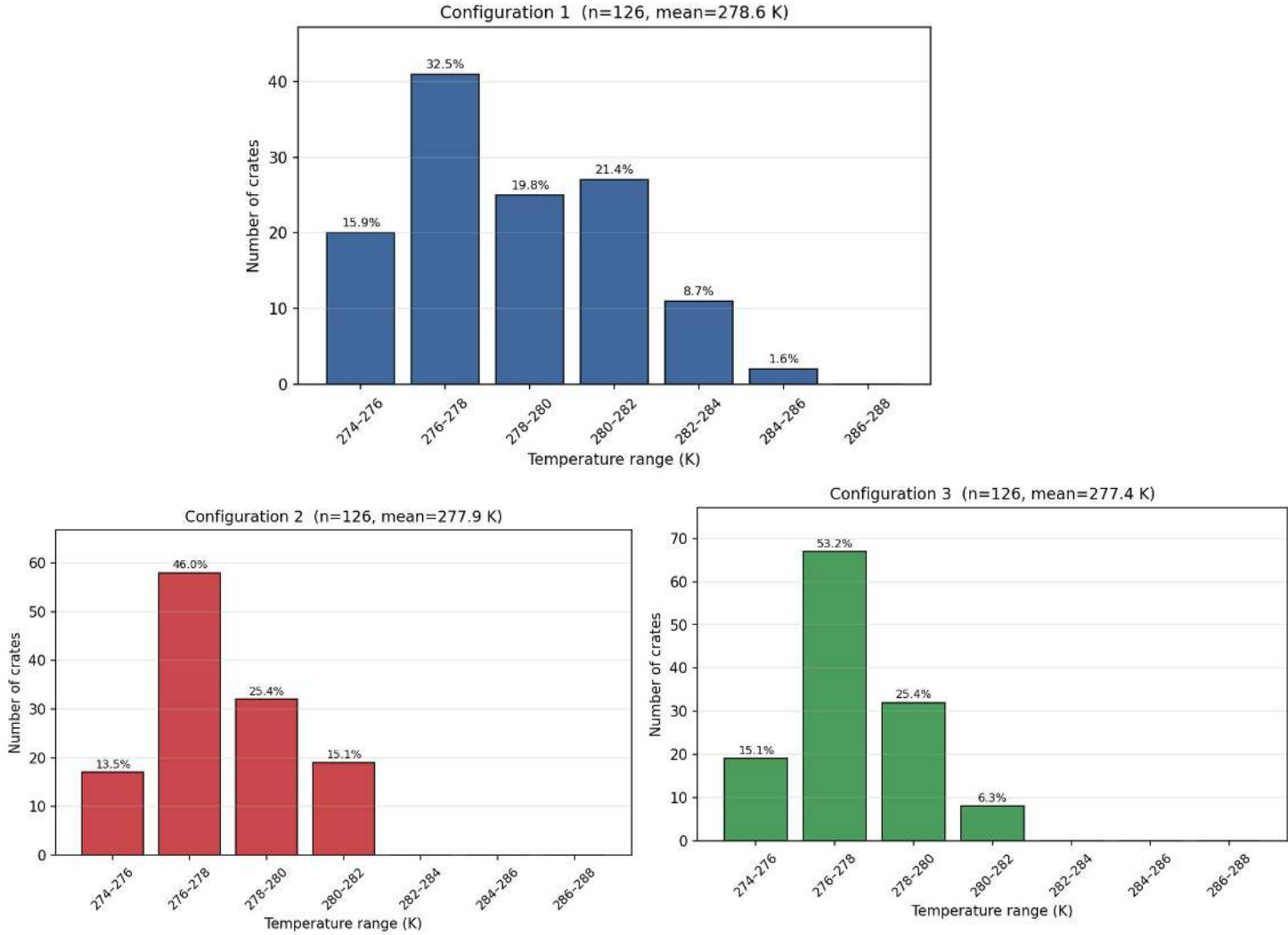


Figure 7: Histograms of temperature distribution across the crates.

Study scope

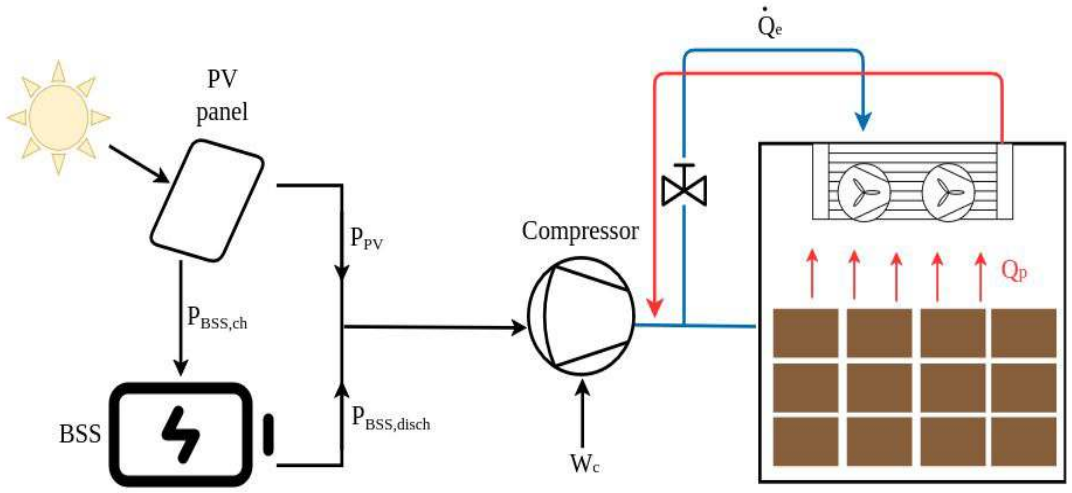


Figure 8: Schematic of the system

System components:

1. photovoltaic array
2. battery storage systems
3. cooling unit (refrigeration-based)
4. cold room

Challenge: **Cooling produce with intermittent solar energy**

Proposed solution: **An optimal off-grid energy management system (EMS) that**

- decide how much solar energy is needed
- when to charge or discharge the battery
- how much cooling capacity is required in the cold room for produce safety

MPC-based / proactive EMS

- Uses mathematical model to predict system behavior in the future
- Takes optimal decisions based on future system behaviour while minimizing a cost function

Advantage: **Anticipate needs before they become problems**

Conclusions

1 CRATE DESIGN

Improve ventilation and cooling rate

→ Better cooling

2 COLD-ROOM CONFIGURATION

Optimize airflow and loading arrangement

→ More uniform cooling

3 INTELLIGENT ENERGY MANAGEMENT

Coordinate solar, battery and refrigeration

→ More reliable cooling

4 OVERALL OUTCOME

REDUCED POSTHARVEST LOSSES

BETTER DESIGN → BETTER COOLING → RELIABLE ENERGY MANAGEMENT → LESS FOOD LOSS

Policy recommendations for resilient cold chains

RESILIENT & SUSTAINABLE COLD CHAINS

1. **INVEST**

   Support decentralized cold-storage infrastructure closer to production areas.

2. **POWER**

   Promote renewable-powered and energy-efficient cooling solutions.

3. **STANDARDIZE**

   Develop performance-based guidelines for airflow, temperature uniformity, loading and produce requirements.

4. **IMPROVE**

   Promote appropriate packaging, handling and loading practices that support effective cooling.

Annex … Experimental cold room



Testbed installed on AIMS-Rwanda Campus

References

[1] Khan, A. A., Siddiqui, Y., Siddique, K. H. M., Bobo, J. A., & Ali, A. (2024). *Minimizing postharvest food losses: A vital strategy to alleviate food insecurity and malnutrition in developing nations: A review*. Discover Food, **4**, 145.

[2] Demafo, A., Geletu, A., & Li, P. (2025). Numerical Study for Efficient Cooling of Perishable Food Products During Storage: The Case of Tomatoes. *Foods, 14*(14), 2508.

[3] World Bank. (2020). *Rwanda Food Smart Country Diagnostic*. Washington, DC: World Bank.

DAAD Deutscher Akademischer Austauschdienst German Academic Exchange Service

AIMS African Institute for Mathematical Sciences RWANDA

Federal Ministry of Education and Research

Alexander von Humboldt Stiftung/Foundation

Thank you !

A) AGRICULTURE AND FOOD SYSTEMS

Optimizing stem cutting propagation of Myrianthus holstii for climate-resilient agroforestry

Gaudence Nishimwe a,b*, A. Sigrun Dahlin c, Fidele Niyitanga d, Suzana Augustino e

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b Rwanda Polytechnic -Musanze College, Department of Agriculture Engineering, P.O Box 226, Musanze, Rwanda

Background of the study

- *Myrianthus holstii* is an underutilized indigenous multipurpose tree
  - Potential to enhance climate-resilient agroforestry,
  - Biodiversity conservation
  - Food security in Sub-Saharan Africa.





Background of the study

- Limited quality planting materials
  - Poor natural regeneration
  - Inadequate propagation techniques.
- This study evaluated the effects of rooting media and IBA concentrations on the vegetative propagation of *M. holstii* stem cuttings under a non-misting propagator.

Material and Methods

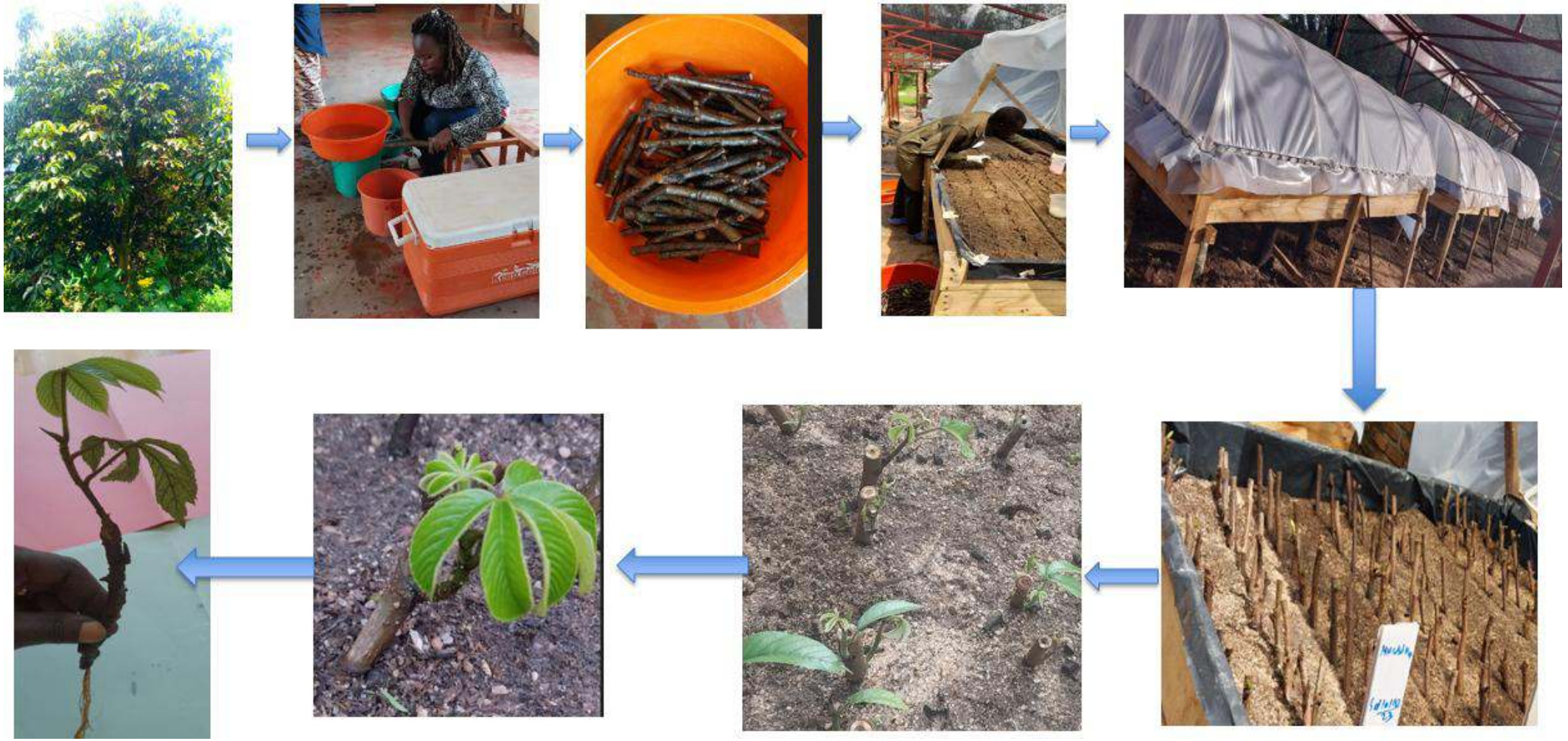


Plate1. photos showing the process of M.H cutting trials under different rooting media.

Material and Methods

Rooting media	IBA concentration	No. of stem cuttings
Saw Dust+ Sand	0.60%w.w	**30**
	0.40%w.w	**30**
	Control	**30**
Sand	0.60%w.w	**30**
	0.40%w.w	**30**
	Control	**30**
Forest Soil	0.60%w.w	**30**
	0.40%w.w	**30**
	Control	**30**
Total no		**270**

Results and Discussions

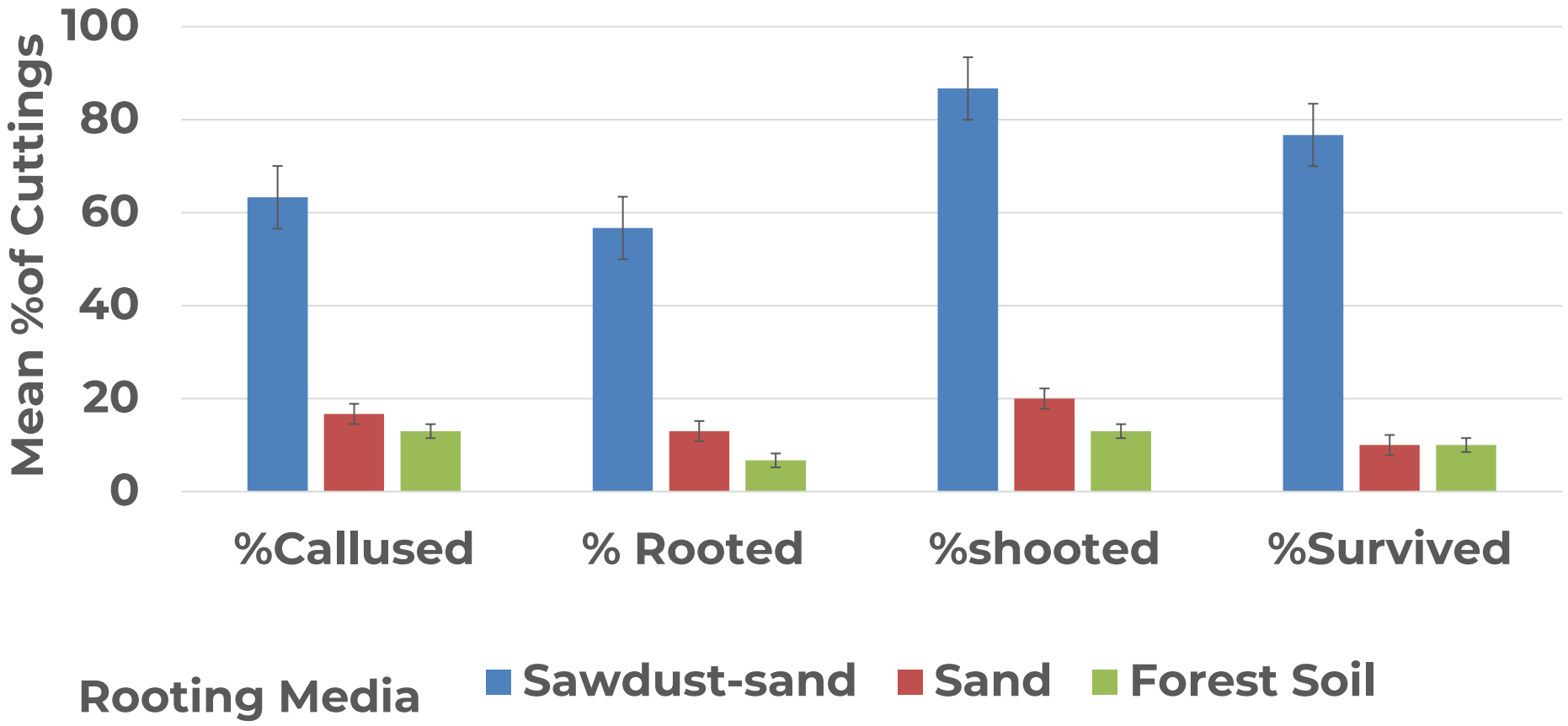


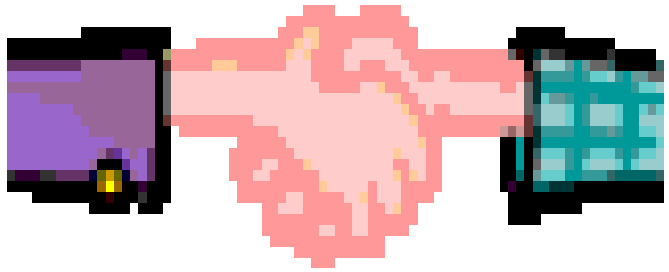
Figure 1. Mean percentage of callused, rooted, shooted and survived cuttings of M.H under different rooting media.

Conclusion and recommendation

- Stem cuttings treated with 0.6% w/w IBA and propagated in sawdust with sand achieved the highest propagation success.
- The combination of sawdust with sand and 0.6% w/w IBA is therefore recommended as an effective propagation protocol for large-scale production of *M. holstii*

Acknowledgement

THANK YOU FOR YOUR KIND ATTENTION



A) AGRICULTURE AND FOOD SYSTEMS

Financing Africa's Net-Zero and Climate-Resilient Transition

From climate-finance evidence to resilient agriculture and food systems

Jeannette Mukangango | Dr. Victoire (Vicky) Ghafi Kondi-Akara | Prof. Cecil Naphtaly Moro Ouma

AIMS Research and Innovation Centre (AIMS RIC)
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1 The food-system stake

What is at risk when climate finance does not reach resilience investments effectively?

Climate resilience depends on investments that protect production, value chains and livelihoods.



When finance does not reach resilience investments, climate shocks travel through farms, storage, markets and livelihoods.

Key question

Which financial and institutional conditions determine whether capital reaches the investments that protect food security and livelihoods?

From climate finance to real-world resilience

Stakes: delayed adaptation • fragile value chains • avoidable livelihood exposure

Sources: IPCC (2022), Climate Change 2022 – Impacts, Adaptation and Vulnerability, Chapter 9: Africa; FAO (2022), The State of Food and Agriculture 2022.

2 The paradox: more finance is necessary, but not sufficient

The scale of need is huge, yet volume alone does not prove that capital reaches investment.

USD 2.8 trillion

estimated African NDC implementation need by 2030

→

~ USD 277 bn per year

annual equivalent, depending on method and period

→

about 23%

of estimated need currently met

The central question

If finance is mobilised, what determines whether it reaches priority climate investments?

Mobilisation ≠ **Effective allocation** ≠ **Resilience outcomes**

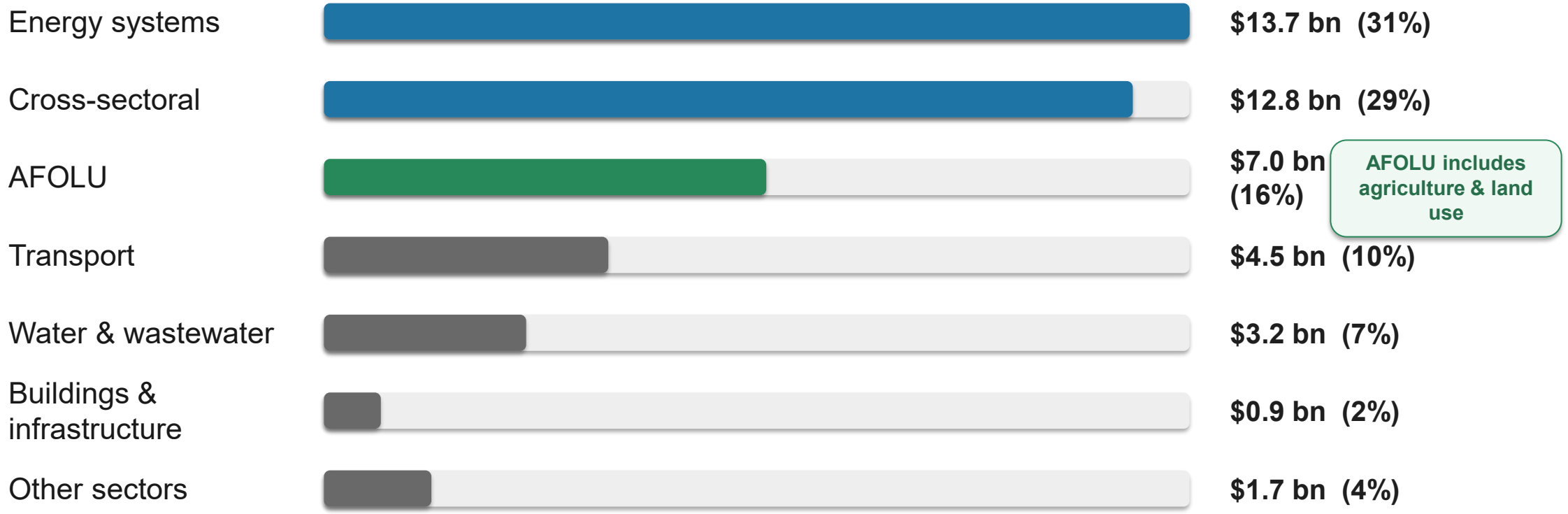
Source: ARIN (2026), Africa's Climate Finance Outlook 2026: Trends, Sub-Regional Realities, and Strategic Entry Points.

3

Where Does Africa's Climate Finance Go?

AFOLU is visible in the data, but food-system finance is broader than AFOLU alone

Tracked climate finance by sector, 2021/22 annual average



Climate finance reaches multiple sectors, but its distribution is uneven.

AFOLU = Agriculture, Forestry and Other Land Use. Cross-sectoral finance targets or benefits more than one sector.

Source: Climate Policy Initiative (2024), Landscape of Climate Finance in Africa 2024.

4

Research question and evidence base

A 53-study review explains why availability does not guarantee investment.



What determines whether climate finance reaches investable climate opportunities?

Manuscript evidence

PRISMA-guided systematic review of 53 studies, thematic synthesis, knowledge graph analysis, SSM and FIT interpretation.

Food-system relevance

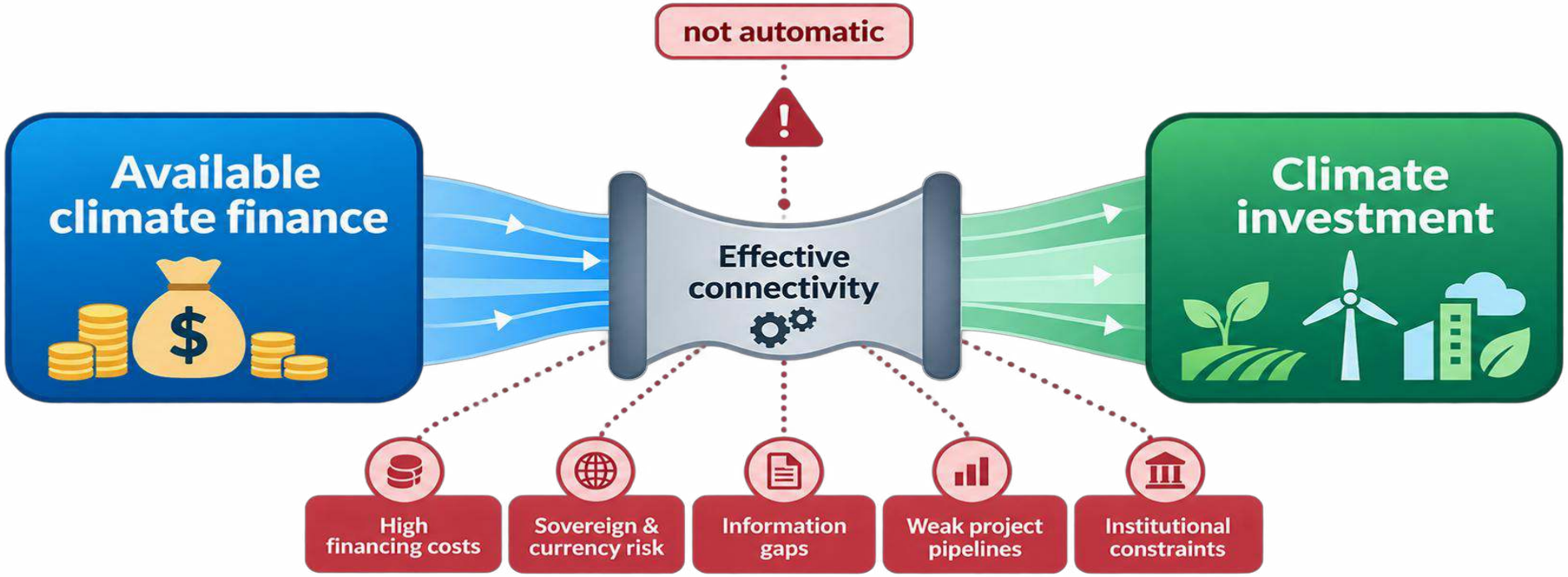
Resilience investments in farms, storage, markets and climate services face barriers of risk, return, information, readiness and governance.

Evidence-led framework **Systematic evidence → relationships → system structure → financial connectivity**

Methods and corpus: PRISMA 2020; Thomas & Harden thematic synthesis; knowledge representation; Soft Systems Methodology; Financial Integration Theory.

5 Core finding: availability ≠ effective connectivity

Africa's climate-finance challenge is both a volume problem and a connectivity problem.



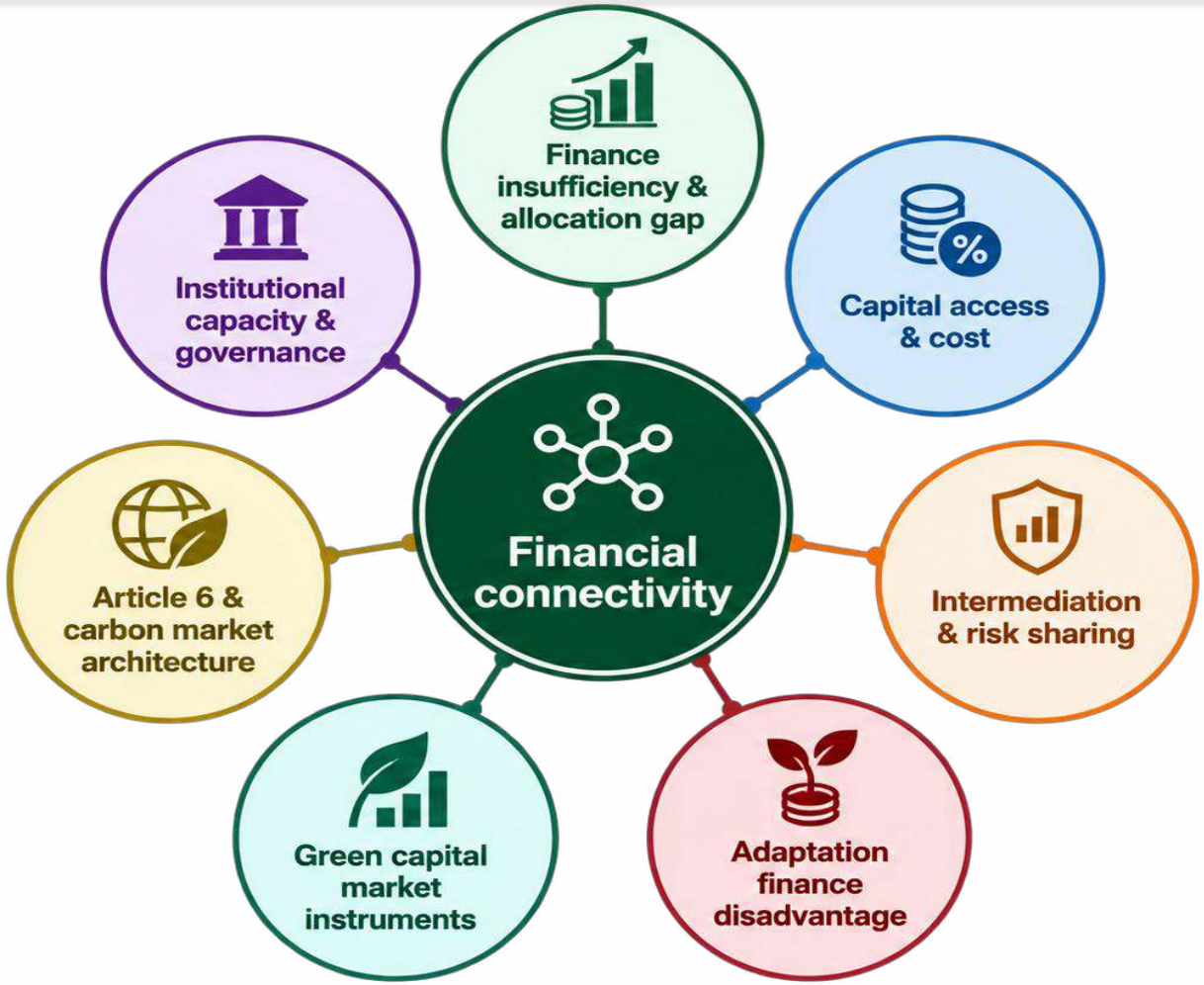
The review shows that capital can be constrained by cost, risk, information, project readiness and institutional conditions.

6

Seven evidence patterns behind the argument

The review links scarcity, allocation, risks, institutions and instruments.

53-study evidence base



These patterns interact; financing mechanisms are context-dependent pathways.

7 Agency: who can change the conditions?

Actors shape the conditions under which capital reaches investment.

Actor	Decisions that affect financial connectivity
Governments & regulators	Policy clarity, taxonomies, domestic market rules, public investment priorities
DFIs, MDBs & climate funds	Concessional capital, guarantees, risk sharing, project preparation support
Private & institutional investors	Risk pricing, due diligence, demand for credible green assets
Project developers & cooperatives	Bankable pipelines, aggregation, MRV-ready proposals, local implementation
Article 6 authorities	Authorization, registries, accounting, MRV, integrity safeguards

Actionable climate finance = actor + barrier + evidence that finance reached investment

8

Different barriers need different responses

Mechanisms may mediate constraints; they do not automatically remove them.

Barrier or constraint	Conditional response
High sovereign, currency or project risk	Guarantees and risk-sharing may redistribute exposure
Weak commercial returns / public-good benefits	Grants, concessional capital or blended structures may improve viability
Information gaps and weak project readiness	Project preparation, MRV, disclosure and data systems can improve investor confidence
Shallow markets and limited issuer access	Market infrastructure and credible bond frameworks must precede green-bond scale-up
Private-capital mobilisation gap	Blended finance is relevant where a clear risk-return or information problem blocks investment
Carbon-market cooperation pathway	Article 6 requires authorization, accounting, MRV and integrity before finance claims are credible

Match the response to the barrier, then verify whether finance reaches the investment.

Sources: CPI (2024); Flammer et al. (2025); Owusu-Mante et al. (2025); Marcu (2016); Allen et al. (2021); manuscript Article 6 safeguards.

9

Food-system resilience financing lens

Connect investment needs to barriers, actors and suitable capital.

Food-system investment domain	Likely financing barrier	Potential connectivity response
Farm & landscape resilience	public benefits, small ticket sizes, climate risk	grants, concessional finance, aggregation
Storage, cold chains & logistics	upfront costs, demand risk, energy reliability	blended finance, guarantees, project preparation
Markets, processing & SMEs	collateral gaps, information asymmetry	DFI intermediation, local finance, data systems
MRV, carbon & nature-based assets	integrity, accounting, transaction costs	Article 6 readiness, MRV capacity, governance

Ask: what type of capital, on what terms, through which actor, to which investment?

10 Beyond more finance: choosing the right finance

Stronger connectivity is valuable only when it supports priority investments on acceptable terms.

More capital → **More debt?** → **Better resilience?**

Not necessarily.

Connectivity can coexist with debt exposure, unequal allocation, weak adaptation investment, or inadequate safeguards.

Suitability	Terms	Outcomes
Does the instrument fit the investment's revenue profile and public benefits?	Does it reduce barriers without creating unsustainable debt or risk transfer?	Does finance reach adaptation, resilience and livelihood priorities?

11 Implications for decision-makers

The framework converts climate-finance evidence into practical diagnostic questions.

1. **Which food-system resilience investments are socially important but commercially difficult to finance?**
2. **Which barrier is stopping finance: risk, return, information, market access, project readiness or governance?**
3. **Which actor can mediate that barrier, and what evidence will show finance reached the investment?**

Use the framework to prioritise resilience investments, assign responsibility, and define evidence of financial connection.

12 Conclusion

From volume to viable resilience

Mobilise more. **Connect better.** **Invest fairly.**

The goal is not simply more climate finance.

**Appropriate finance, on appropriate terms,
reaching priority resilience investments.**

Including the investments that protect food security and livelihoods.

Thank you

13 References

1. Page et al. (2021), PRISMA 2020 statement; Thomas & Harden (2008), thematic synthesis

2. Bekaert & Harvey (1995; 2003), financial integration and segmentation

3. CPI (2024), Landscape of Climate Finance in Africa 2024

4. ARIN (2026), Africa's Climate Finance Outlook 2026

5. IPCC (2022), Chapter 9: Africa; FAO (2022), The State of Food and Agriculture 2022

6. Flammer et al. (2025), blended finance; Owusu-Mante et al. (2025), sovereign green bonds

7. UNFCCC Paris Agreement; Marcu (2016); Allen et al. (2021); Tessema et al. (2026) for Article 6/carbon market safeguards.

A) AGRICULTURE AND FOOD SYSTEMS

Mid-Season Machine Learning Prediction of End of Season Water Requirement Satisfaction Index (WRSI) for Maize in Kirehe District, Rwanda (Season B, 2001–2023)

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The Drought Challenge in Eastern Rwanda

- **Exposure:** Kirehe District: Season B drought probability >30%, reaching 42% in the worst hit areas (Rwanda National Risk Atlas)
- **Vulnerability:** Only 10% of Rwanda's cropland is irrigated (2023) smallholder maize producers rely almost entirely on rainfall
- **Impact:** 2021–2023 climate shocks cut maize production by 8% and bean output by 9–16% across Eastern Province
- **The gap:** No district level, data driven early warning system exists for Season B in Kirehe, weakening MINEMA's Drought Contingency Plan and NST2 (2024–2029)

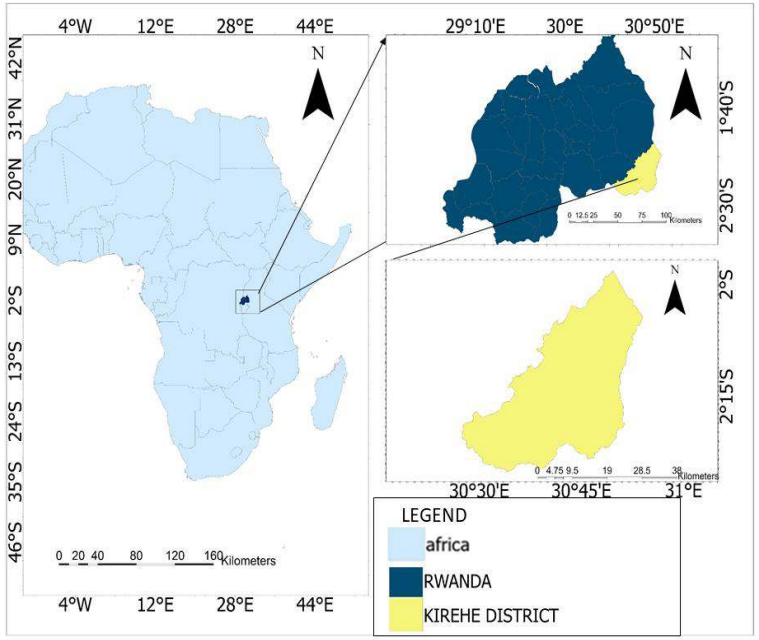


Figure: Kirehe District study area, Eastern Province, Rwanda

Research Aim and Objectives

- **General objective:** Build and test the first machine learning system that predicts drought severity for Kirehe's Season B maize partway through the growing season
- **Objective 1:** Assemble 23 years of satellite and rainfall data (2001–2023) covering every part of Kirehe District
- **Objective 2:** Train three machine-learning models and test them rigorously, using a strict year-by-year validation method; identify which factors matter most for prediction
- **Objective 3:** Find out how early in the season we can still make a reliable prediction giving MINEMA a usable warning window

Data Sources and Methodology

- 23 years of Season B data (2001–2023) 10 more years than Rwanda's official drought record covers
- Rainfall: satellite rainfall estimates, updated every 10 days
- Soil moisture and water demand: from a global climate reanalysis dataset
- Vegetation health and land temperature: from NASA satellite imagery
- Ground truth: drought labels calculated the same way as Rwanda's official National Risk Atlas, so results are directly comparable

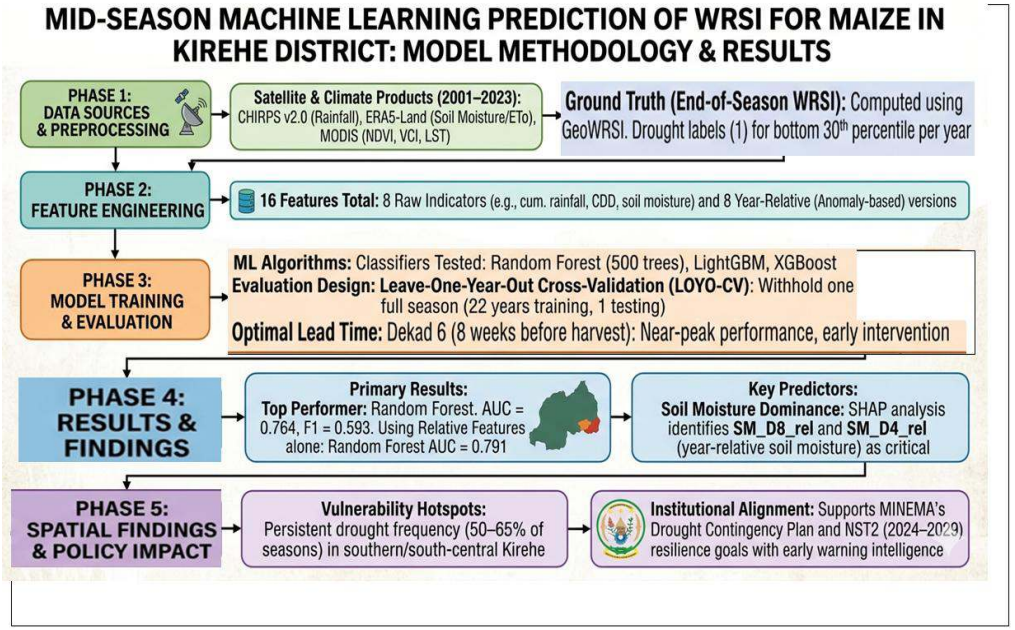


Figure: ML-based drought prediction workflow

Ground Truth and Feature Engineering

- **Labelling:** Each location-year is labelled "Drought" if it falls in the driest 30% of years on record
- **Dataset:** 182,390 observations across nearly 8,000 locations in Kirehe; about 3 in 10 were drought years
- **16 features:** 8 core indicators covering rainfall, soil moisture, dry spells, and vegetation health
- **Anomaly encoding:** Each indicator is also expressed as "how unusual is this year compared to normal" the approach that turned out to work best (see next slide)

Models and Experimental Design

- **Random Forest:** One of three ML methods tested combines hundreds of decision trees for robust, reliable predictions
- **LightGBM:** A second ML method, fast and efficient on large datasets
- **XGBoost:** A third ML method, widely used and highly accurate on structured data
- **Validation:** Tested one season at a time, using the other 22 to learn so results reflect real forecasting, not memorization
- **Experiments:** We also tested which inputs matter most, and how early in the season predictions stay reliable

Model Performance: Random Forest Wins

- **Random Forest:** The most reliable of the three models correctly flagged about 62% of actual drought seasons (accuracy score 0.764 of 1.0, where 0.5 is random guessing)
- **XGBoost:** Noticeably less accurate than Random Forest
- **LightGBM:** The least accurate of the three models tested
- **Why RF wins:** It handles Kirehe's patchy, spatially clustered drought pattern better than the other two methods

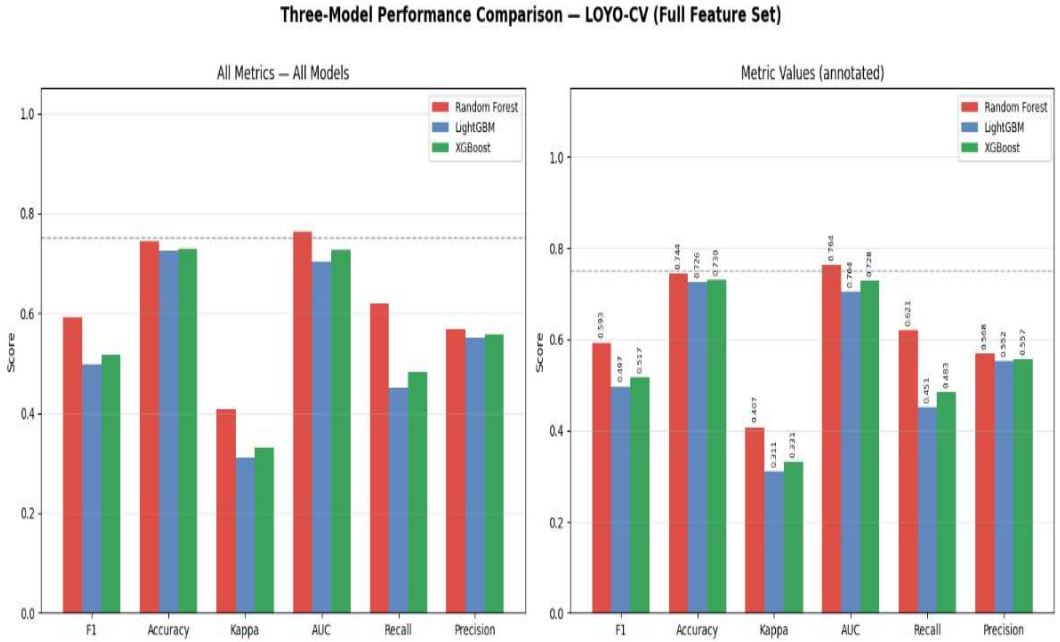


Figure: LOYO-CV performance across all three models (full 16-feature set)

How Well Does Each Model Tell Drought from Normal?

- Random Forest (red line): highest accuracy of the three models
- XGBoost (green) and LightGBM (blue) both trail Random Forest, in that order
- All three models far outperform random guessing
- Random Forest also leads on a second accuracy measure fewer missed droughts and fewer false alarms overall

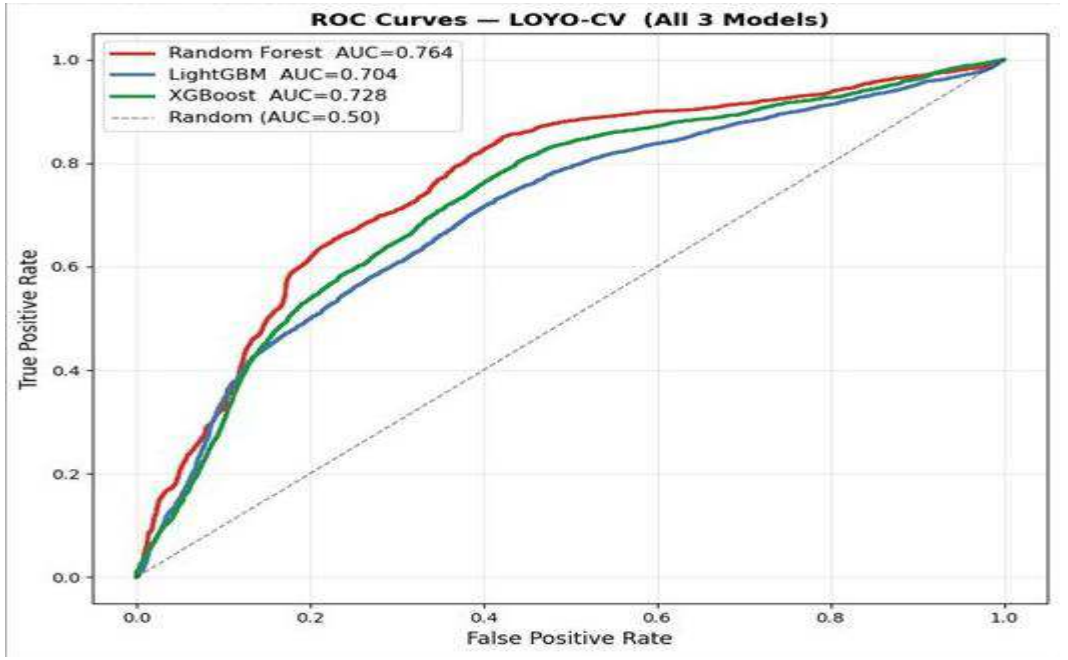


Figure: ROC curves, LOYO-CV (all 3 models)

How Early Can We Predict? Rolling-Horizon Results

- **Dekad 4 (10-week lead):** Prediction is already reliable enough for an early "watch" alert
- **Dekad 6 (8-week lead):** Accuracy peaks here the best trade-off between early warning and reliability
- **Dekad 8 (6-week lead):** Barely any accuracy gain over the 8-week mark
- **Implication:** MINEMA can trigger pre-harvest contingency plans up to 8 weeks early, with almost no loss in confidence

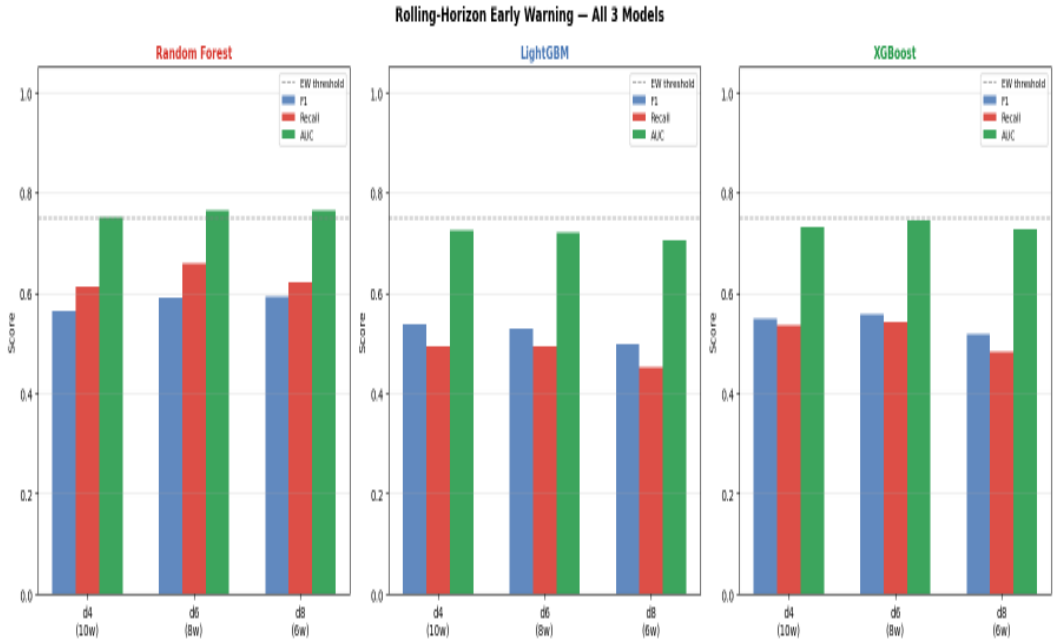


Figure: Rolling-horizon early warning, all 3 models

Simpler Inputs, Better Predictions

- **Key finding:** Comparing each year to its own "normal" predicts drought better than raw numbers alone, for all three models
- **Best configuration:** Random Forest using only "how unusual this year is" features reached its best accuracy yet beating the version using all available inputs
- **Why:** Mixing raw and relative versions of the same variable adds noise rather than new information
- **Operational guideline:** Future systems should track "how unusual conditions are," not raw measurements

What Drives Drought Risk? SHAP Feature Importance

- This shows which factors most influence the model's drought predictions soil moisture dominates across all three models
- Random Forest relies most on how unusual recent soil moisture is compared to normal
- LightGBM and XGBoost lean on current soil moisture levels, with similar factors close behind
- Rainfall and vegetation health play a real but secondary role

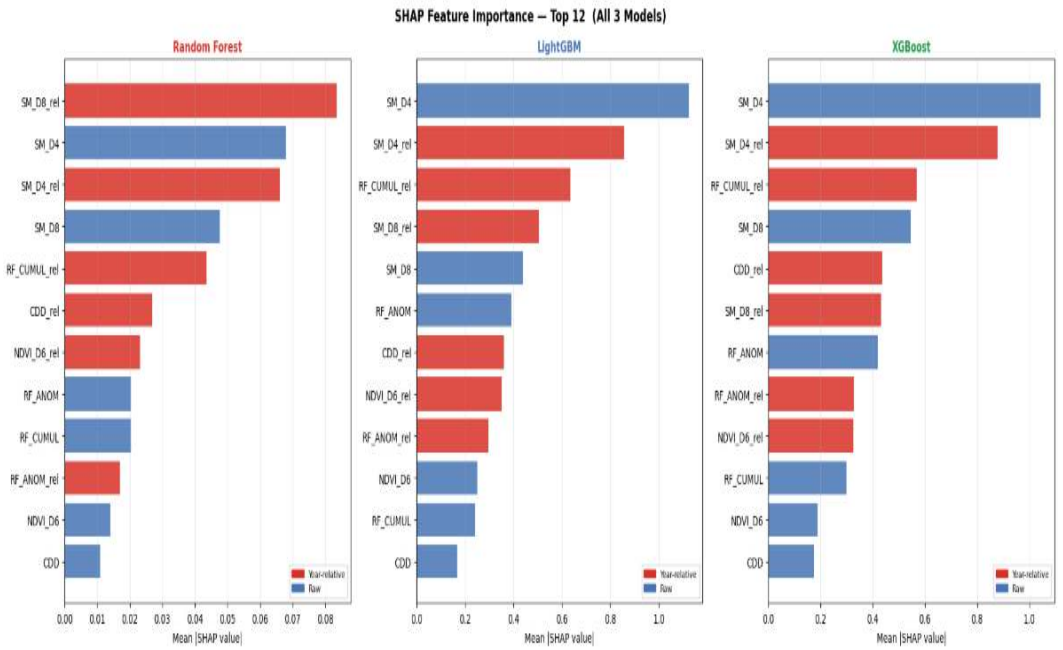


Figure: SHAP feature importance, top 12 features (all 3 models)

Where Is the Risk? Spatial Drought Hotspots

- Clear north south gradient: northern Kirehe consistently shows lower drought probability
- Southern areas face drought probability of 60–80% in a typical Season B
- Some locations were predicted to experience drought in over half of the 23 seasons studied
- Pattern is spatially consistent across all three models and matches the National Risk Atlas

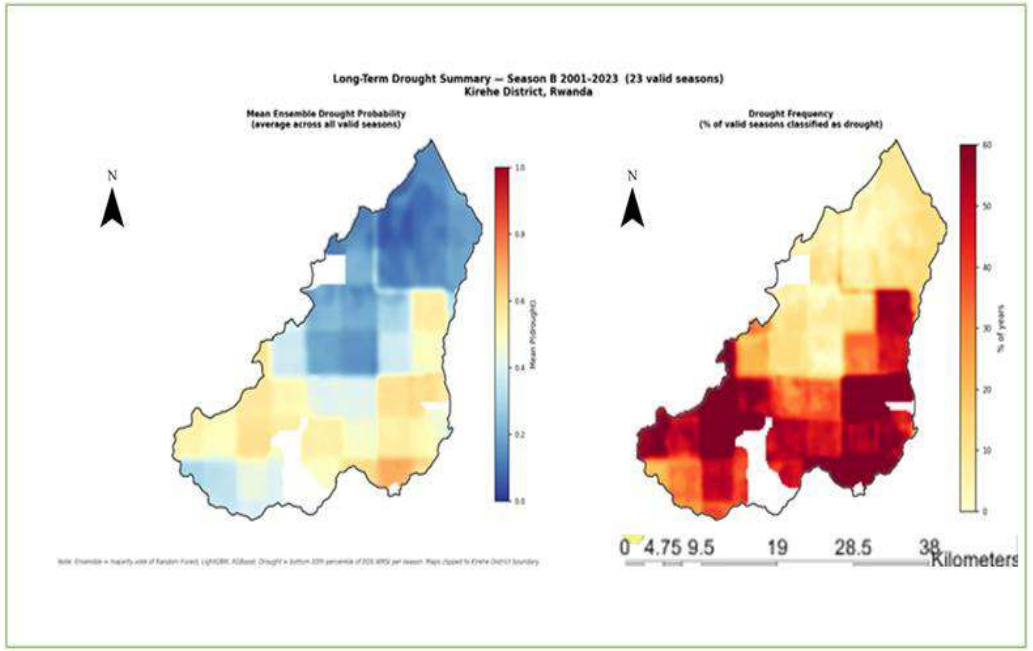


Figure: Long-term drought summary, Season B 2001–2023, Kirehe District

Policy Relevance and Operational Pathway

- **MINEMA:** This model's drought maps directly support Rwanda's national drought contingency planning
- **NST2 (2024–2029):** Feeds into Rwanda's national development strategy for climate resilience
- **PSTA 5 / Agri Hubs:** Can be built into the agriculture ministry's digital farmer-support tools
- **NDC and FEWSNET:** Helps target climate adaptation funding and improves regional food-security forecasts

Limitations

- 23 years of data is still a small sample for capturing rare, extreme drought years
- Neighbouring locations aren’t fully independent, which can slightly overstate how well the model generalizes
- Labelling the driest 30% as "drought" can add noise in years when the whole season was mild
- Doesn’t yet account for factors like household wealth, market access, or which maize variety farmers plant

Conclusion and Recommendations

- First multi-model machine-learning system for district-level, mid-season drought prediction in Rwanda
- Random Forest is the most reliable model; useful predictions are possible 6–10 weeks before harvest
- Soil moisture anomalies are the strongest, most consistent predictor across all models
- Recommend building this into MINEMA and Rwanda Agriculture Board monitoring, using near-real-time soil moisture data
- Framework is replicable to other drought-prone Rwandan districts with local recalibration

A) AGRICULTURE AND FOOD SYSTEMS

Potato tuber moth (*Phthorimaea operculella* (Lepidoptera: Gelechiidae) farmers' perception and seasonal occurrence in Burera and Rutsiro districts of Rwanda

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Introduction

Potato tuber moth (PTM) (*Phthorimaea operculella (*Zeller) (Lepidoptera: Gelechiidae) is a global pest (Devaux et al., 2020) and severely impacts potato production system (Jung et al., 2020).

Potato is the primary host, and both potato and the potato moth originated in Western South America (Chandel et al., 2020; Li et al., 2024).

The current climate variability brought new insect pests (Mori *et al*., 2015) and PTM is a good example of a major pest in tropical and subtropical regions (Kroschel *et al*., 2020).

Climate change increases PTM's geographic range, increases its winter survival, increases the number of PTM generations per season and diminishes the effectiveness of conventional control practices.

Cont..,

•In Rwanda, PTM is on top among the severe pests limiting potato production in Burera, Gakenke, Musanze, Ngororero, and Nyabihu districts (Okonya *et al*., 2019).

• Yield losses of up to 70% under field (Kroschel & Schaub, 2013); while under storage the losses may go up to 100% for untreated tubers (Kroschel *et al*., 2020).

•Hence, there is a need to adopt adaptive management strategies to mitigate pest population dynamics (Skendžić et al., 2021).

•Timely pest control requires knowledge of pest symptoms for early identification of threats (Creissen & Meador, 2024).

Cont'…..,

Optimal pest management is achieved when farmers are aware of pest seasonal occurrences, and apply precautions (Bhattacharyya et al., 2023)

However, in Rwanda, documentation on farmers' knowledge of PTM management; and PTM seasonal occurrence remains limited despite these being key drivers of successful PTM control, consequently, this limits proper monitoring and setting of effective control approaches.

Therefore, the purpose of this study was to enhance potato productivity by providing information on farmers' knowledge of PTM management; and seasonal occurrence the potato tuber moth in Rwanda.

Specifically, this study evaluated farmers' knowledge of potato moth management strategies on potato farmland and examined PTM seasonal occurrence in field conditions across three growing seasons in Burera and Rutsiro districts.

Methodology

The study was conducted in Burera district and Rutsiro and three sectors that is mostly involved in potato cultivation were selected in each district for the survey and field assessment.

Burera district is located at 1°28´26.18´´S latitude and 29o50´4.85´´E longitude, elevations between 1450 and 2100 m asl, average temperature ranging from 16 °C to 22 °C (DDS, 2024-2029).

Rutsiro district is located -1°57'36" latitude, 29°23'22" Longitude, and the altitude between 1,400 m at the edge of Kivu Lake and 2600 m at Crete Congo-Nile mount.

The average temperature 20°C and 24°C and rainfall increases gradually as we approach the Congo-Nile (Rutsiro district, 2029).

Con't,.....

The study design and procedure of sampling

A structured survey: purposive sampling method, and participants were potato producer for at least six consecutive growing seasons and the willingness to participate in the study.

Field observation was done to evaluate PTM occurrence in three consecutive growing seasons.

Interview with farmers

Survey period was between April and July 2023; and responded were 102 from households.

The head of household was interviewed: main constraints, PTM symptoms, pick month in which the PTM symptoms are commonly observed, the source of potato seed, and PTM control strategies.

Cont...,

Field observation to evaluate the level of PTM occurrence under farmers' fields

The observation was done in three consecutive growing seasons from June 2023 to June 2024 (season C 2023, A and B of 2024).

Thirty potato fields were randomly selected to evaluate PTM occurrence in each season.

Five quadrats with two meters by two meters using an "X" shape transect were used and PTM data were collected from 5 randomly selected potato plants, which equaled 25 plants from each field.

Collected Data : Counting the total number of plants in each quadrat, diseased plants per quadrat, and diseased and healthy leaves per plant, diseased and healthy potato tuber weight

Data analysis

Survey data were analyzed using descriptive statistics (frequency, percentages, means, and standard deviation) to generate summaries and tables at district level using IBM SPSS Statistics version 27.

PTM seasonal occurrence data were processed by analysis of variance (ANOVA) using SAS 9.4M8.

Square root transformation was used on the data collected in Rutsiro district to improve validity, stabilize variance, and make the data normally distributed.

After detecting significance of differences among seasons, district, sector and potato varieties, means separation was accomplished with the Least Significant Difference (LSD) test (P=0.05).

Results

- **Respondents based on their gender**
- Males were 47.1% and 66.7%, while females were 52.9% and 33.3% in Burera and Rutsiro districts, respectively.
- **Table 1** - Potato producers interviewed

	Burera district			Rutsiro district	
	Parameters	Frequency	percentage	Frequency	percentage
Gender	Male	48	47.1	68	66.7
	Female	54	52.9	34	33.3

Table 2 - Monthly average temperature and RH in Burera and Rutsiro districts during the study period of 2023 to 2024

	Monthly average temperature (°C) and RH		
Season	Months	Burera	Rutsiro
Season C, 2023	April	17.58/82	19.17
	May	18.60/78.1	20.08
	June	18.80/71.35	20.54
	July	19.88/60.58	20.97
	Augustin	20.10/66.05	21.70

	Monthly average temperature (°C)/RH		
Seasons	Months	Burera	Rutsiro
Season B, 2024	February	18.66/80.79	20.33
	March	18.86/81.01	20.93
	April	18.58/86.18	20.25
	May	19.22/81.28	20.90
	June	20.21/64.73	20.81
	July	20.52/58.12	20.86

	Monthly average temperature (°C)/RH		
Season	Months	Burera	Rutsiro
Season A, 2024	September	17.95/82.54	19.90
	October	18.13/81.86	20.30
	November	17.47/88.45	18.85
	December	18.31/87.49	19.99
	January	18.22/81.55	19.66

Source: Meteo Rwanda, 2023 and 2024

Results of interviews with potato producers in Burera and Rutsiro districts

Table 3 - Potato production constraints as reported by farmers in Burera and Rutsiro districts

	Burera district				Rutsiro district			
	Frequency	Percent (%)	Mean	Std. Deviation	Frequency	Percent (%)	Mean	Std. Deviation
Pest and diseases	57	55.9	2.12	1.868	50	49	1.41	2.154
Limited A.P.	44	43.1	2.72	1.906	46	45.1	2.00	1.449
Poor soil fertility	22	21.6	4.07	2.389	29	28.4	4.41	1.931
Climate change	26	25.5	4.65	2.003	34	33.3	4.52	1.767
Lack of market	28	27.5	4.89	1.866	32	31.4	4.83	1.940
Inacc to credit	60	58.8	5.82	1.316	55	53.9	5.37	1.297
Unclean seed	35	34.3	5.90	1.838	47	46.1	5.75	1.733
Animals	3	2.9	9.86	0.546	0	0	9.93	0.693
Lack of storage	10	9.8	9.9.	0.299	8	7.8	9.88	0.473

Table 4 – farmers' knowledge of PTM symptoms under field and storage in Burera district

PTM symptoms	Frequency	Percent	Std. deviation	Mean
Dried leaves	39	38.2		
Excavation on leaf	6	5.9		
Eggs on tuber	4	3.9	1.533	2.78
No information	44	43.1		
White larvae	9	8.8		

Table 5 *- control measures against PTM in Burera district*

	Burera district			
Parameters	Frequency	Percent (%)	Mean	Std. Deviation
Pesticide application	102	100	1	0.000
Quality seed	24	23.5	8.12	3.41
Uproot diseased	8	7.8	9.45	1.891
Rotation	31	30.4	8.18	2.773
weeding	15	14.7	9.26	1.78
Fertilizer application	8	7.8	9.69	1.081
Mixing pesticides	71	69.6	8.61	0.855

The results of PTM occurrence as observed under potato farms in Burera and Rutsiro districts

Table 8 - Seasonal comparison of PTM infestation in Burera and Rutsiro districts

	Values				
	Variables	Means	Pr > F	F Value	Coeff Var
Seasons	C	0.27a	<.0001	38.22	40.82
	A	0.12c			
	B	0.18b			
District	Burera	0.30a	<.0001	24.32	
	Rutsiro	0.07b			
District*Season	Burera/season C	0.47a	<.0001	44.04	
	Burera/Season B	0.28b			
	Burera/season A	0.16c			
	Rutsiro/season B	0.07c			
	Rutsiro/season A	0.07c			
	Rutsiro/season C	0.06c			

Means with the same letter are not significantly different (Tukey Grouping)

Table 9 -Potato yield in Burera and Rustiro districts across seasons

		Values			
Variables		Means	Pr > F	F Value	Coeff Var
Seasons	C	10.96b	<.0001	60.00	10.86
	A	13.77a			
	B	14.096a			
District	Burera	13.58a	0.1013	2.72	
	Rutsiro	12.299a			
District*Season	Burera/season C	10.81c	<.0001	15.91	
	Burera/Season B	13.96ab			
	Burera/season A	15.96a			
	Rutsiro/season B	12.23bc			
	Rutsiro/season A	13.57ab			
	Rutsiro/season C	11.10c			

Means with the same letter are not significantly different (Tukey Grouping)

Discussion and conclusion

•Potato production constraints in Burera and Rutsiro districts of Rwanda

• Reported constraints are lack of access to credit to purchase agricultural inputs, insect pests and diseases, limited access to pesticides and fertilizers, insufficient quality seed, climate change, lower prices on the market, and poor soil fertility

• Similar constraints were reported by potato producers in many African countries Muthoni and Shimelis (2023).

•The reported constraints were probably due to the lack of credit guarantee, and that become a barrier to accessing agricultural credit, whereby smallholder farmers were unable to purchase the agricultural inputs as also reported by Taremwa et al. (2022)

Potato tuber moth symptoms reported by farmers

• The moth was identified among the major constraints to potato production in Burera district, probably because farmers have produced the crop for a long time; most of them do not practice crop rotation, use unclean seed, and the presence of temperatures that favor moth generation.

•Some respondents were not able to differentiate potato moth symptoms from other pest symptoms due to lower knowledge of moth identification; and inability to differentiate moth symptoms from other disease symptoms (Okonya and Kroschel, 2016; Adhikari et al. (2024))

• Farmers reported dried potato leaves as moth symptoms in Burera district; this was due to moth larvae mining potato leaves.

• Alyokhin et al. (2022) said that PTM larvae feed by excavating tunnels on the tuber and leaf mining.

•Practices for insect pest management in Burera and Rutsiro districts

•The use pesticides was the main practice for insect pest management, including PTM. Similar results have been reported by Okonya and Kroschel (2016) in Uganda, Midega et al.(2012) in Kenya, and Nyirenda et al. (2011) in Zambia.

•This study indicated that most potato producers commonly mix two or more pesticides in a single spray application to reduce labor expenses and costs associated with repeated field operations. Similar results were reported by Okonya and Kroschel (2016) and Kanario et al. (2025).

• Excessive pesticide use is one among driven factors that cause resistance in insect pests (Liang et al., 2025).

- **Occurrence of PTM across seasons in Burera and Rutsiro districts**
- High PTM occurrence in Burera district than in Rutsiro.

- They grow the crop year-round, and improper crop rotation brings the buildup of PTM due to eggs and larvae hidden in the soil and permanent host availability.

- Seasons C and B had higher moth occurrence than season A in Burera district. Moth existence is greater in the range of 17.5 - 27.5 °C of temperature (Andreadis et al. (2017).

- Kirundo was reported to be more susceptible to PTM. It is a preferred potato variety among farmers due to its high-yielding ability (Muhinyuza et al., 2022).

•Potato yield in Burera and Rutsiro districts

• Season A gave a high potato yield in both districts due to conducive environmental conditions that reduced PTM infestation.

•High temperatures in season C reduced potato yield, as also reported by Gouerou et al. (2025), who said that an increase in temperature causes a decrease in potato yield.

• Our results discovered that most farmers are unable to identify moths on their farm, plant unclean seed, and mix pesticides for moth management, which increases toxicity and pest resistance.

Conclusion and Recommendations

High temperatures observed in season C promote PTM generation and reduce potato yield.

Besides, smallholder potato farmers grow the crop year-round with improper crop rotation that causes the buildup of PTM due to eggs and larvae hiding in the soil and permanent host availability.

Solutions needed are adopting the growing period (season A), using clean potato varieties, and practicing Integrated Pest Management in potato moth management.

Breeding programs should prioritize the development of potato cultivars with Kirundo traits, resistance to PTM and tolerant of extreme conditions

Extension services should be strengthened to keep on training potato farmers on the use of synthetic pesticides and their consequences.

END

B

CLIMATE DATA & MONITORING SYSTEMS

B) CLIMATE DATA & MONITORING SYSTEMS

Climate-induced Displacement in Rwanda: Case Study of Landslides in Rutsiro District, Western Rwanda

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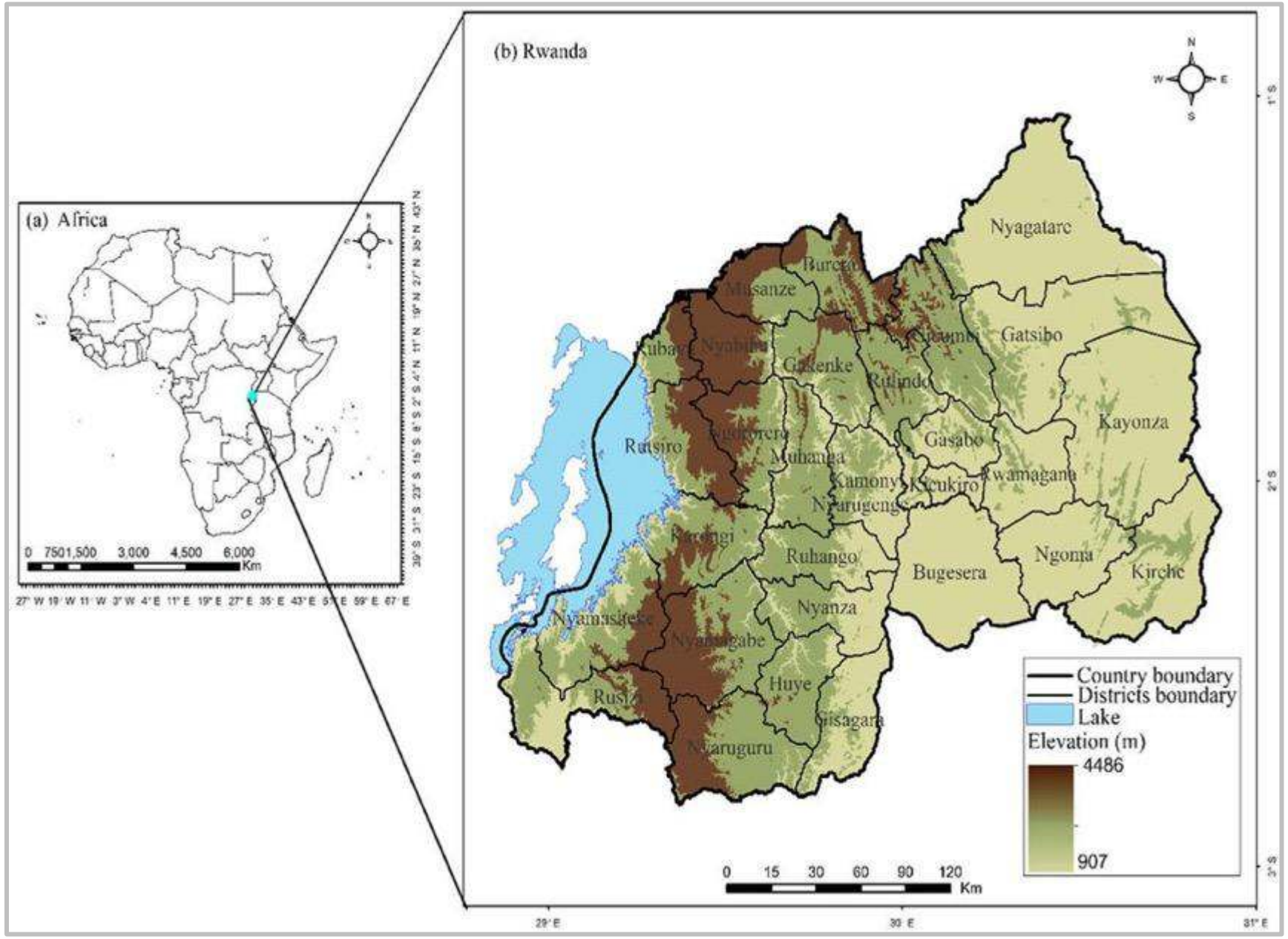
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Outline

- **Introduction**
  - Background
  - Problem Statement
  - Objectives
  - Definitions of Key Concepts & Terms
- **Methodology**
  - Study Area Description
  - Data Collection Methods and Instruments
  - Data Analysis
- **Results and Discussion**
  - Demographic and Socioeconomic Aspects of Respondents
  - Climatic Conditions in the Study Area
  - Exposure to Landslides
  - Landslide Vulnerability in Rutsiro District
  - Landslide-induced Displacement in Rutsiro District
  - Proposed Solutions to the Problem of Landslide-induced Displacement
- **Conclusion and Recommendations**

Introduction

- **Background**
  - Climate change is increasing the frequency and intensity of climate-induced disasters worldwide, including floods, droughts, storms, and landslides (IPCC, 2023).
  - Between 1970 and 2019, weather and climate hazards accounted for **50% of all disasters, 45% of disaster-related deaths, and 74% of economic losses globally** (WMO, 2021).
  - Landslides are among the most destructive natural disasters in mountainous regions, causing loss of life, destruction of infrastructure, environmental degradation, and population displacement (Gariano & Guzzetti, 2016; Muhammed et al., 2024).
  - Heavy rainfall, steep slopes, fragile soils, deforestation, and inappropriate land use are the major factors contributing to landslide occurrence (Dusabeyezu & Nsanzumukiza, 2024).
  - Rwanda is highly vulnerable to climate-induced disasters because of its mountainous terrain, intense rainfall, and dependence on rain-fed agriculture (MINEMA, 2024b).
  - The Western and Northern Provinces experience frequent landslides that destroy homes, infrastructure, farmland, and livelihoods, leading to population displacement (MINEMA, 2018).
  - Rutsiro District is one of the most affected districts due to its steep slopes, high rainfall, and recurrent landslide events.



Three Major Geo-physical Landscapes of Rwanda

(Sebaziga et al., 2024)

Introduction (Cont.)

- **Problem Statement**
  - Despite Rwanda's efforts to strengthen **climate resilience and disaster risk reduction**, existing policies provide limited guidance on managing **climate-induced population displacement**, particularly from landslides (MoE, 2023; RoR, 2020).
  - **Rutsiro District** experiences recurrent landslides due to steep slopes, fragile soils, and intense rainfall (MIDIMAR, 2015; Fashaho et al., 2014; Habiyakare & Ntwali, 2024).
  - Current relocation practices are largely **temporary and emergency-based**, with limited consideration of long-term sustainable resettlement and environmental implications (MINEMA, 2024a; UN, 2017).
  - In addition, there is limited assessment and documentation of the impacts of landslide-induced population displacement, which limits understanding and the development of effective strategies.
  - This study therefore assessed the impacts of landslide-induced population displacement in Rutsiro District and identified suitable relocation areas to support sustainable disaster risk management.

Introduction (Cont.)

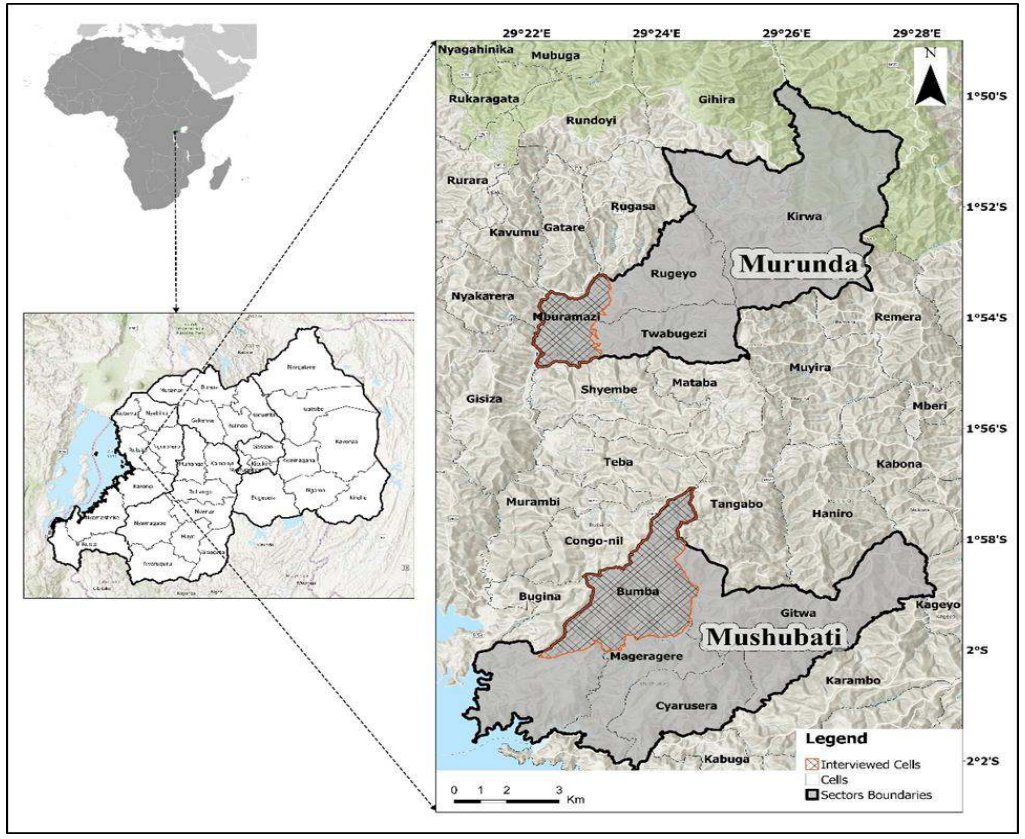
- **Objectives**
  - The general objective of this study was to assess the impacts of climate-induced displacement in Rwanda with a particular focus on landslides in Rutsiro district, Western Province.
  - Specifically, the study intended to:
    - ✓ To analyse the extent to which Rutsiro district was vulnerable to landslides.
    - ✓ To assess the adverse effects of landslides on population displacement in Rutsiro district.
    - ✓ To propose sustainable solutions to address the problem of landslide-induced displacement in the study area.

- **Definitions of Key Concepts/Terms**
  - **Displacement:** the movement of persons who have been forced or obliged to flee or to leave their homes or places of habitual residence, in particular because of or to avoid the effects of armed conflict, situations of generalized violence, violations of human rights or natural or human-made disasters.
  - **Climate-induced displacement:** the forced movement of people from their homes due to sudden or slow environmental changes caused by global warming.
  - **Planned relocation in the context of climate-induced disasters:** it is a process where people or groups move from their homes to a new location, supported by the State. It aims to protect them from disaster and environmental risks, occurring within national borders and at various levels (UNHCR, 2015).

Methodology

Study Area Description

- The study was conducted in Murunda and Mushubati sectors of Rutsiro district.
- Both sectors are located in the highlands pf Western Rwanda with Mushubati sector extending into some lowland areas around Lake Kivu.
- **Temperature Patterns**: Moderate temperatures in Murunda sector (16.28–17.16°C) & Mushubati is comparatively warmer (17.16–20.56°C).
- **Rainfall Patterns**: High precipitations in Murunda (1,198–1,335 mm) compared to Mushubati (1,157–1,244 mm).



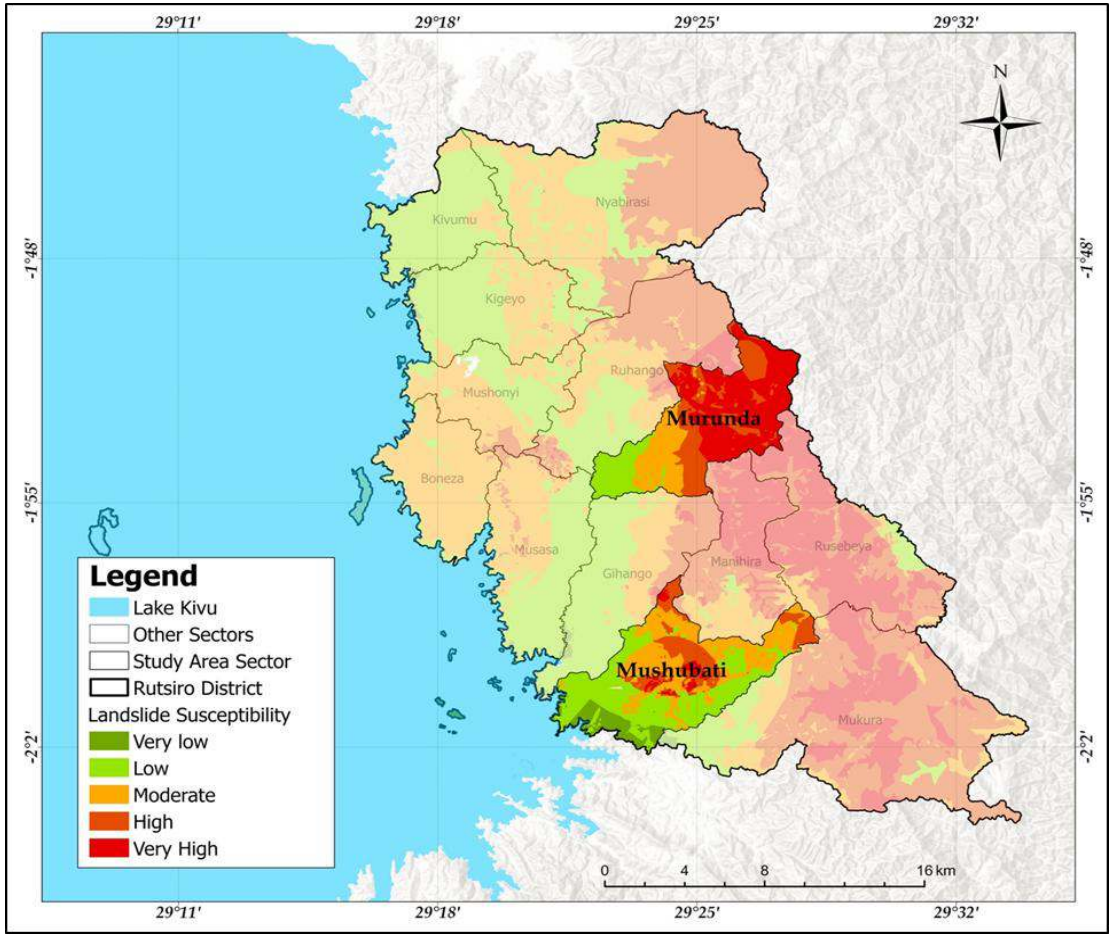
Map of the Study Area

Methodology (Cont.)

- **Secondary Data Collection**
  - Secondary data were collected from reliable national and international sources.
  - Demographic and socioeconomic information was mainly obtained from the 2022 Rwanda Population and Housing Census.
  - Geospatial datasets, including land use, elevation, road networks, health and education facilities, and administrative boundaries, were obtained from Esri and NLA.
- **Primary Data Collection**
  - **Field Observation**
    - ✓ Ground-truth assessment of landslide areas, destroyed houses and high-risk zones.
  - **Household Survey**
    - ✓ **Target Population**: **382 households** in Murunda and Bisyo villages.
    - ✓ **Sample Size**: **195 households** determined using Yamane (1967) formula.
  - **Interviews**
    - ✓ Conducted to Collect information on climate-induced disasters, preparedness, response mechanisms and challenges.
- **Data Analysis**
  - Demographic and socioeconomic data were analyzed using SPSS and Excel.
  - Geospatial technology was used to produce relocation suitability map in the study area.

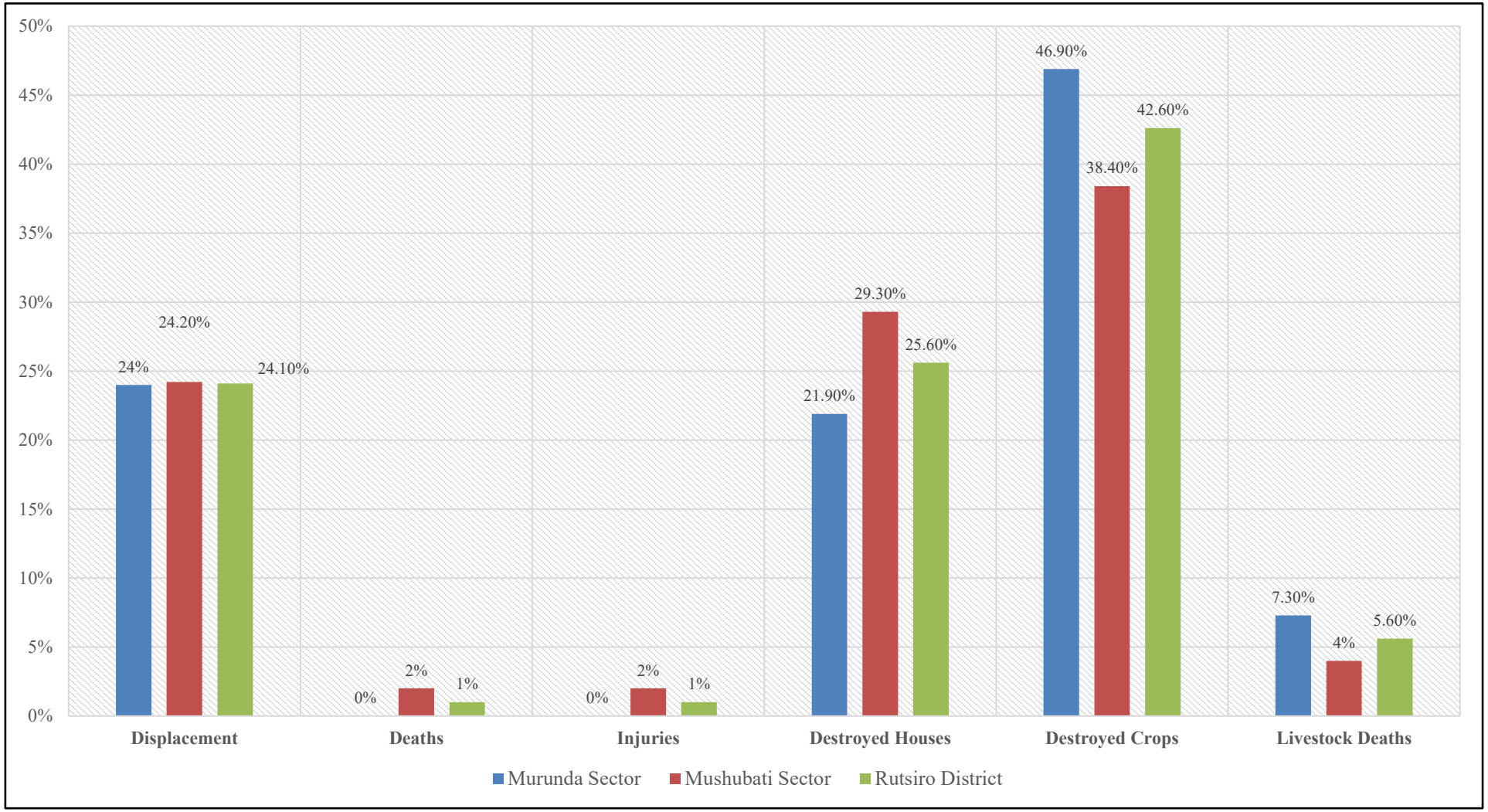
Results and Discussion
Exposure to Landslide in Rutsiro District

- Rutsiro District is highly vulnerable to landslides.
- 82.5% of households are located in high-risk landslide zones.
- 47.2% experienced landslides more than 11 times in the last 30 years.
- Vulnerability is driven by steep slopes, intense rainfall, and high dependence on agriculture (86.2%).
- Murunda Sector is the most vulnerable due to steeper slopes and higher rainfall.



Susceptibility Landslide Map of the Study Area

Results and Discussion (Cont.)
Vulnerability to Landslide in Rutsiro District



Human and Socio-economic Impacts of Landslides in Rutsiro District

Results and Discussion (Cont.)
Impacts of Landslides on Population Displacement

- **Human Impacts**
  - **38.5%** of households were displaced.
  - **1.0%** fatalities and **1.0%** injuries were reported.
- **Economic Impacts**
  - **42.6%** experienced crop damage/destruction.
  - **38.4%** experienced house damage/destruction.
  - **5.6%** reported livestock deaths.
- **Livelihood Impacts**
  - **33.9%** lost soil fertility.
  - **22.6%** experienced housing loss.
  - **13.3%** reported reduced crop yields.
  - **9.2%** experienced income loss.

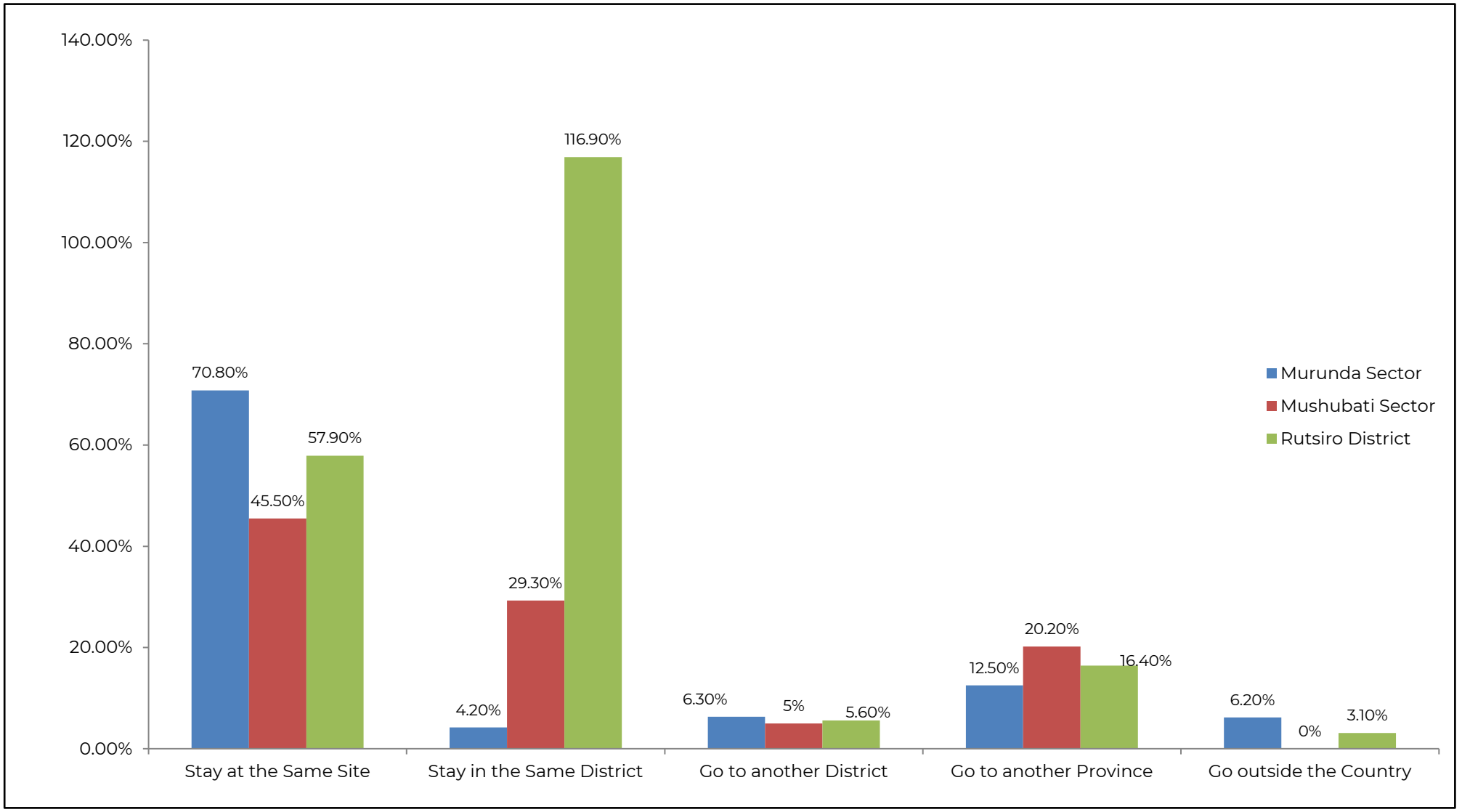






Susceptibility Landslide Map of the Study Area

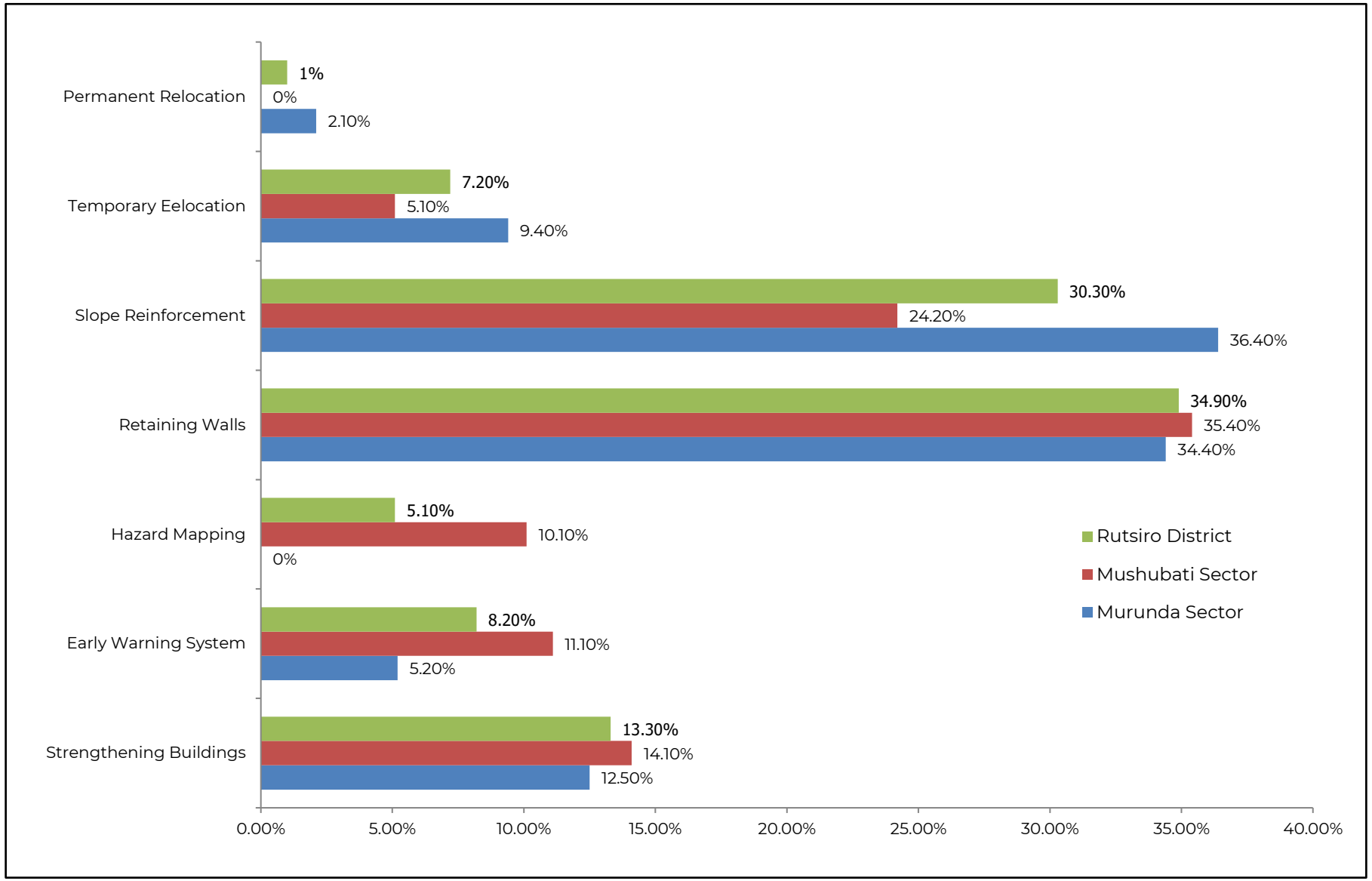
Results and Discussion (Cont.)



Destination Choices among Landslides-induced Displaced People

Results and Discussion (Cont.)

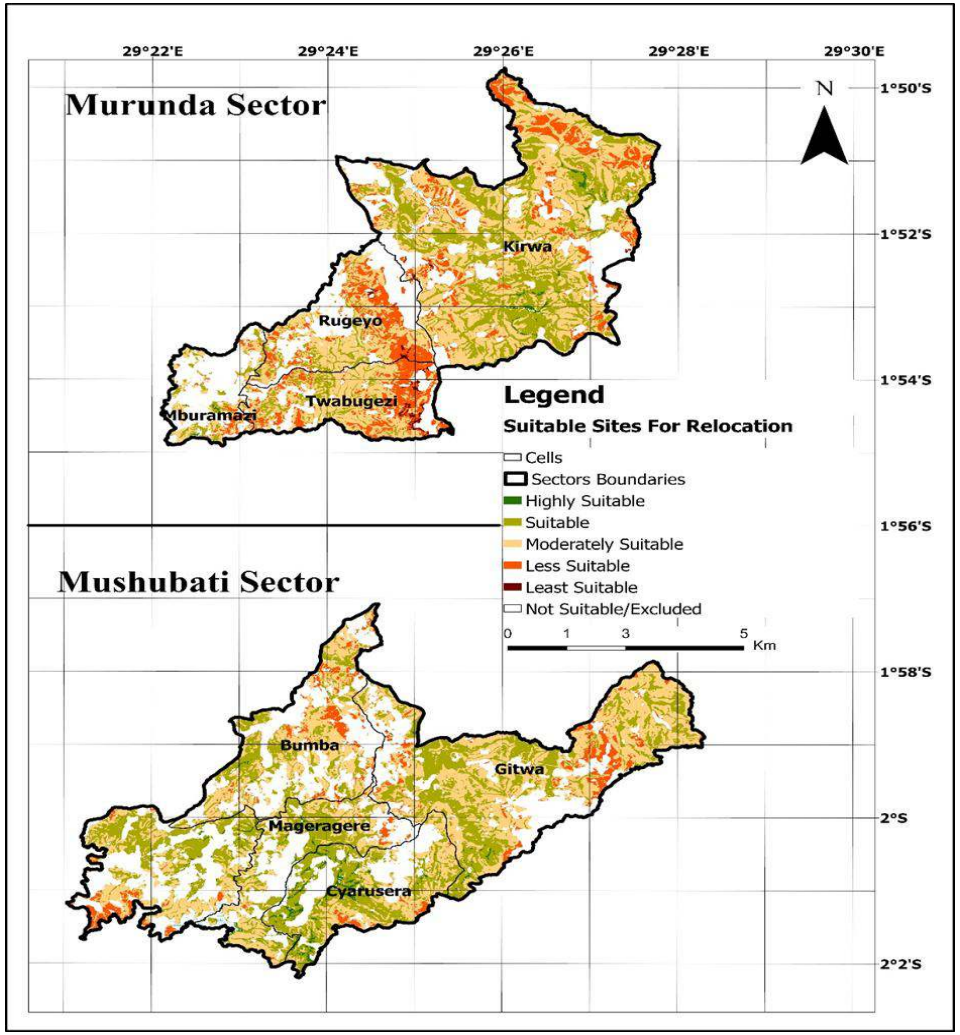
Proposed Solutions to the Problem of Landslide-induced Displacement



Susceptibility Landslide Map of the Study Area

Results and Discussion (Cont.)
Proposed Relocation Sites for Displaced People

- **GIS-MCDA Workflow**
  - Multi-Criteria Decision Analysis (MCDA) using **ArcGIS Pro**.
  - **Weighted Overlay** technique applied to integrate spatial criteria.
  - **Minimum Mapping Unit (MMU)** used to remove very small polygons and improve map usability.
- **Evaluation Criteria**
  - Slope
  - Land Use/Land Cover (LULC)
  - Road accessibility
  - Health facility accessibility
  - Educational facility accessibility
- **Output**
  - Relocation suitability map classified into **five suitability classes.**



Relocation Suitability Map

Conclusion and Recommendations

❖ Conclusion

- Rutsiro District is highly vulnerable to landslides, particularly Murunda and Mushubati, due to steep slopes, intense rainfall, and climate variability.
- 94.3% of respondents observed rainfall changes, and 47.2% experienced more than 11 landslides over the past 30 years.
- Landslides caused major impacts, including crop destruction (42.6%), house destruction (25.6%), population displacement (24.1%), and loss of soil fertility (33.9%).
- Communities preferred structural mitigation (retaining walls 34.9% and slope reinforcement 30.3%) rather than permanent relocation.
- GIS-based MCDA identified 2,453.41 ha (31.64%) as Highly Suitable and Suitable where relocation is unavoidable.

❖ Recommendations

- Strengthening structural mitigation through retaining walls, slope stabilization, and resilient housing with government support.
- Enhancing disaster preparedness by expanding early warning systems, hazard mapping, and community disaster education.
- Promoting livelihood diversification to reduce dependence on agriculture (86.2% of households).
- Using GIS technology to identify suitable sites where relocation is unavoidable.



Thank you for Listening!!!

B) CLIMATE DATA & MONITORING SYSTEMS

Integrated Radiative Index for the Sahel (IRIS): A multivariate satellite-based framework for monitoring hydroclimatic variability

Younousse Biaye [1,*] · El Hadji Dème [1,2] · Bouya Diop [1,3]

[1] LSAO-MED · [2] LERSTAD, Unit of Applied Sciences and Technology (UFR SAT), Gaston Berger University, Saint-Louis, Senegal

[3] CEREMAC, Guinea

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WHAT THIS TALK DELIVERS

1. **One coupled state variable**
   PC1 of 22 coupled channels
2. **Three self-organized regimes**
   from an untuned ±1σ rule
3. **One new observable**
   the radiative TB–T_{2m} dipole

MOTIVATION · THE MEASUREMENT GAP

A coupled machine, diagnosed one variable at a time

Variability is set by the joint configuration of moisture, dynamics and radiation.

1 Covariance is discarded

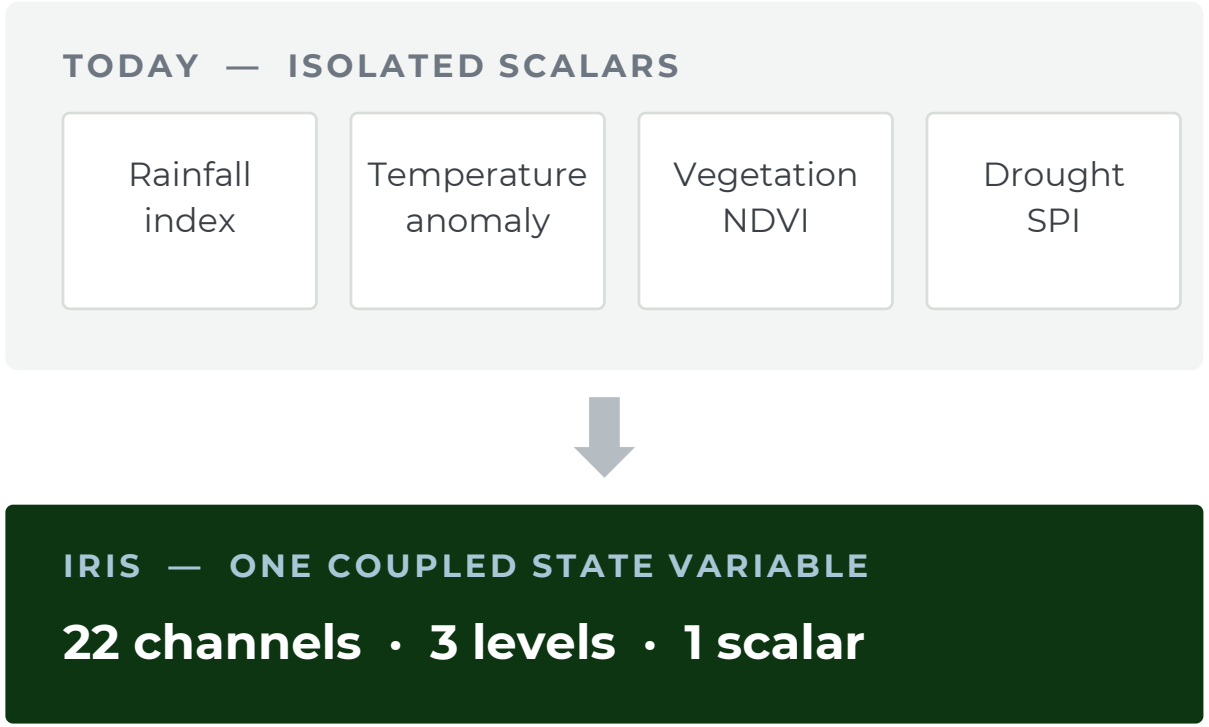
A regime is a joint configuration of variables not any single field.

2 Rainfall arrives too late

Spatially undersampled, temporally intermittent, and available only after the fact.

3 No language for transitions

The abrupt dry ⇄ convective reorganizations matter most and are never diagnosed.



The largest Sahelian storms have tripled in frequency since 1982 (Taylor et al., Nature, 2017) — intensification that no single scalar diagnoses.

CONSTRUCTION · DATA & METHOD

From 22 observed variables to one constrained scalar

Passive microwave sees through the convection that defeats infrared diagnostics.

200 hPa
Upper troposphere · easterly jet

700 hPa
Mid troposphere · monsoon flow

Surface — 2 m
fluxes · soil emissivity

PASSIVE MICROWAVE
19–92 GHz (V / H)

19 GHz · surface window

22 GHz · water vapour

37 GHz · mid-troposphere

85 GHz · ice scattering

92 GHz · upper humidity

PD (V–H) · microphysics

IRIS = v_1^T z · one scalar, 22 coupled dimensions

THE ESTIMATOR, IN THREE STEPS

Standardize $z_i = (x_i - \mu_i) / \sigma_i , \quad i = 1…22$

Diagonalize $R = V \Lambda V^T , \quad \lambda_1 \geq \lambda_2 \geq … \geq \lambda_{22}$

Project $IRIS = v_1^T z , \quad variance = \lambda_1 / \Sigma \lambda_k$

SIGN FIXED BY PHYSICS, NOT BY FIT

IRIS > 0 · dry-radiative — high window TB and T_{2m}, low RH_{700}

IRIS < 0 · moist-convective — 85/92 GHz depressed by ice, high RH_{700}

Archive: harmonized ATOVS-class microwave radiances + ERA5 (Hersbach et al., 2020), 1992–2025, 18°W–45°E, 10°–20°N

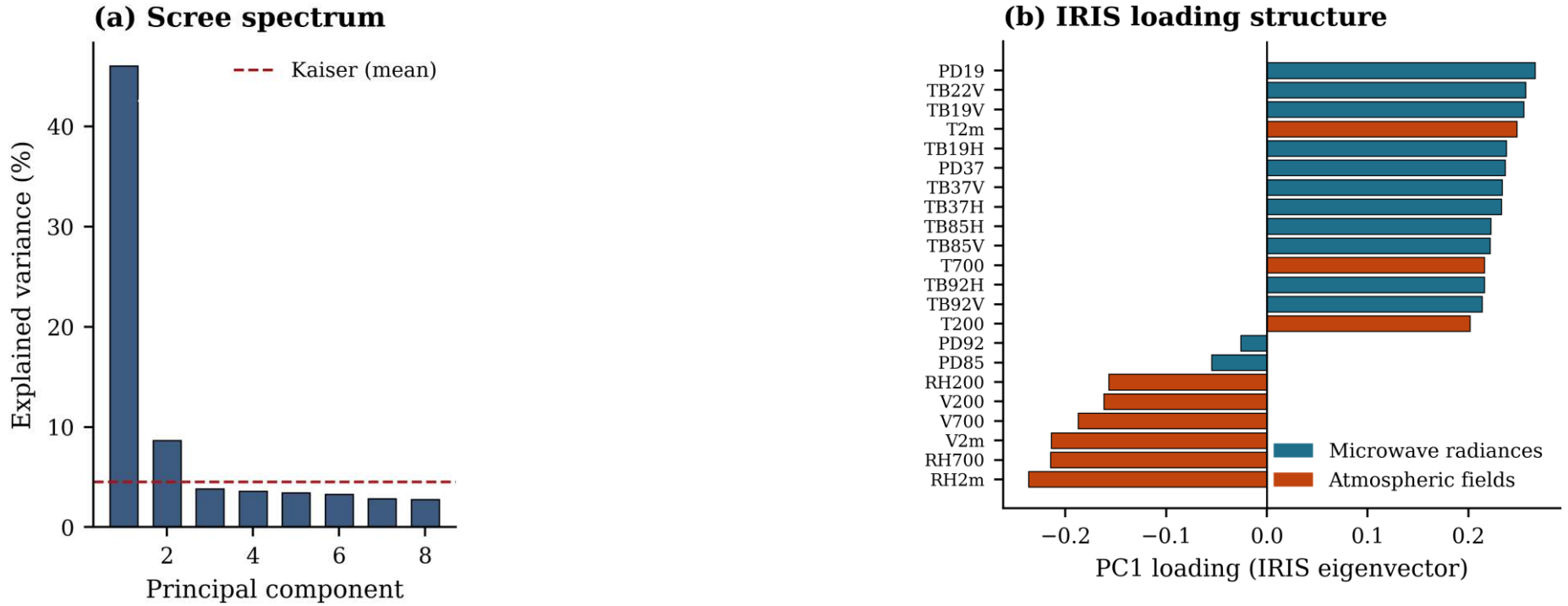
RESULT 1 · STRUCTURE

A single coupled mode organizes the Sahelian state

72.1%
of total variance carried by PC1 the IRIS axis

5.3×
eigenvalue gap over the second mode (10.13 vs 1.91)

22 → 1
coupled dimensions collapsed into one interpretable scalar

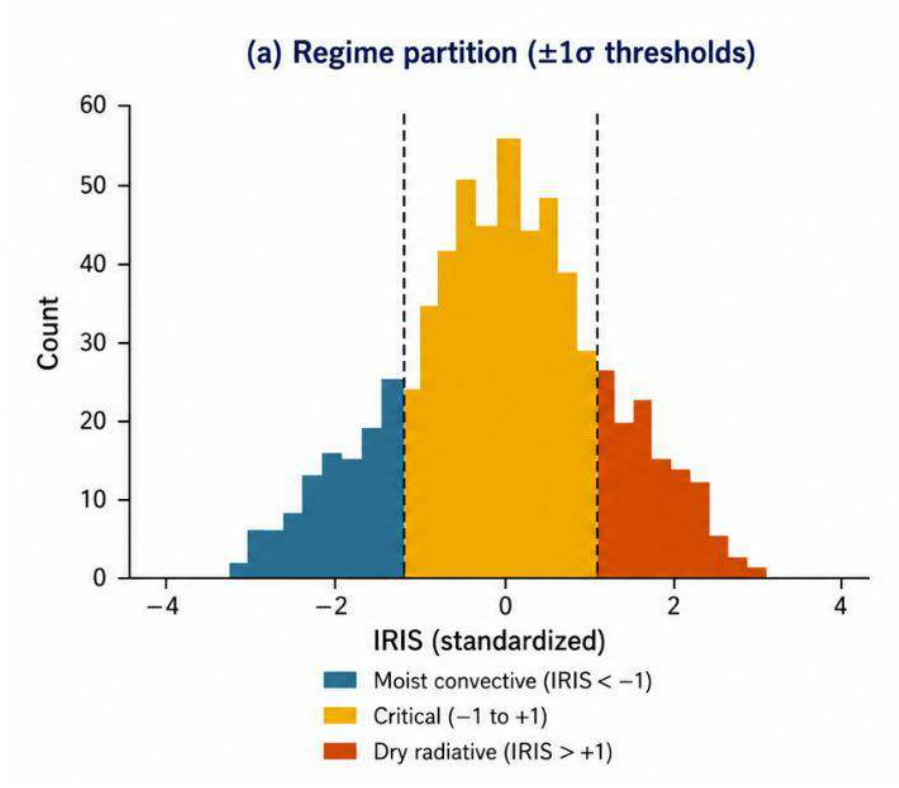


Scree spectrum of the correlation-matrix eigenvalues (left) and the PC1 loading structure (right); microwave radiances in blue, atmospheric fields in orange.

RESULT 2 · REGIMES

Three self-organized regimes from one untuned threshold

Because IRIS is standardized, the natural boundaries are ±1σ nothing is fitted to an outcome.



The Sahel lives in the coupling-amplified critical band.

Moist-convective **14.7%**

IRIS < −1σ

Deep convection · 85/92 GHz depressed by ice · RH_{700} > 70%

Critical **72.1%**

−1σ ≤ IRIS ≤ +1σ

Amplified coupling · bifurcation-prone · most sensitive state

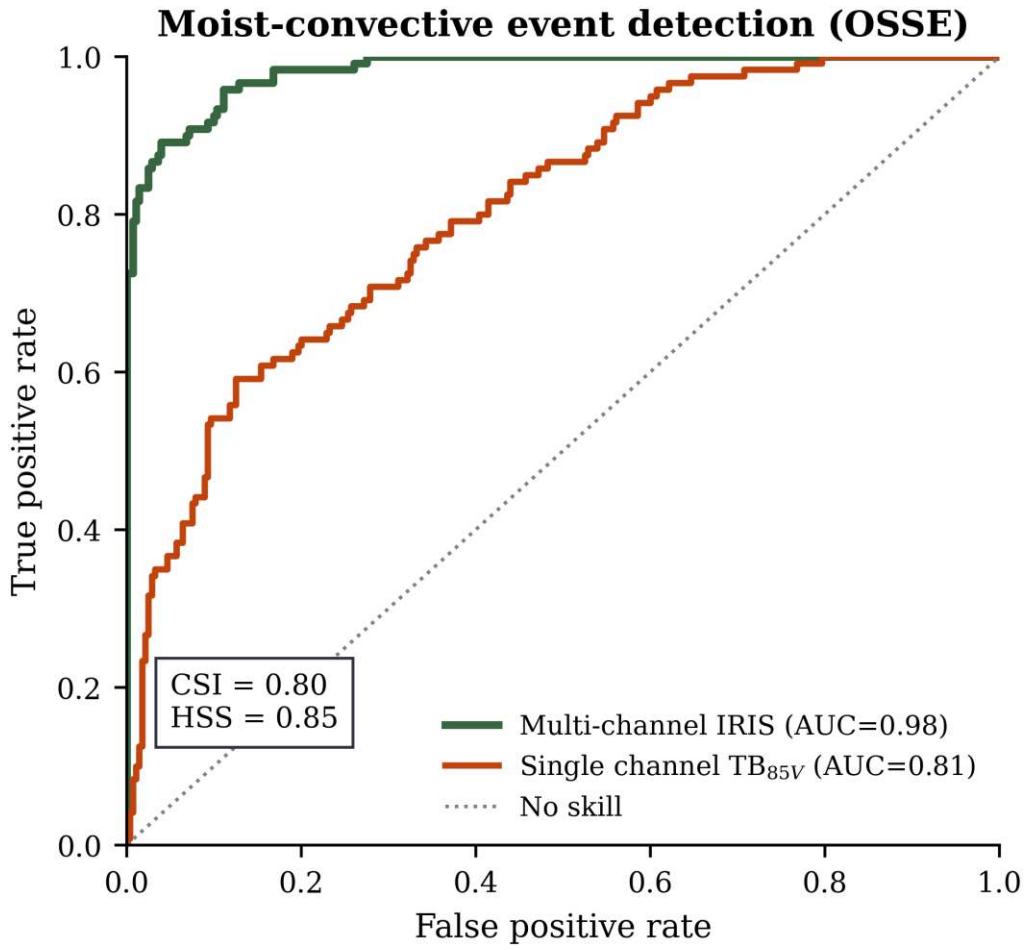
Dry-radiative **15.5%**

IRIS > +1σ

Radiative subsidence · high window TB and T_{2m} · RH < 40%

RESULT 3 · SKILL

Multichannel fusion is operationally decisive



0.98
Multichannel IRIS
area under the ROC curve

0.81
Best single channel — TB_{85V}
the classical convective proxy

CSI = 0.80
critical success index

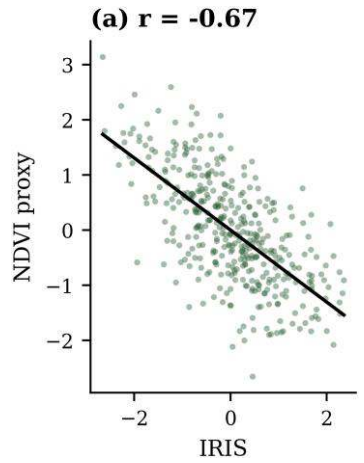
HSS = 0.85
Heidke skill score

The gap between the two curves is the information carried by the joint radiative–thermodynamic–dynamic configuration. Fusion is not elegance — it is skill.

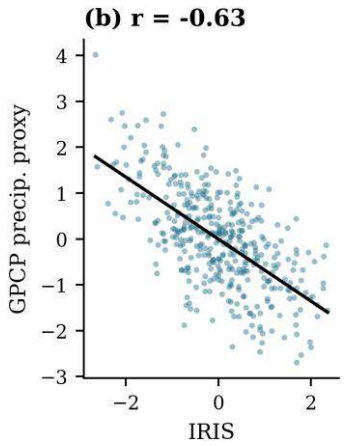
RESULT 4 · INDEPENDENT VALIDATION

Validated against targets it never saw

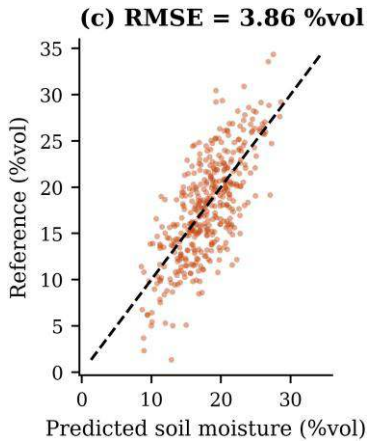
Independent skill and a one-month head start on the biosphere.



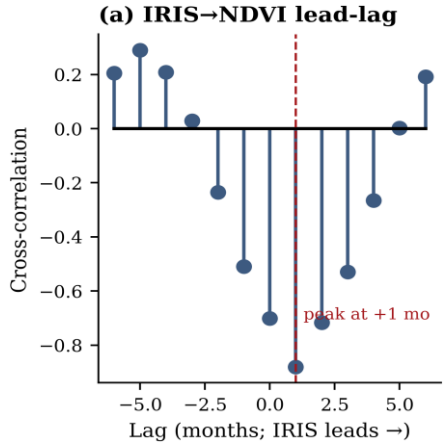
Greenness (NDVI-class) r = −0.67



Precipitation (GPCP-class) r = −0.63



Soil moisture RMSE = 3.86 %vol



Cross-correlation peaks at +1 month, with IRIS leading

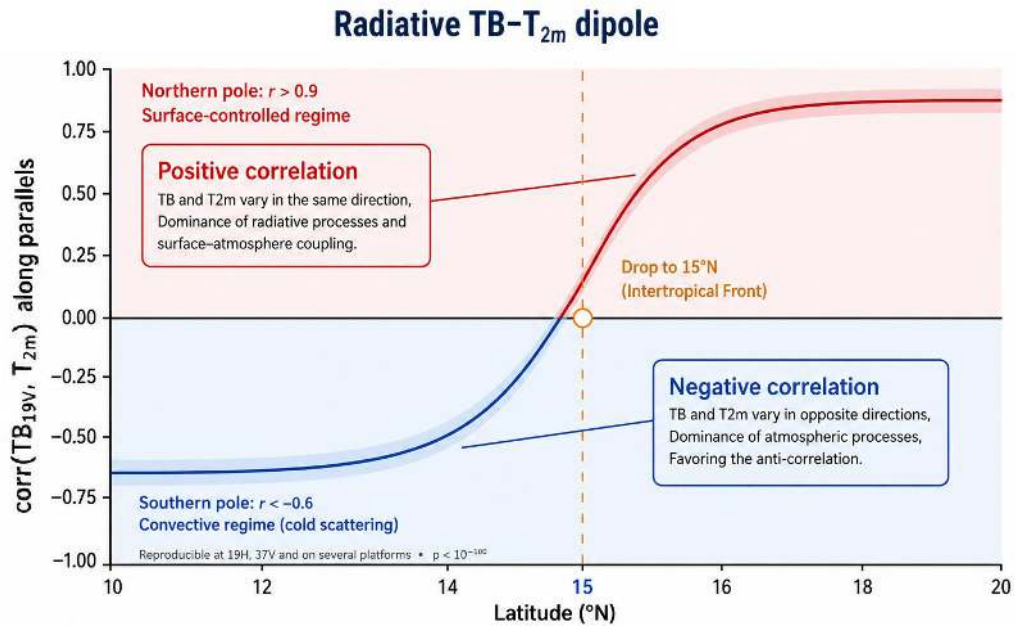
The atmospheric state conditions the surface before the biosphere responds: the lag-1 regression explains **R^2 = 0.78** of greenness variance.

Seasonally aggregated, this is the 4–6-week horizon agro-pastoral decisions use.

Correlations obtained with no reference to the validation targets — the index is not fitted to them.

RESULT 5 · A NEW SPACE-OBSERVABLE

The radiative TB–T_{2m} dipole: the Sahel as a bipolar interface



North of ≈ 15°N — surface-controlled (r > 0)

Low but stable emissivity ties TB to the physical temperature of the bare, hot soil: insolation raises TB and T_{2m} together.

South of ≈ 15°N — convection-controlled (r < 0)

Monsoon convection injects ice-phase hydrometeors that scatter and depress TB, while cloud cover moderates T_{2m}.

Zero-crossing = the Inter-Tropical Front

A space-observable tracer of the surface-to-convection interface. Confirmatory statistic: the zero-crossing latitude, across 19V / 19H / 37V.

Defensible claim: the sign reversal and its latitudinal anchoring — not any single extreme p-value.

OPERATIONAL VALUE

From an index to anticipatory action

One interpretable scalar, one regime language what an early-warning system can use.

1

Tiered drought early warning

Watch — moderately positive IRIS, sustained

Alert — strong, persistent positive anomaly

2

Pre-season monsoon predictor

March–May mean IRIS scores the pre-monsoon state

Negative → vigorous monsoon

Positive → deficient season

3

Vegetation anomaly detection

Project expected greenness from the current IRIS state

The departure isolates water deficit, delay or stress

INSTITUTIONAL INTEGRATION

Sharper vulnerability detection · spatial prioritization · timing of response

Transferability to other semi-arid margins is advanced as a hypothesis for testing — not as a claim of universal validity.

Estimator characterized now, observations next

We state in advance what would falsify IRIS, and we will report the outcome either way.

ESTABLISHED — PHYSICALLY CONSTRAINED OSSE

Estimator properties, recomputed from a calibrated synthetic ensemble (fixed seed)

Explained variance, regime separation, ROC / CSI / HSS, validation correlations

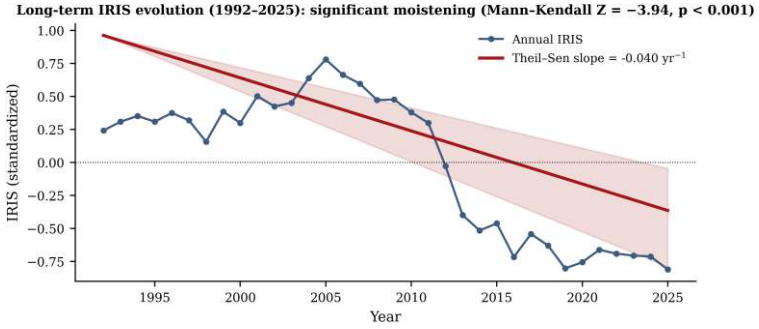
Exactly reproducible today, by anyone

NOT YET ESTABLISHED — AWAITS REAL DATA

The observational magnitude of every statistic shown today

The sign and field-significance of the trend shown at right

Whether the regimes and the dipole survive on real data



Mann–Kendall Z = −3.94, Theil–Sen slope = −0.040 yr^{-1} — an estimator demonstration, not an observed trend.

PRE-REGISTERED CONFIRMATORY ANALYSIS

1. Harmonize the cross-platform ATOVS radiance record
2. Co-locate ERA5 on the common Sahelian grid
3. Recompute PC1 with block-bootstrap intervals
4. Validate on AVHRR/MODIS NDVI, GPCP, soil moisture
5. Test regime stability and the dipole zero-crossing
6. Assess trend with field-significance control

CONCLUSION

One scalar for a coupled system

1. **One dominant coupled mode**
   46.0% of the variance, with physically interpretable loadings
2. **Three self-organized regimes**
   from an untuned ±1σ rule, with the Sahel poised in the critical band
3. **Near-ideal convective detection**
   AUC 0.98 against 0.81 for the best single channel
4. **Independent skill and a one-month lead**
   over the vegetation response, at the horizon decisions use
5. **A new space-observable**
   the radiative TB–T_{2m} dipole, anchored at the Inter-Tropical Front

THE CLAIM

From descriptive climatology toward physically grounded, falsifiable diagnosis reproducible today, confirmable next.

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Thanks to LSAO-MED and LERSTAD (UGB), the ATOVS/PMW programmes, and the Copernicus Climate Change Service.

B) CLIMATE DATA & MONITORING SYSTEMS

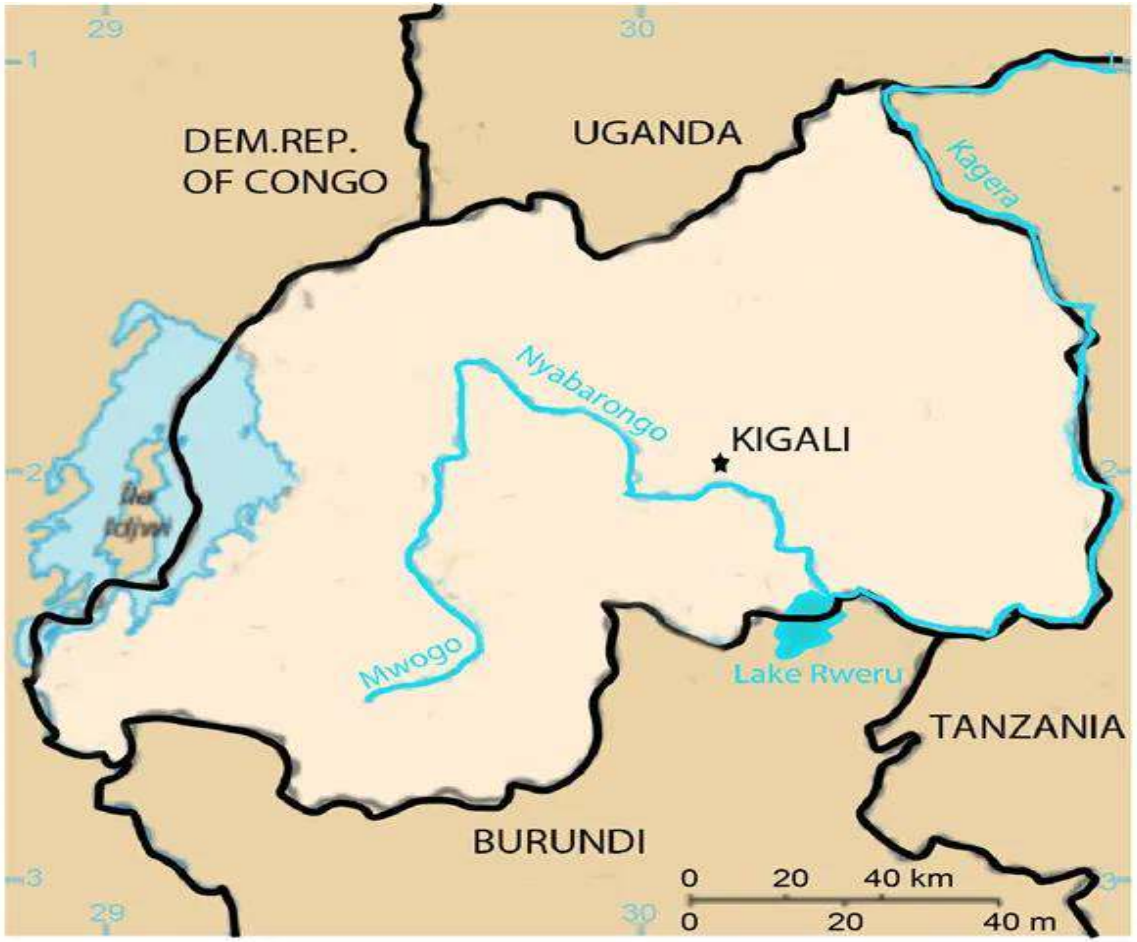
Sentinel-1 SAR Flood Extent Mapping of the Nyabarongo–Kigali Corridor, Rwanda

Stephen Nyaranga[13] | Prof. Dr. Mouhamadou Bamba Sylla[1] | Dr. Ben Howard[2] | Prof. Dr. Wouter Buytaert[2] | Dr. Mercy Mwaniki[3]

[1] AIMS-RIC, Kigali, Rwanda |
[2] Imperial College London, UK |
[3] Jomo Kenyatta University of Agriculture and Technology(JKUAT), Kenya |

snyaranga@aimsric.org | CLARITY-Africa Wellcome Trust Programme

Introduction: Why Flood Mapping Matters in Rwanda

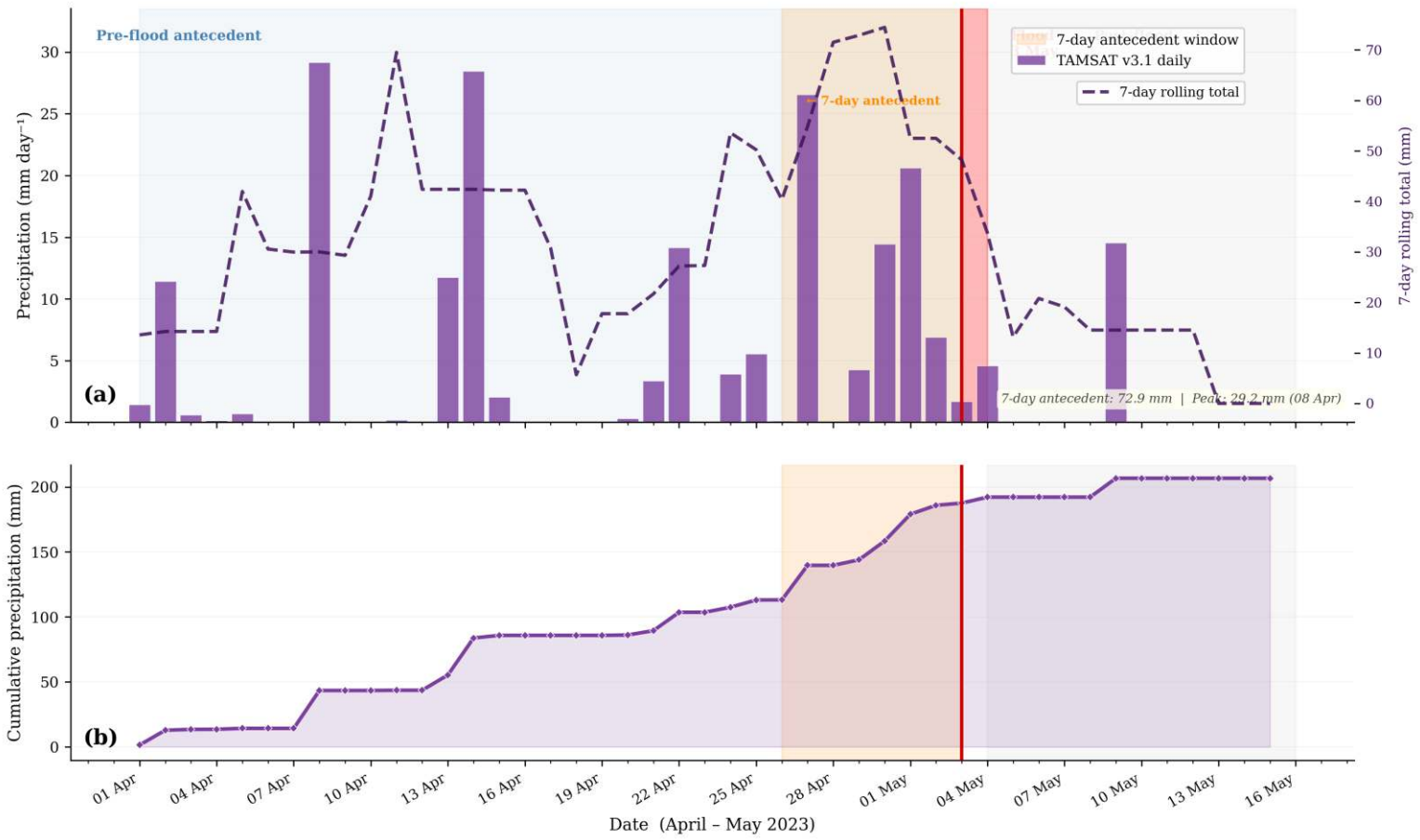




- Flooding is Rwanda's most frequent and economically damaging natural hazard, affecting farmland, wetlands and informal settlements in and around Kigali every rainy season.
- Persistent cloud cover across the central highlands makes optical satellite imagery unreliable during flood events. Synthetic Aperture Radar (SAR) operates day and night through cloud and rain, making it the only practical tool for near-real-time flood mapping in this environment.

[1] Ranasinghe et al. (2021) Climate change information for regional impact and risk assessment. IPCC AR6 WGI Ch.12 — Sylla MB contributing author.
[2] Diedhiou A., ..., Sylla MB et al. (2018) Changes in climate extremes over West and Central Africa at 1.5°C and 2°C. Environ. Res. Lett. 13, 065020.
[3] MINEMA (2020) Rwanda Disaster Statistics 2011–2019. Ministry of Emergency Management, Kigali.

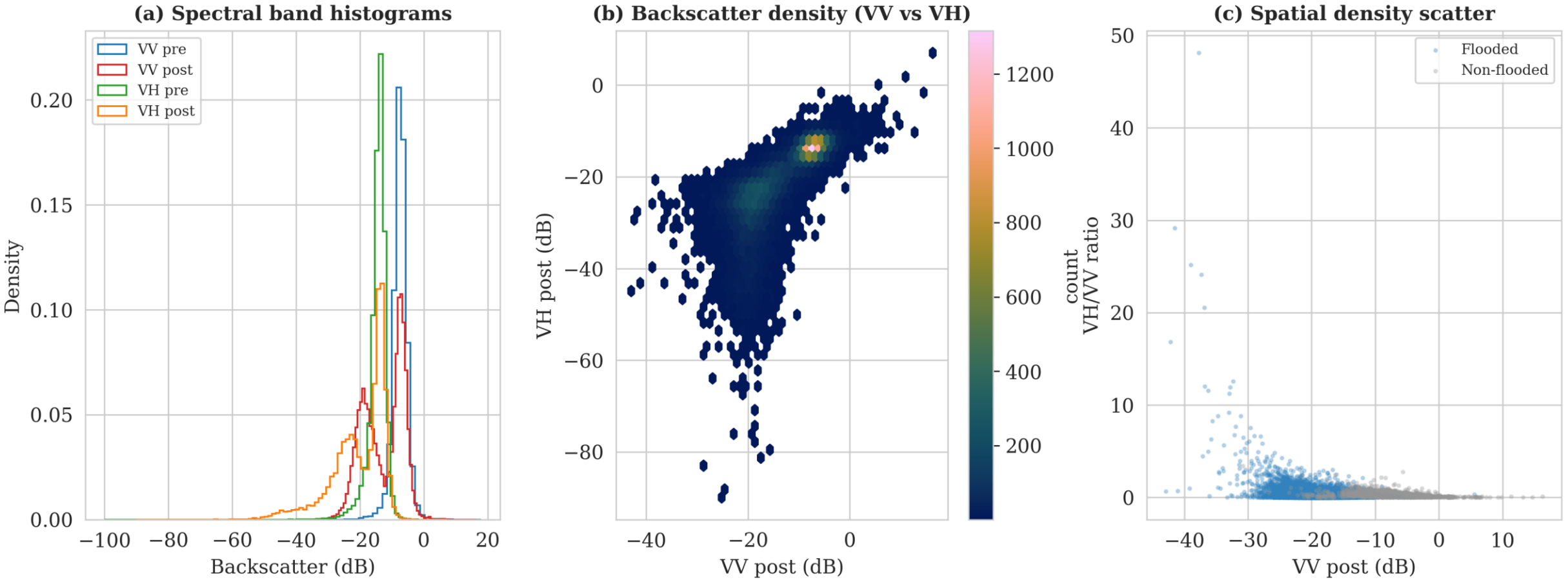
Rainfall Context: TAMSAT v3.1 Daily Precipitation, April–May 2023



Panel (a): daily rainfall bars with 7-day rolling total (right axis). Panel (b): cumulative precipitation. The red line marks the flood acquisition date (3 May 2023); the orange shading highlights the 7-day antecedent window (72.9 mm total).

[4] Maidment R.I. et al. (2017) A new, long-term daily satellite-based rainfall dataset for operational monitoring in Africa. Sci. Data 4, 170063. https://doi.org/10.1038/sdata.2017.63

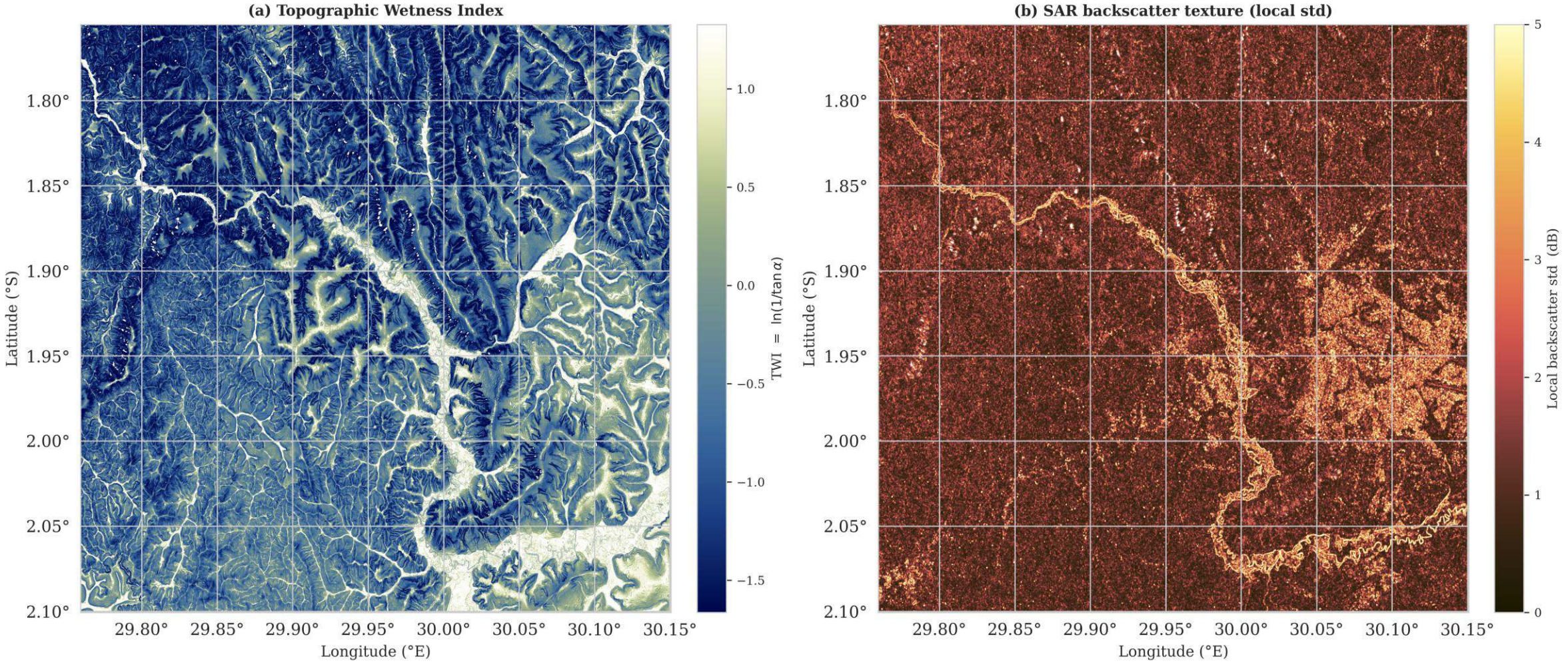
SAR Feature Analysis: Spectral Histograms and Backscatter Density



Panel (a): pre- and post-flood VV/VH backscatter density distributions showing the flood-induced shift to lower VV values. Panel (b): joint VV–VH density hex plot highlighting the spectral separation of open-water pixels. Panel (c): VH/VV ratio scatter separating flooded from non-flooded pixels.

[5] Small D. (2011) as above.

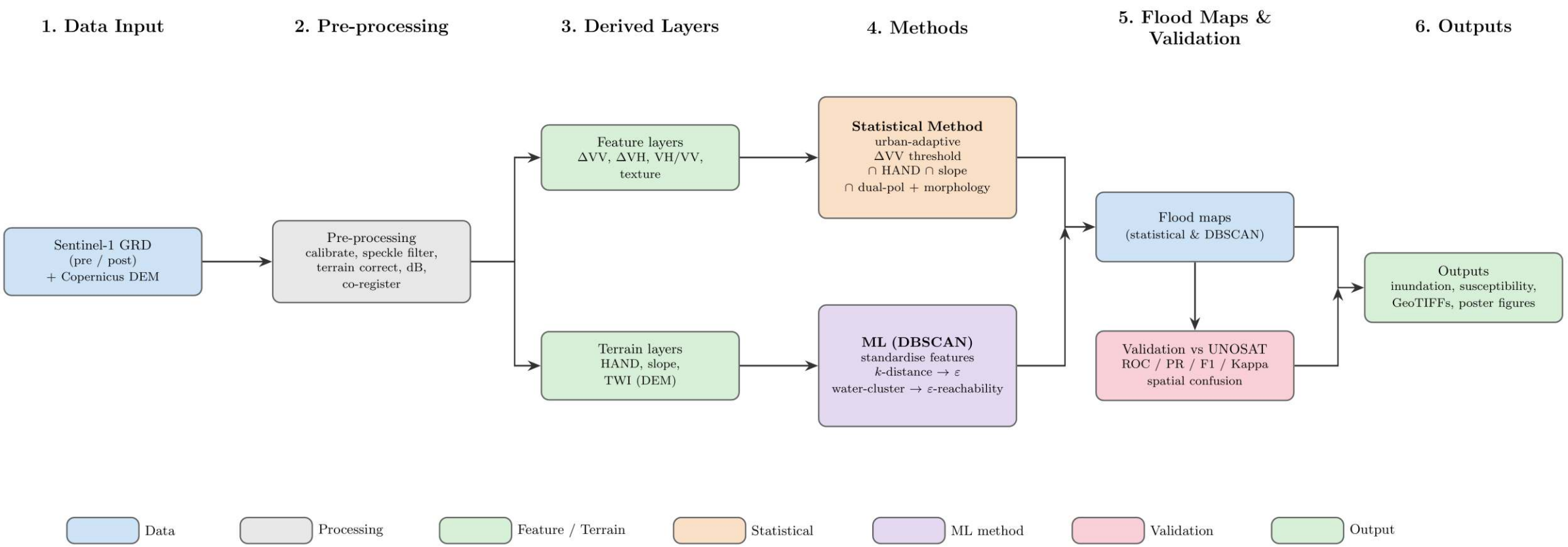
Terrain and Urban Diagnostic Maps: TWI and SAR Texture



Panel (a): Topographic Wetness Index (TWI = ln(1/tanα)), high values in white delineate drainage channels and valley floors, motivating the terrain constraint. Panel (b): local standard deviation of post-flood VV backscatter (7×7 window), elevated texture in the flood corridor motivates the urban-adaptive threshold.

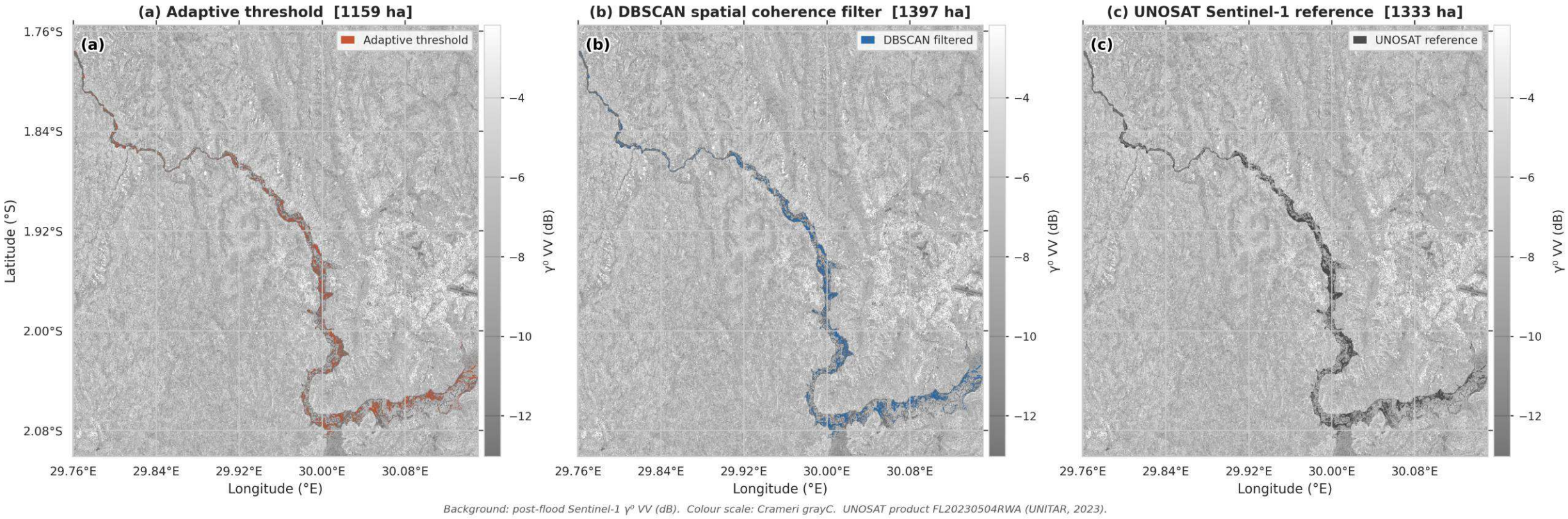
[7] Nobre A.D. et al. (2011) Height Above the Nearest Drainage, a hydrologically relevant new terrain model. J. Hydrol. 404, 13–29.

MCAFM Pipeline: Multi-Constraint Adaptive Flood Mapping Framework



The pipeline routes Sentinel-1 SAR and Copernicus DEM through six stages: data input, radiometric preprocessing, feature and terrain layer extraction, dual-path detection (statistical + DBSCAN ML), flood map generation, and UNOSAT-referenced validation.

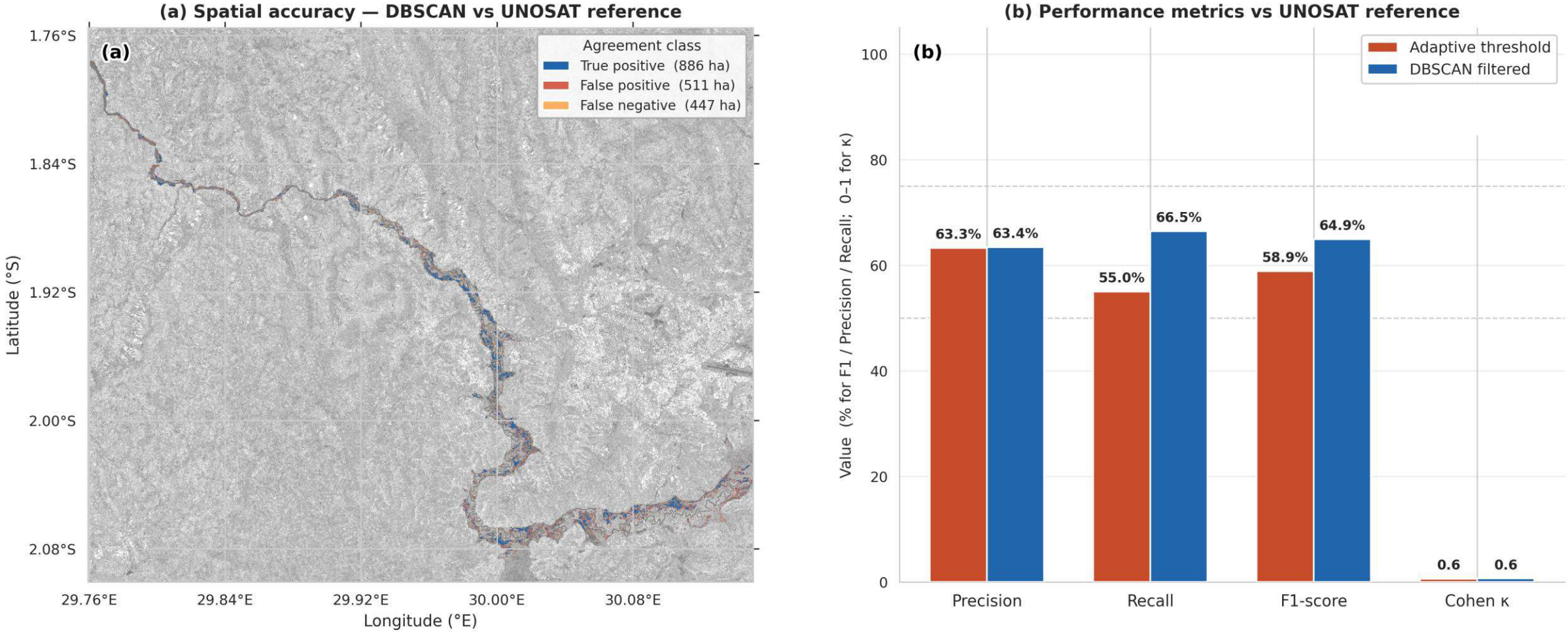
Flood Extent Results: Adaptive Threshold, DBSCAN Filter, and UNOSAT Reference



All panels show post-flood VV (Crameri grayC) as background. Panel (a): adaptive threshold product (1,159 ha). Panel (b): DBSCAN-filtered MCAFM product (1,397 ha). Panel (c): UNOSAT Sentinel-1 emergency reference (FL20230504RWA, 1,333 ha). The DBSCAN filter removes isolated noise while preserving spatially coherent flood patches.

[8] UNOSAT – UNITAR (2023) Flood Extent Map, Kigali, Rwanda, 3 May 2023. Product FL20230504RWA. Geneva: UNITAR.

Accuracy Assessment: Spatial Agreement and Performance Metrics vs UNOSAT

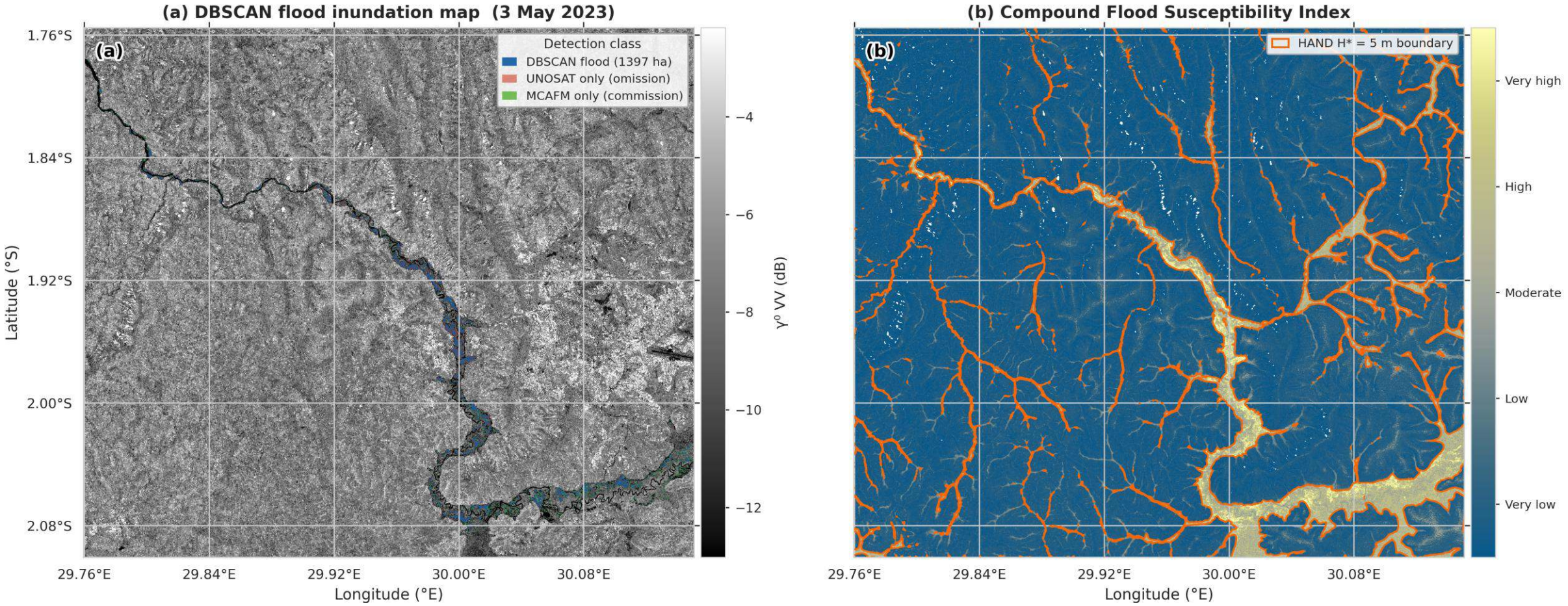


UNOSAT reference: FL20230504RWA (UNITAR, 2023). TP = correctly detected; FP = commission error; FN = omission error. Background: post-flood γ^0 VV (Crameri grayC).

Panel (a): spatial confusion map, blue: true positive (886 ha), red: false positive (511 ha), orange: false negative (447 ha). Panel (b): performance metrics comparing the adaptive threshold and DBSCAN-filtered products against UNOSAT; DBSCAN improves F1 score from 58.9% to 64.9% and Cohen κ from 0.60 to 0.65.

[8] UNOSAT - UNITAR (2023) as above.

Flood Susceptibility: Inundation Map and Compound Susceptibility Index



*Panel (a): DBSCAN flood inundation map overlaid on post-flood VV, showing detection class (TP, FP commission, FN omission). Panel (b): Compound Flood Susceptibility Index (FSI = 0.35*H-norm + 0.20*S-norm + 0.15*W-norm + 0.30*D-norm); the orange contour marks the HAND H* = 5 m floodplain boundary.*

[7] Nobre A.D. et al. (2011) as above.

Conclusion

- MCAFM delineated 1,397 ha and UNOSAT reference: 1,333 ha (bias +4.8%)
- F1 = 64.9%, Precision = 63.4%, Recall = 66.5%, Cohen κ = 0.646 (substantial agreement)
- HAND terrain masking reduced false positives by 2.3–3.1× on steep hillsides
- Urban-adaptive VV thresholding reduced commission errors ~1.8× in peri-urban zones
- Pipeline is rerunnable without labelled training data, directly applicable to Rwanda's disaster risk reduction operations

B) CLIMATE DATA & MONITORING SYSTEMS

22 September 2025, 14:15 – 15:30 PM, Breakout Room I

Assessing the Impact of Irrigation and Crop Type on Soil Respiration in Agricultural Soils

Author : Therese Ave Maria
Affiliation : University of Rwanda – College of Agriculture, Forestry and Food Sciences (CAFF)
Email : t.avemaria@ur.ac.rw

BACKGROUND & RATIONALE

- Agricultural soils are an important component of the terrestrial carbon cycle.
- Soil respiration is a major pathway of CO_2 exchange between soils and the atmosphere.
- Soil CO_2 emissions vary with crop type, management practices, plant development, and soil conditions.
- With Rwanda expanding irrigation and agricultural intensification, understanding their climate implications is increasingly important.

Why Field Monitoring?

From agricultural management to climate evidence

AGRICULTURAL PRACTICES

- Crop choice
- Irrigation
- Fertilization

SOIL & PLANT PROCESSES

- Root activity
- Microbial activity
- Carbon turnover

CLIMATE DATA & MONITORING



- Temperature
- Soil moisture
- Water level
- Solar radiation

CO_2

Soil CO_2 flux

(mg CO_2 m^{-2} h^{-1})

EVIDENCE FOR DECISION-MAKING

- Climate-smart agriculture
- Water management
- Emission assessment

KEY MESSAGE: Reliable field measurements are needed to understand how agricultural management affects carbon emissions under real Rwandan conditions.

Rwandan agricultural systems | Field-based monitoring | CO_2 Data for climate action

THE KNOWLEDGE GAP

- Limited field-based evidence from tropical marshland agroecosystems.

- Few studies simultaneously evaluate:
  - Multiple crop types
  - Irrigated and rainfed systems
  - Crop-covered and non-vegetated soil
  - Different crop growth stage

- Short-term or controlled experiments may not capture the complexity of real agricultural conditions.

RESEARCH QUESTION & OBJECTIVES

Research question

How do crop type and water management influence soil CO_2 emissions under marshland agricultural conditions in Rwanda?

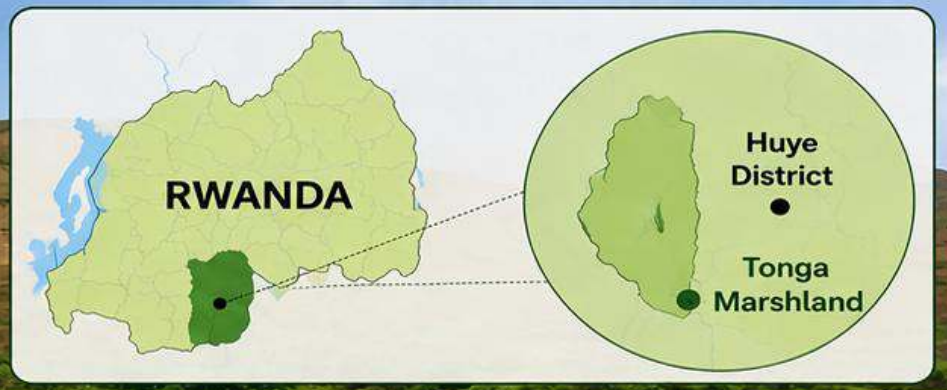
Objectives

- Assess the effects of crop type and irrigation on soil CO_2 emissions.
- Compare emissions between crop-covered and non-vegetated soil.
- Evaluate variation across crop growth stages and seasons.
- Examine relationships between CO_2 emissions and environmental drivers.

2ND RWANDA CLIMATE SCIENCE SYMPOSIUM 2026

STUDY SITE

Tonga Marshland, Huye District, Rwanda



SITE DESCRIPTION

- Huye District, Southern Province, Rwanda
- University of Rwanda experimental site
- Upper part of the marshland
- Transitional zone between upland and permanently waterlogged conditions

CLIMATE CONTEXT

- Tropical savanna climate
- Annual rainfall: ~1,200–1,400 mm
- Bimodal rainfall pattern
- Two cropping seasons

STUDY PERIOD

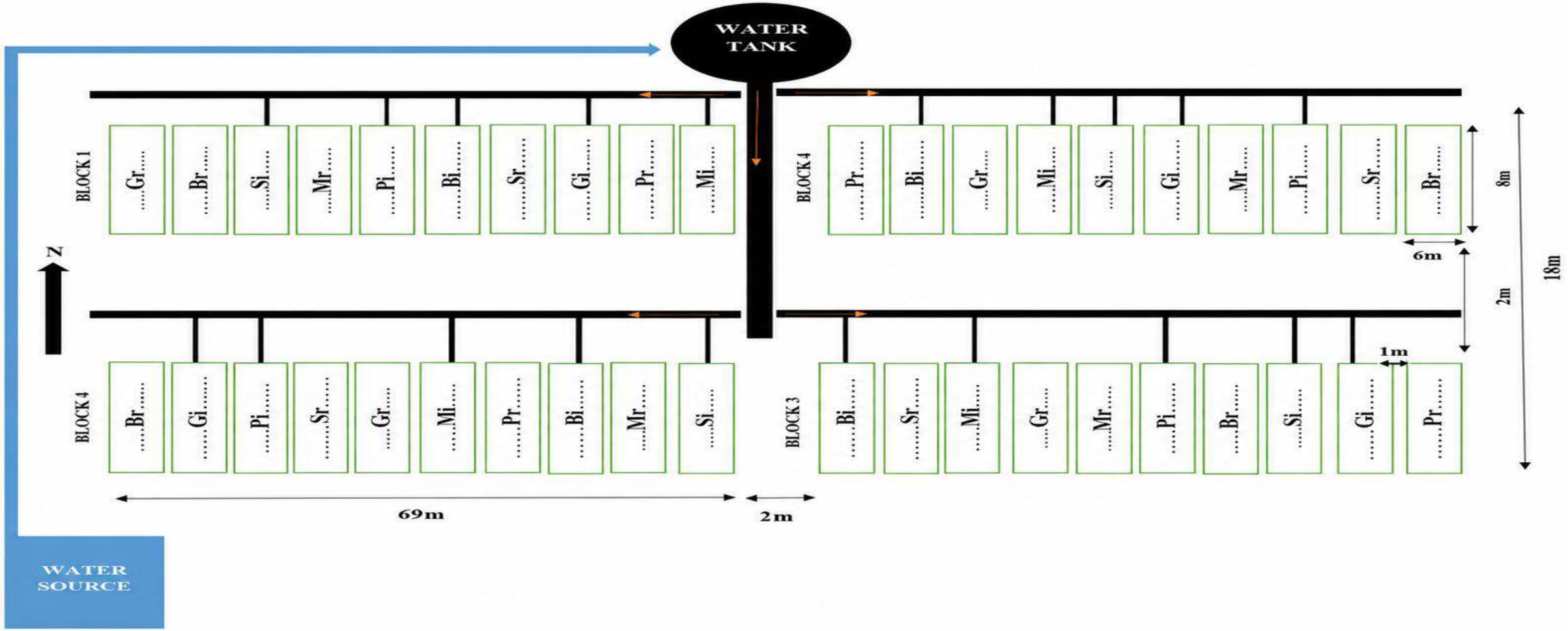
September 2024 – June 2025

FOCUS

Understanding how irrigation, crop type and crop development influence soil CO_2 emissions under real field conditions.

Generating reliable field data to support climate-smart agriculture and policy decisions in Rwanda.

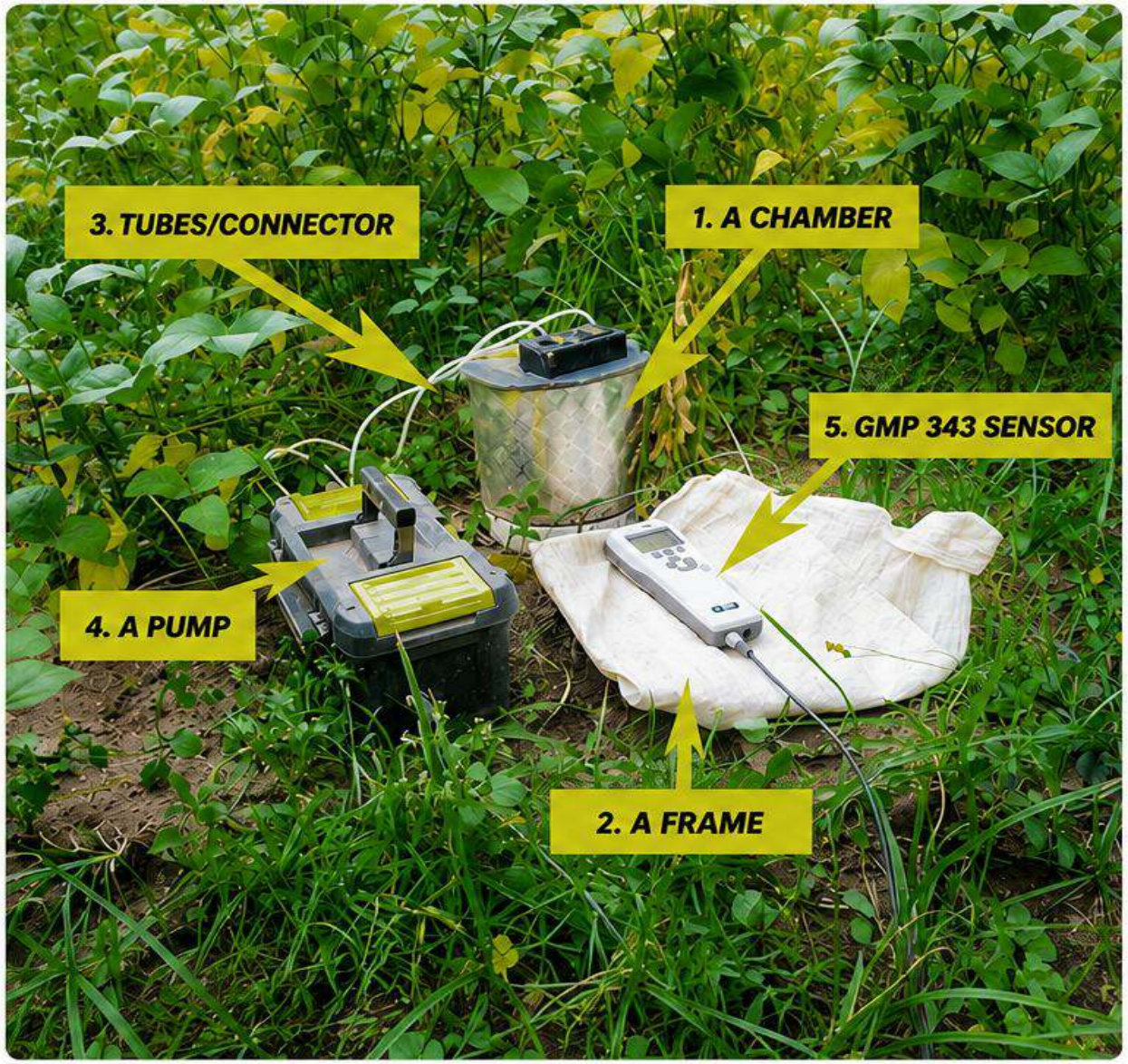
Experimental Design



CROP &,' WATER-REGIME CODES

Gr	Brachiaria – Rainfed	**Si**	Soybean – *Irrigated*
Gi	Brachiaria – Irrigated	**Br**	Common bean – Rainfed
Mr	Maize – Rainfed	**Bi**	Common bean – Irrigated
Mi	Maize – Irrigated	**Pr**	Irish potato – Rainfed
Sr	Soybean – Rainfed	**Pi**	Irish potato – Irrigated

CLIMATE DATA & CO_2 MONITORING SYSTEM



How were climate and soil CO_2 data collected?

Closed static chamber

↓

CO_2 sensor

↓

CO_2 concentration every 15 seconds

↓

3-minute measurement period

↓

Rate of concentration change

↓

Soil CO_2 flux

Environmental variables monitored

- Air temperature
- Soil temperature
- Soil moisture
- Groundwater level
- Photosynthetically Active Radiation (PAR)

Turning Field Measurements into CO_2 Flux

CO_2 concentration

↓

Change in concentration over time

$\Delta C/\Delta t$

↓

Chamber volume & surface area

↓

Temperature & atmospheric pressure

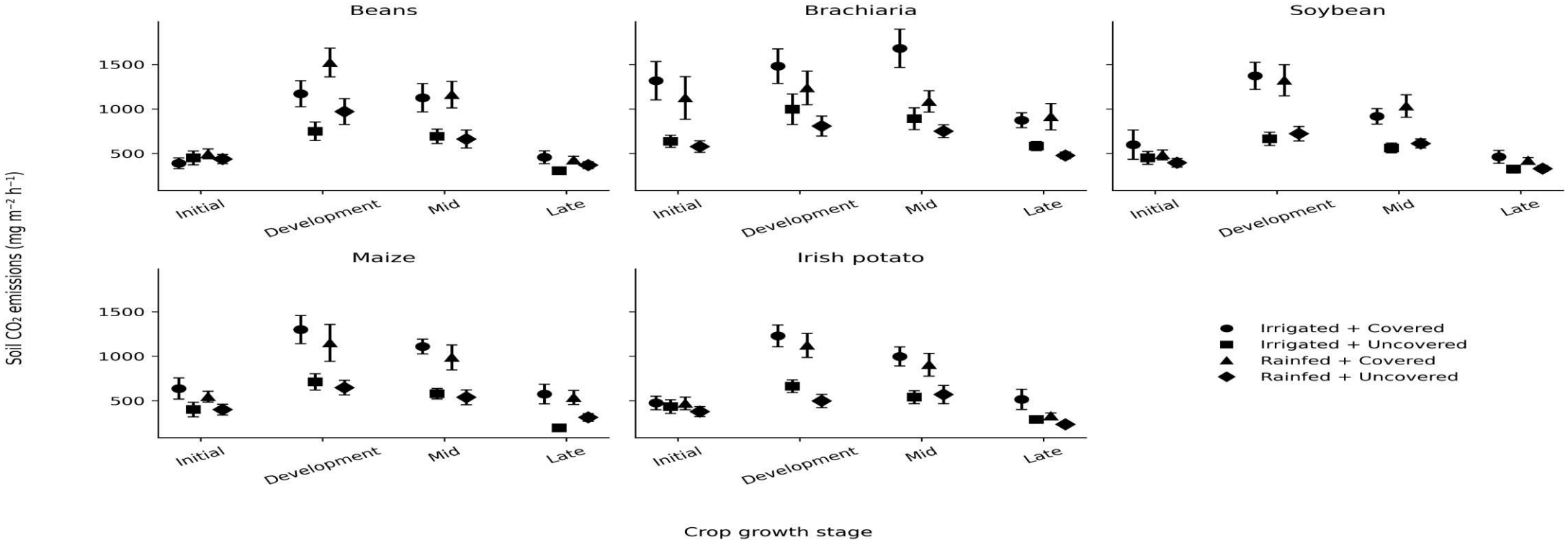
↓

CO_2 FLUX(mg CO_2 m^{-2} h^{-1})

Statistical Analysis (using R)

Linear mixed-effects models + Type III ANOVA +Tukey-adjusted comparisons

FINDING 1: CROP TYPE & GROWTH STAGE



- Crop type significantly affected emissions ($p < 0.001$).
- Growth stage significantly affected emissions ($p < 0.001$).
- Brachiaria generally recorded the highest emissions, while Irish potato was generally the lowest.
- Emissions were generally highest during the development stage.

Key takeaway: **Crop type and growth stage were stronger drivers of soil CO_2 emissions**

FINDING 2: IRRIGATION DID NOT INCREASE SOIL CO_2

- Irrigation effect on soil CO_2
  ❌ Not significant ($p = 0.073$)

- But irrigation significantly increased crop yield
  ✅ $p < 0.001$

Key finding

- Irrigation → Higher productivity → No significant increase in total soil CO_2

Climate implication

Irrigation can improve agricultural productivity without necessarily increasing total soil CO_2 emissions under the study conditions.

FINDING 3: PRODUCTIVITY VS EMISSION INTENSITY

- Irrigation significantly reduced yield-scaled CO_2 emissions for:

  Beans - $p = 0.018$
  Irish potato - $p < 0.001$

- For maize, soybean and Brachiaria, reductions were not statistically significant.

Key message

- **Higher productivity without proportional increases in soil CO_2 can improve production efficiency.**

FINDING 4: FERTILIZATION & ENVIRONMENTAL MONITORING

Fertilization

Soil CO_2 increased after fertilization

Significant increases occurred for:

- Beans
- Maize
- Irish potato
- Soybean

Environmental monitoring

- PAR was the only environmental variable significantly associated with CO_2 emissions
- Soil moisture, soil temperature and groundwater level were not significant predictors

FROM RESEARCH TO POLICY

1. Promote productivity with climate efficiency

Irrigation can increase crop productivity without necessarily increasing total soil CO_2 emissions.

2. Use yield-scaled emissions

Assess climate performance **per unit of agricultural production**, not only absolute emissions.

3. Adopt crop-specific management

Crop type and growth stage strongly influence soil CO_2 emissions.

4. Strengthen field-based climate monitoring

Repeated measurements of soil CO_2, soil moisture, temperature and other environmental variables can improve Rwanda's evidence base.

5. Integrate climate and agricultural decisions

Irrigation, crop choice, fertilization and productivity should be evaluated together.

LIMITATIONS

- Single marshland site → limits generalization to other agroecosystems.
- Two cropping seasons → longer-term variability was not captured.
- Moderate sample size → may limit detection of short-term effects.
- Total soil respiration measured → root and microbial contributions could not be separated.
- Rainfall before sampling may have reduced differences between irrigated and rainfed plots.

Future directions : Conduct long-term, multi-site studies across different climatic conditions.

THANK YOU!!!!!!!!!!!!!!

2ND RWANDA CLIMATE SCIENCE SYMPOSIUM 2026
Where Rwanda's climate research meets policy

Climate-Sensitive Energy Demand Modelling in Togo Using LEAP Under IPCC AR6 Scenarios

AUTHORS

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BACKGROUND AND CONTEXT

From international commitments to national energy planning

GLOBAL COMMITMENTS

International climate agreements (e.g. the Paris Agreement) commit countries to climate action.

NATIONAL STRATEGIC DOCUMENTS

Countries translate these commitments into strategic documents.
NDCs and Long-Term Low-Emission Development Strategies (LT-LEDS).

PLANNING TOOLS

In the energy sector, these strategies are largely built using LEAP — the most widely used long-term energy-planning platform.

LEAP IN THE ENERGY-PLANNING CONTEXT

WHAT IS LEAP ?

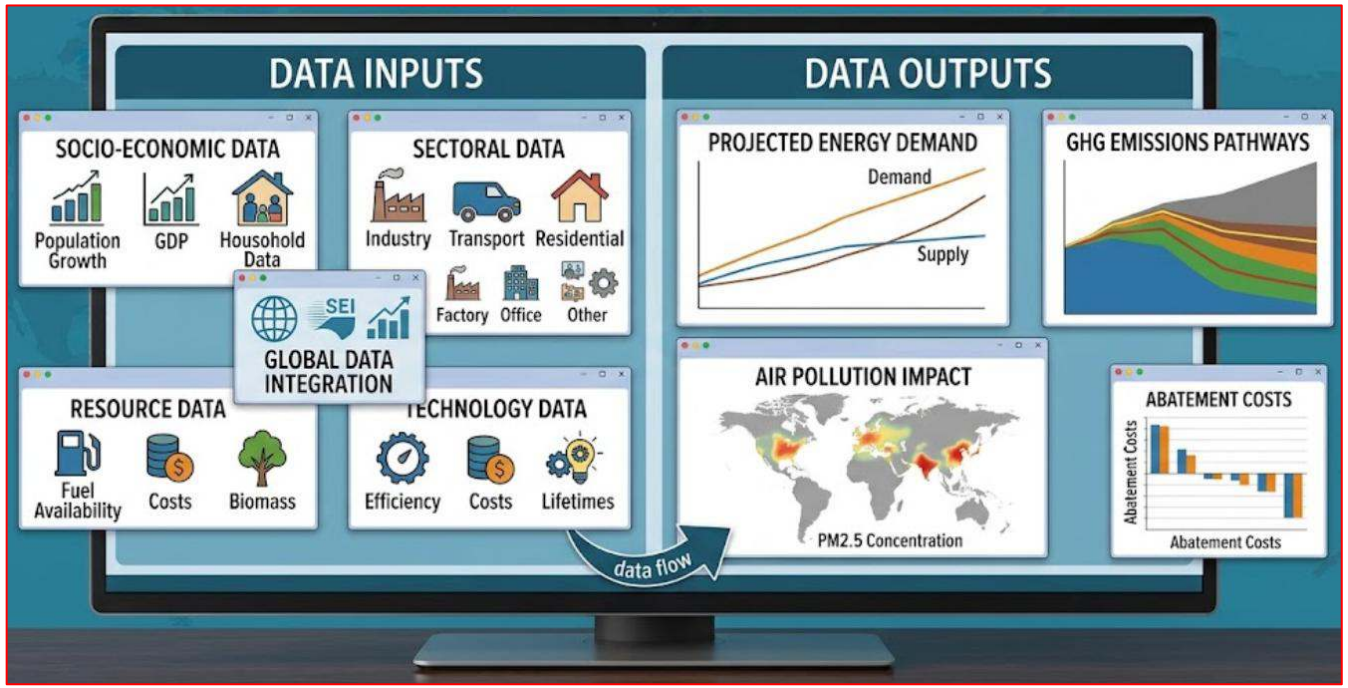
A scenario-based, bottom-up accounting tool for long-term energy and climate-policy analysis

Low Emissions Analysis Platform

Developed by SEI and in active use across more than 190 countries

USED TO BUILD

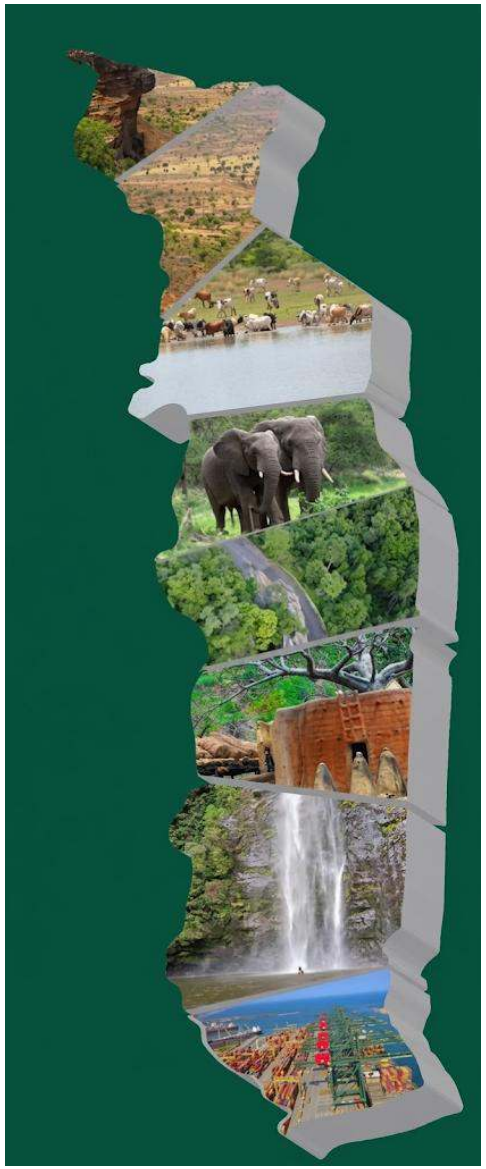
- NDCs
- Long-Term Low-Emission Development Strategies
- National energy plans

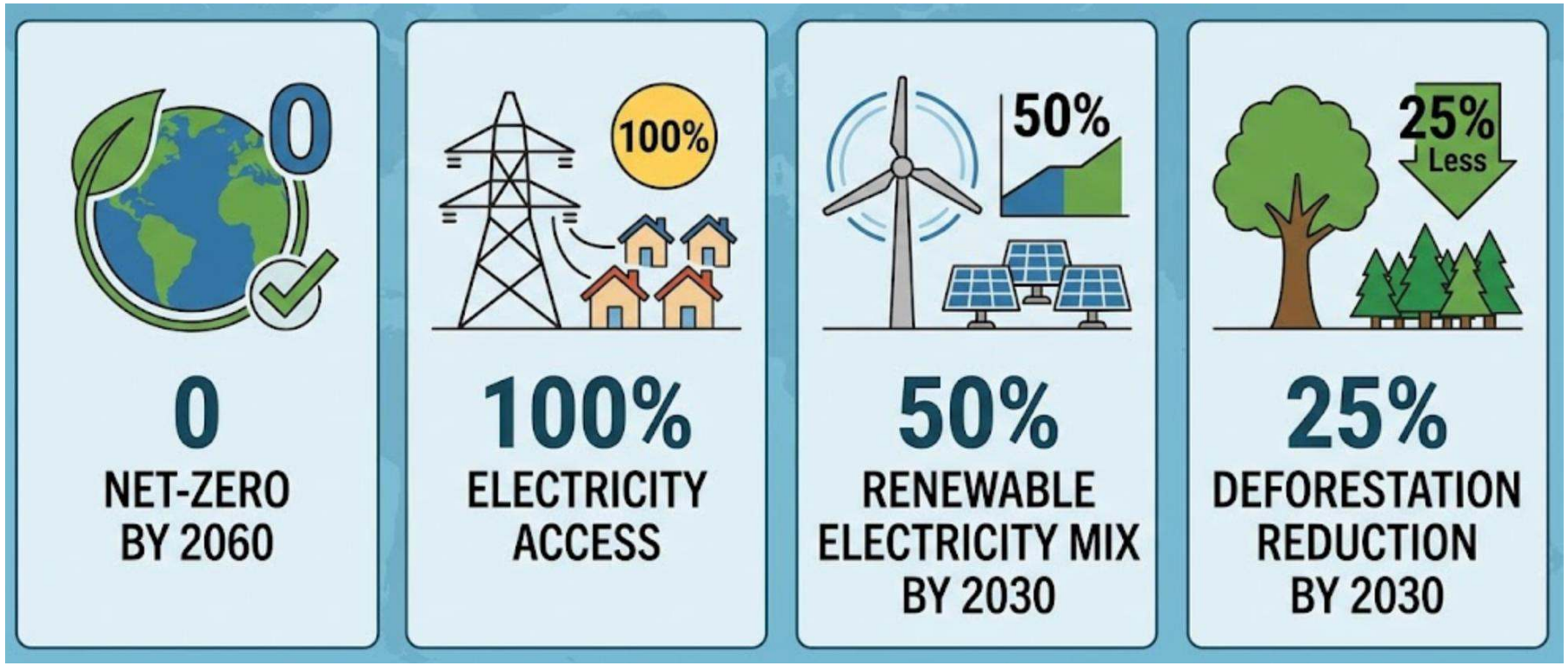




Gap : LEAP models fail to integrate climate variability and extreme weather risks into energy system planning

Togo's LT-LEDS 2025–2060: built with LEAP





RESEARCH OBJECTIVES

01

Demonstrate how climate information can be integrated into the LEAP-based modelling underlying Togo's LT-LEDS 2025–2060.

02

Assess how climate change influences long-term energy demand and supply in Togo under different IPCC AR6 climate scenarios.

RESEARCH QUESTIONS

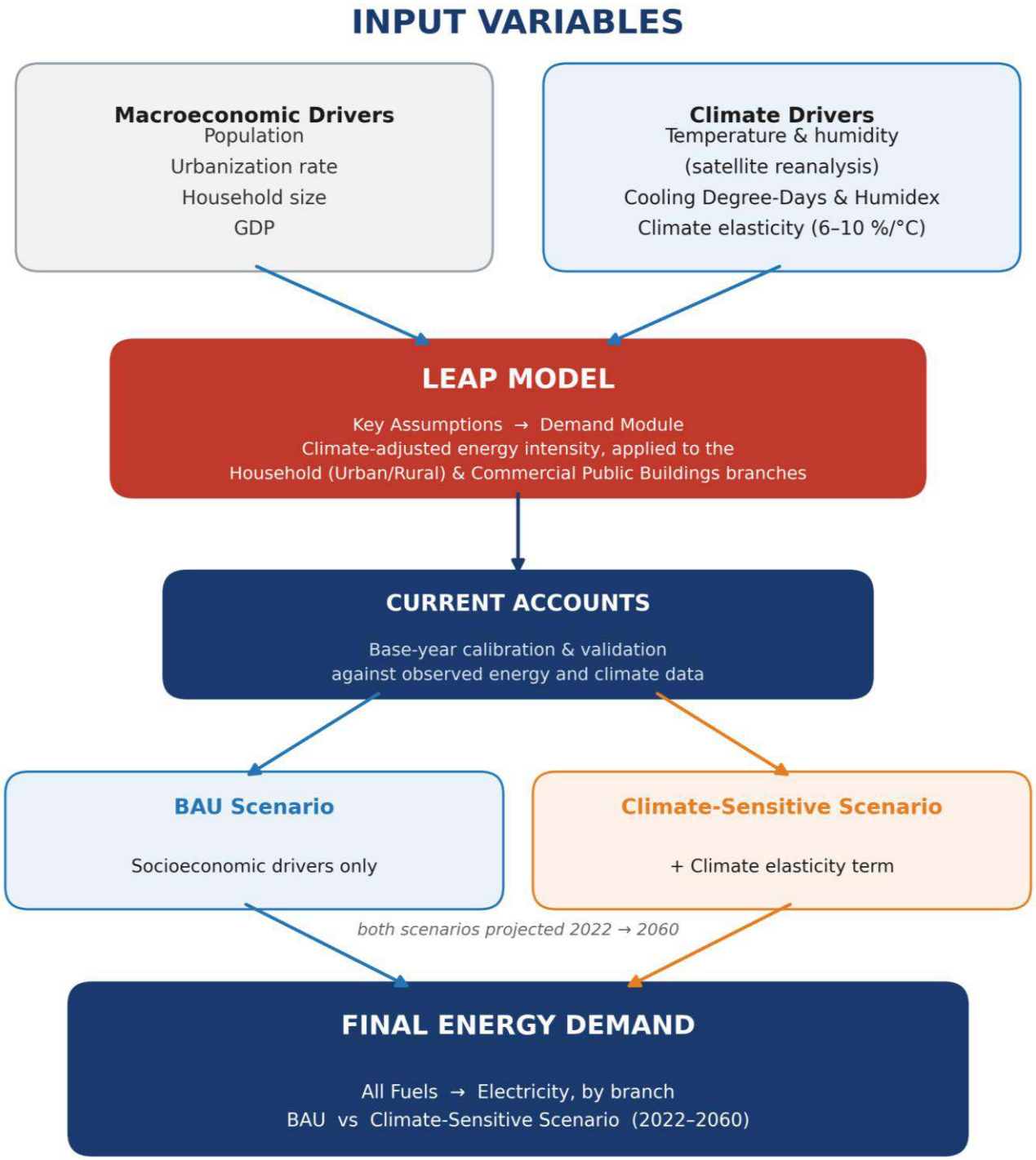
How can climate information be integrated into the LEAP-based modelling behind Togo's LT-LEDS?

How does climate change affect long-term energy demand under different IPCC AR6 scenarios?

METHODOLOGY

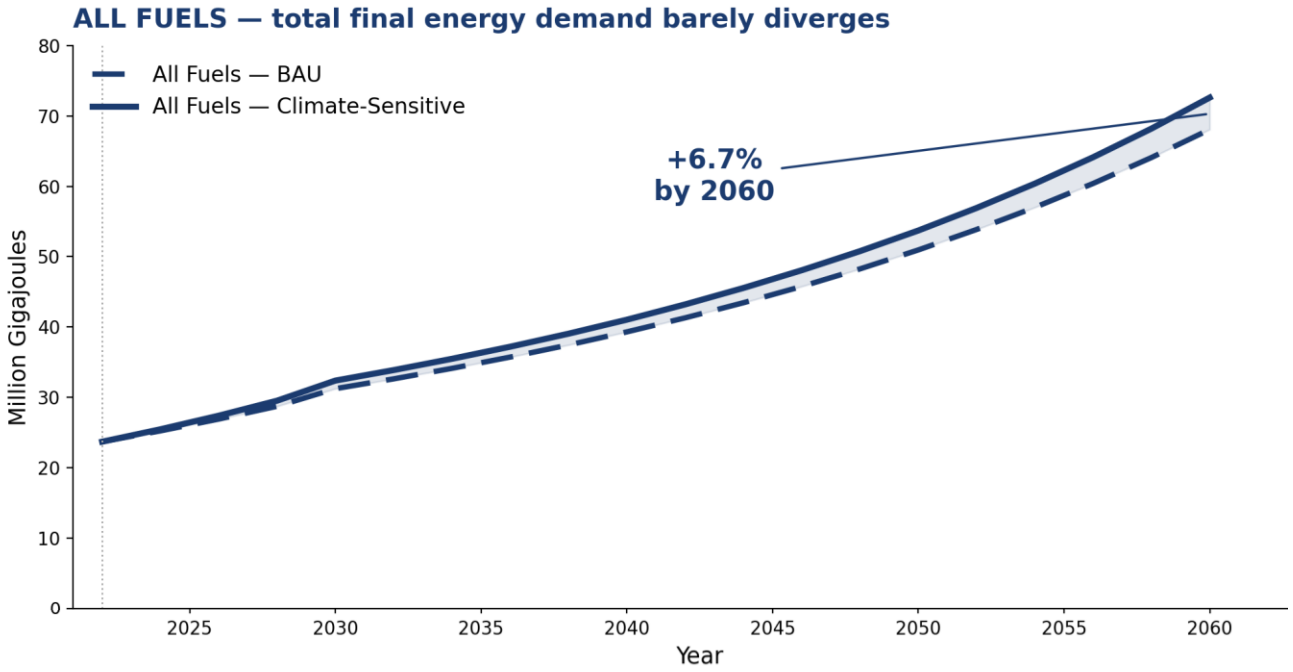
From data to energy-demand projections

The climate-sensitive scenarios complement the LT-LEDS baseline by adding climate as an explicit demand-side driver.



PRELIMINARY RESULTS

From base year to 2060: where does the climate-driven increase go?



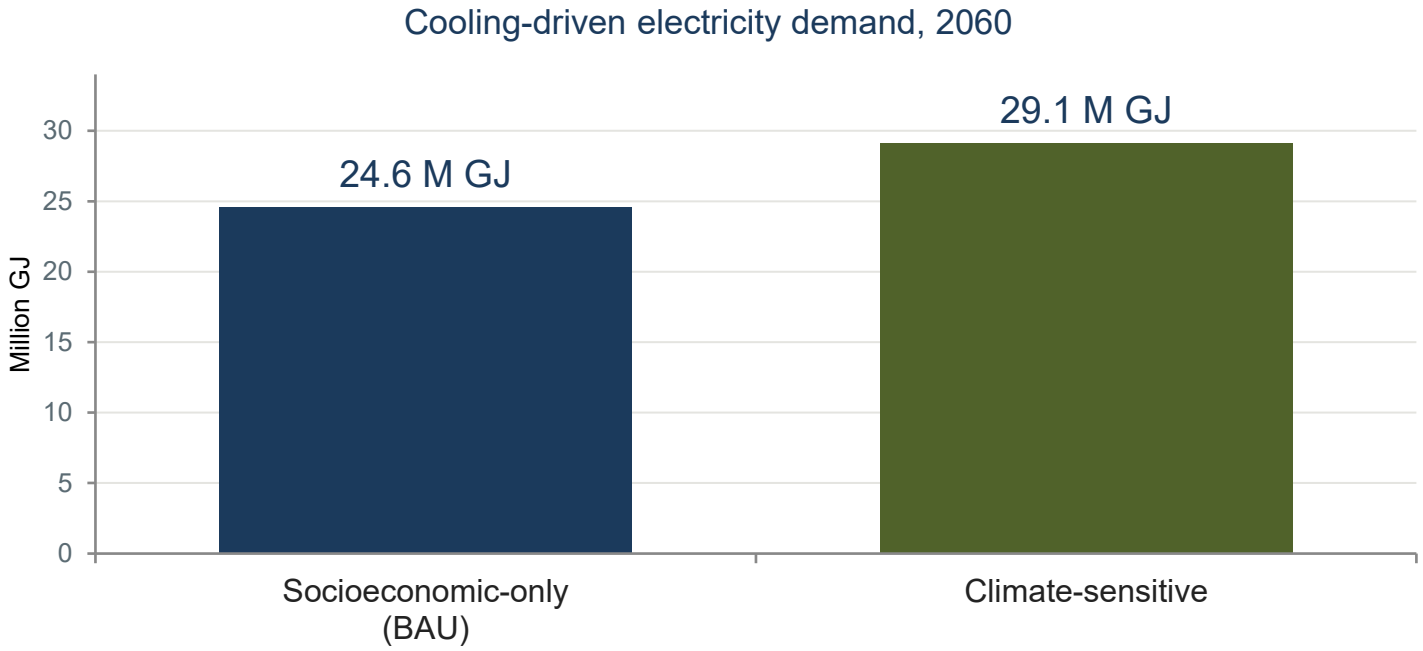
Moderate Macro-Divergence : Total final energy demand increases by **+6.7%** by 2060 under the Climate-Sensitive scenario.

PRELIMINARY RESULTS

+18%

by 2060

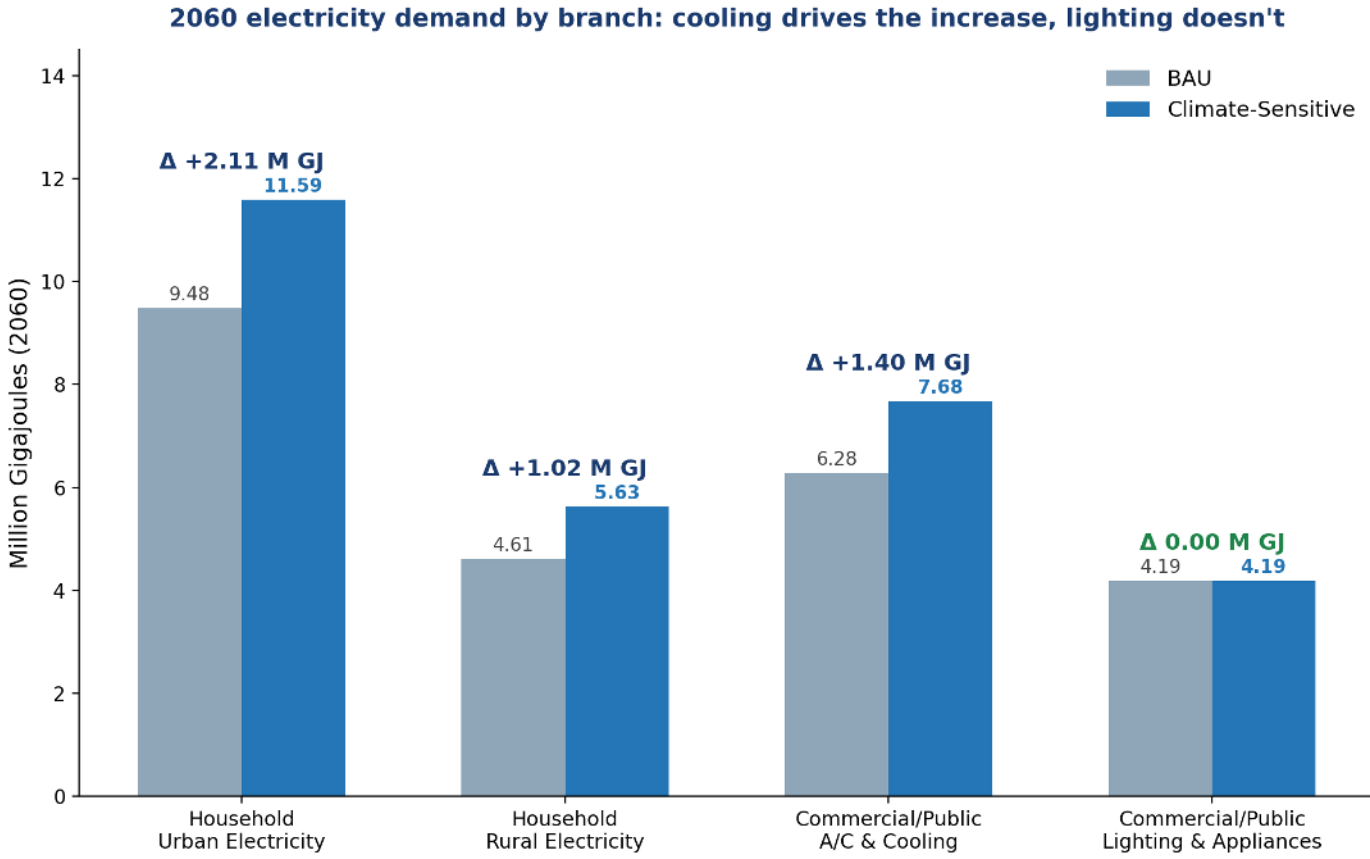
Increase in cooling-driven electricity demand, climate-sensitive vs. socioeconomic-only LEAP scenario



Scope: cooling-driven electricity demand only — not total energy demand

PRELIMINARY RESULTS

- 100% Cooling Driven: Climate shift exclusively impacts space cooling.
- Urban Households: +2.11 M GJ (+22.3%) from heat and AC adoption.
- Commercial Sector: +1.40 M GJ (+22.3%) for A/C systems.



- Lighting and non-thermal appliances show 0.00 M GJ change, validating that climate elasticity strictly isolated thermal demand responses.

WHY DOES IT MATTER, AND WHAT COMES NEXT?

From data to climate-informed energy planning

01

Better assessment

More climate-informed future energy-demand projections.

02

Better infrastructure planning

Improved understanding of future generation and grid requirements.

03

Greater resilience

Reduced risk of underestimating future electricity needs under changing climate conditions.

Integrating climate information in LEAP can strengthen future energy-system planning under climate uncertainty.

WHY DOES IT MATTER, AND WHAT COMES NEXT?

Conclusion & next steps

WHAT WE KNOW SO FAR

Climate change can become an additional driver of electricity demand, particularly through cooling needs.

Preliminary results indicate an 18% increase in cooling-driven electricity demand by 2060 compared with the socioeconomic-only scenario.

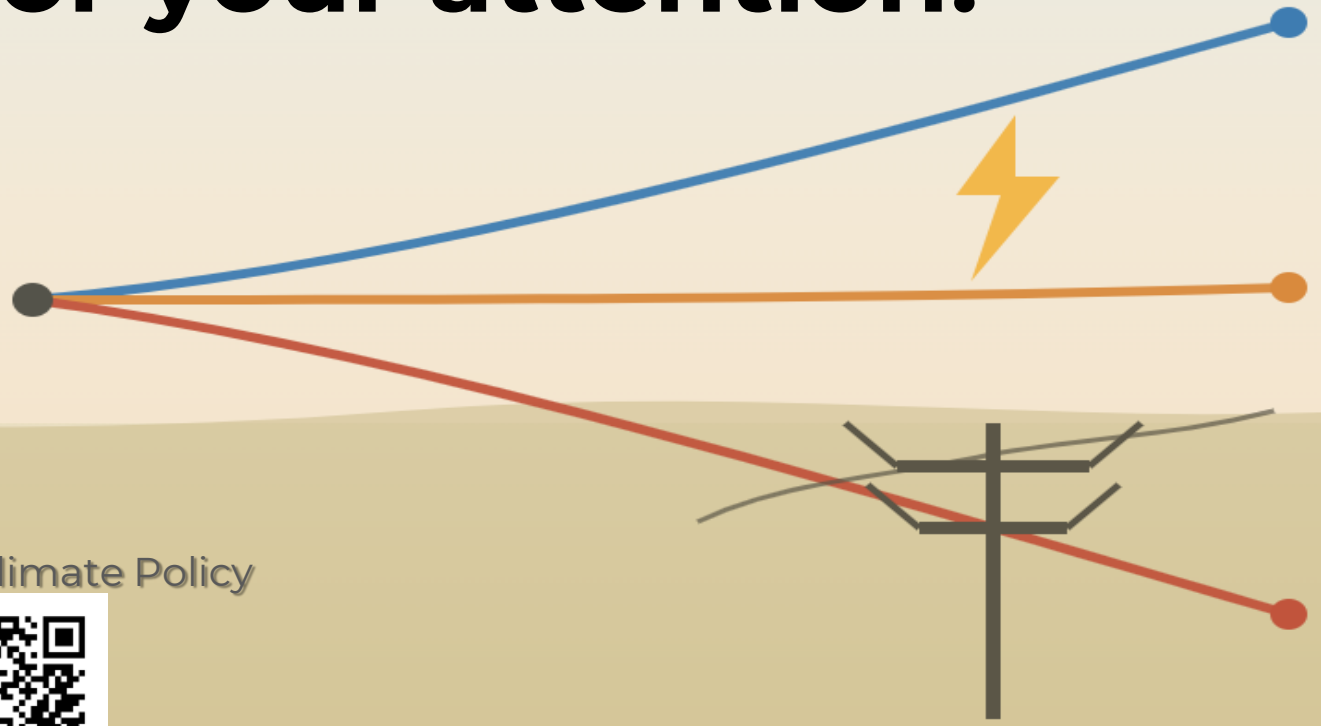
WHAT COMES NEXT

- Feed findings into the ongoing review of Togo's LT-LEDS 2025–2060
- Extend the framework to additional demand sectors
- Extend the analysis to supply-side components
- Integrate techno-economic and financial assessments

Climate-informed energy modelling can help anticipate tomorrow's energy needs under a changing climate.



Thank you for your attention!



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C

URBANIZATION, INFRASTRUCTURE & ENERGY

C) URBANIZATION, INFRASTRUCTURE & ENERGY

E-Motorbike Adoption in Kigali: Challenges, Opportunities, and Policy Pathways for Sustainable Urban Mobility

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Background & Context

Motorcycles dominate urban mobility in Kigali — 52% of the 221,000 registered vehicles — with the fleet growing ~12% annually.

Reliance on internal combustion engine (ICE) motorcycles drives air pollution and fuel-import dependency (12% of Rwanda's import bill).

The Government of Rwanda has committed to phasing out ICE motorcycles in favor of electric motorbikes (e-motos), backed by tax exemptions and import-duty relief.

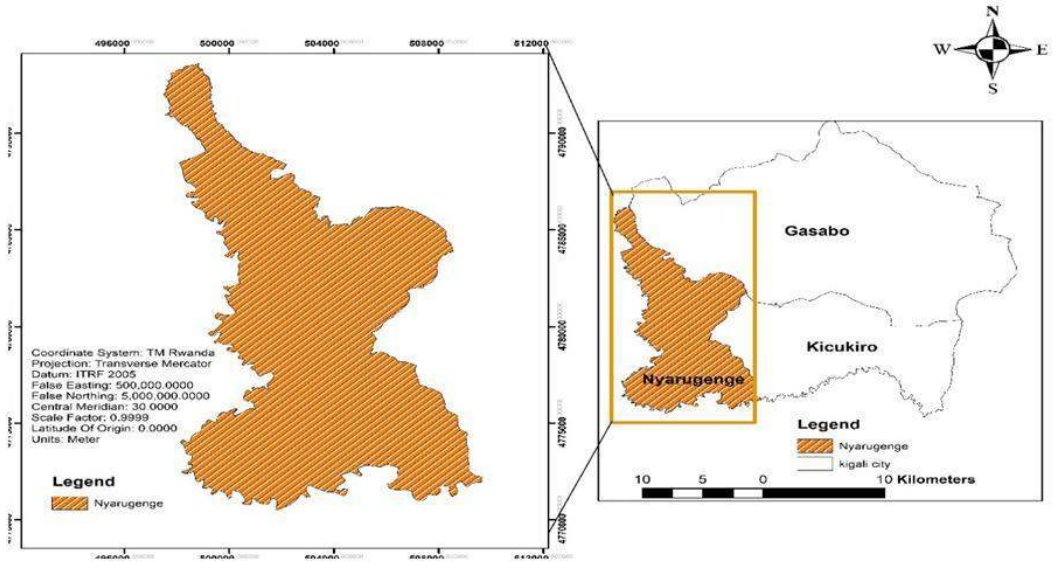
Yet adoption remains critically low — a gap directly relevant to Rwanda's NDCs and NST2 sustainable transport goals.

Research Objectives

- Assess current awareness and use of e-motorbikes among motorcycle users in Nyarugenge District, Kigali.
- Examine the major challenges hindering widespread e-motorbike adoption.
- Identify key opportunities and policy levers for promoting sustainable electric mobility in an urban African context.

Study Area
Nyarugenge District

- One of Kigali's 3 districts — 10 sectors, 47 cells, 134.2 km².
- 374,319 residents (21.4% of Kigali City's population).
- Bordered by the Nyabarongo River along its western and southern edge.
- By 2025: 12,361 fuel motorbikes vs. only 1,016 electric motorbikes registered in the district.



Methodology

A mixed-methods approach combining secondary and primary data collection:

- **Library research —** literature review and government policy document analysis.
- **Surveys —** structured questionnaire (closed, semi-open, open-ended) via Google Forms.
- **Interviews —** motorists, commuters, government officials (CoK, MININFRA, RURA, RSB), and company reps (Ampersand, Spiro, Gorilla).
- **Field observation —** across all 10 sectors of Nyarugenge District.
- **GIS mapping —** GPS-captured charging station coordinates, analyzed in ArcGIS.

Sample & Data Collection

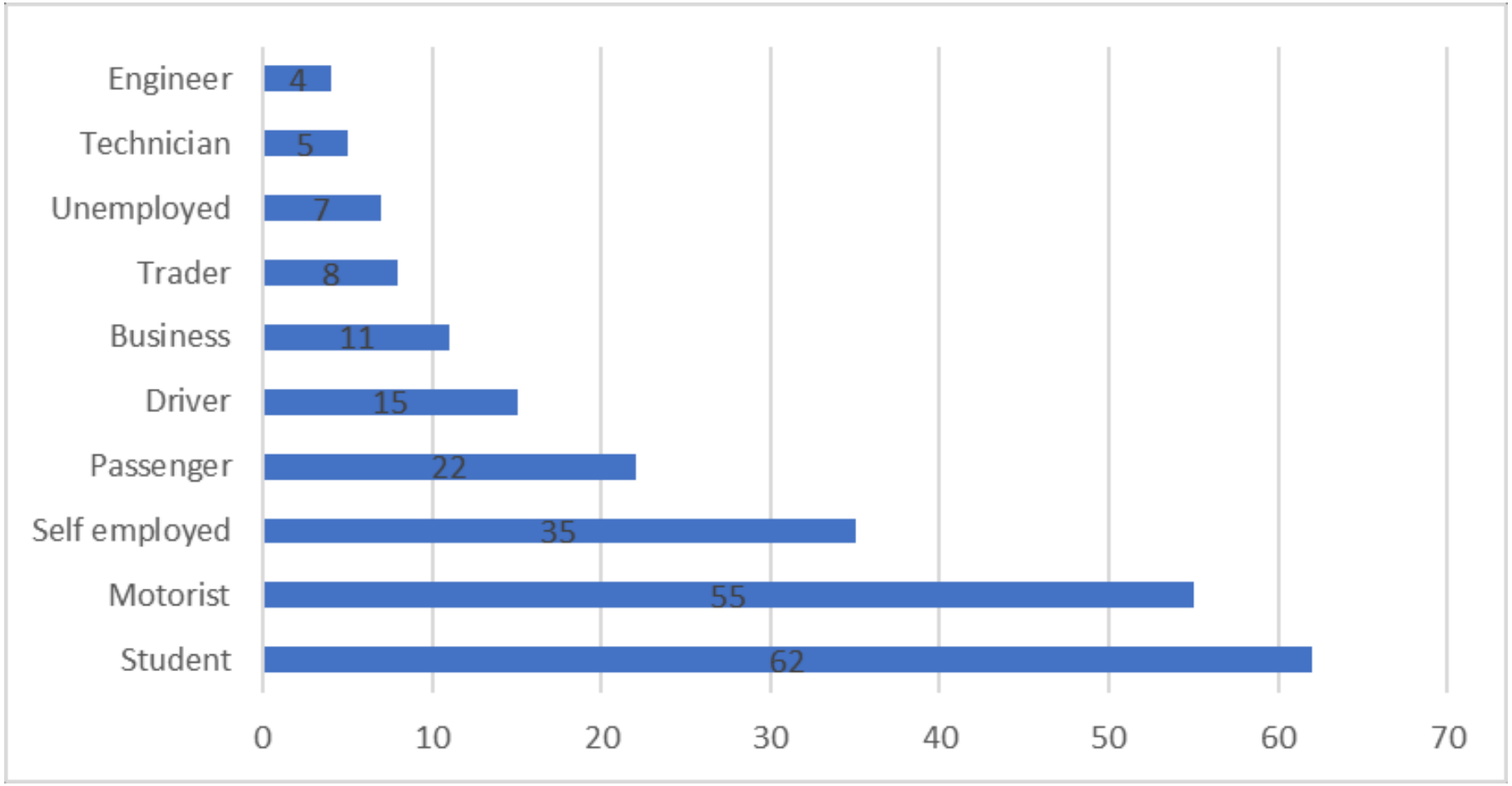
Sample size determined using the Yamane formula (95% confidence, N = 374,319):

Occupation	Total Population	Sample	Sample by Occupation
Motorist	374,319	400	100
Commuter			300

Stakeholder	Sample Size
Government officials	4
Company representatives	3

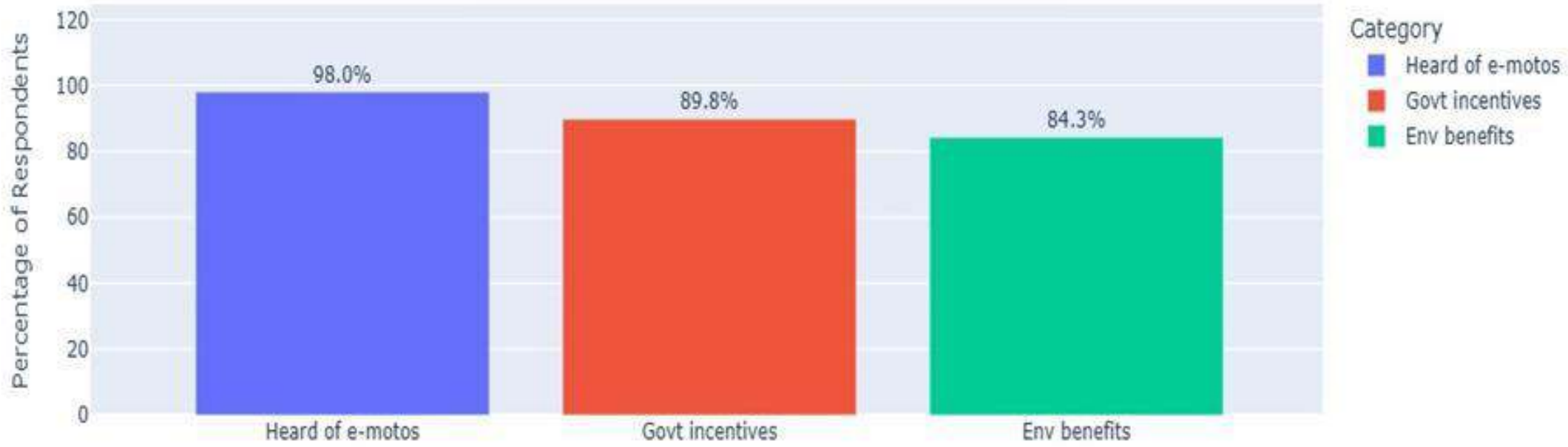
Respondent Profile

401 valid responses — 44% aged 18–25; 49% male, 43% female. Most reside in Nyarugenge District.



Awareness & Usage of E-Motos

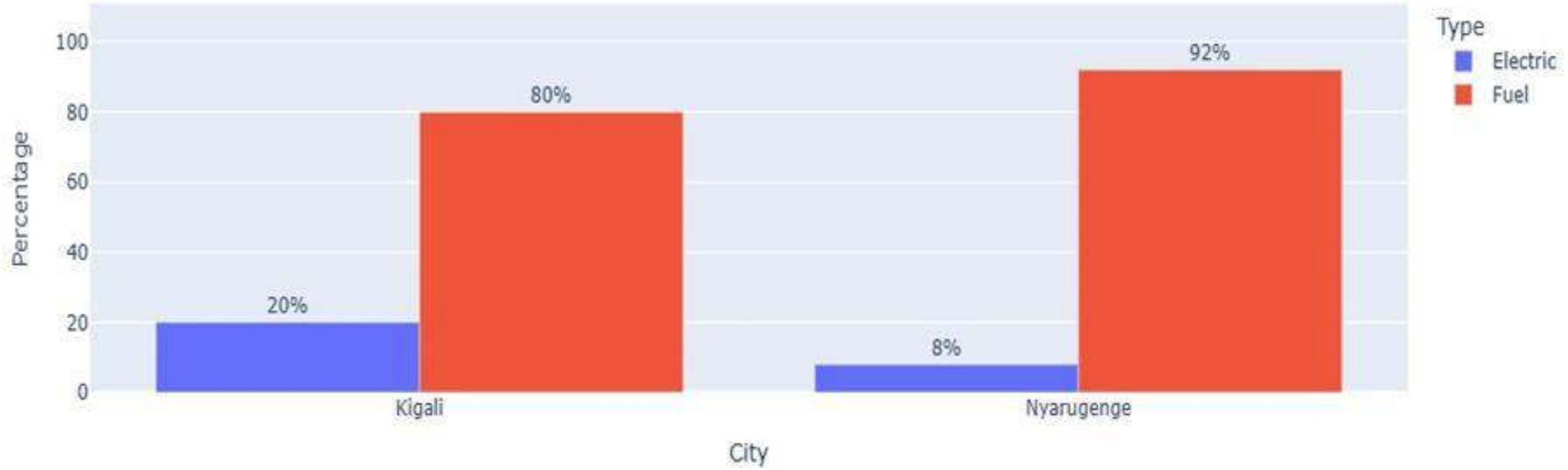
Awareness and usage among Nyarugenge respondents are remarkably high:



- **97%** have personally used or ridden an e-motorbike as a commuter or motorist
- **65%** of users rate their satisfaction 4 or 5 out of 5

The Adoption Gap

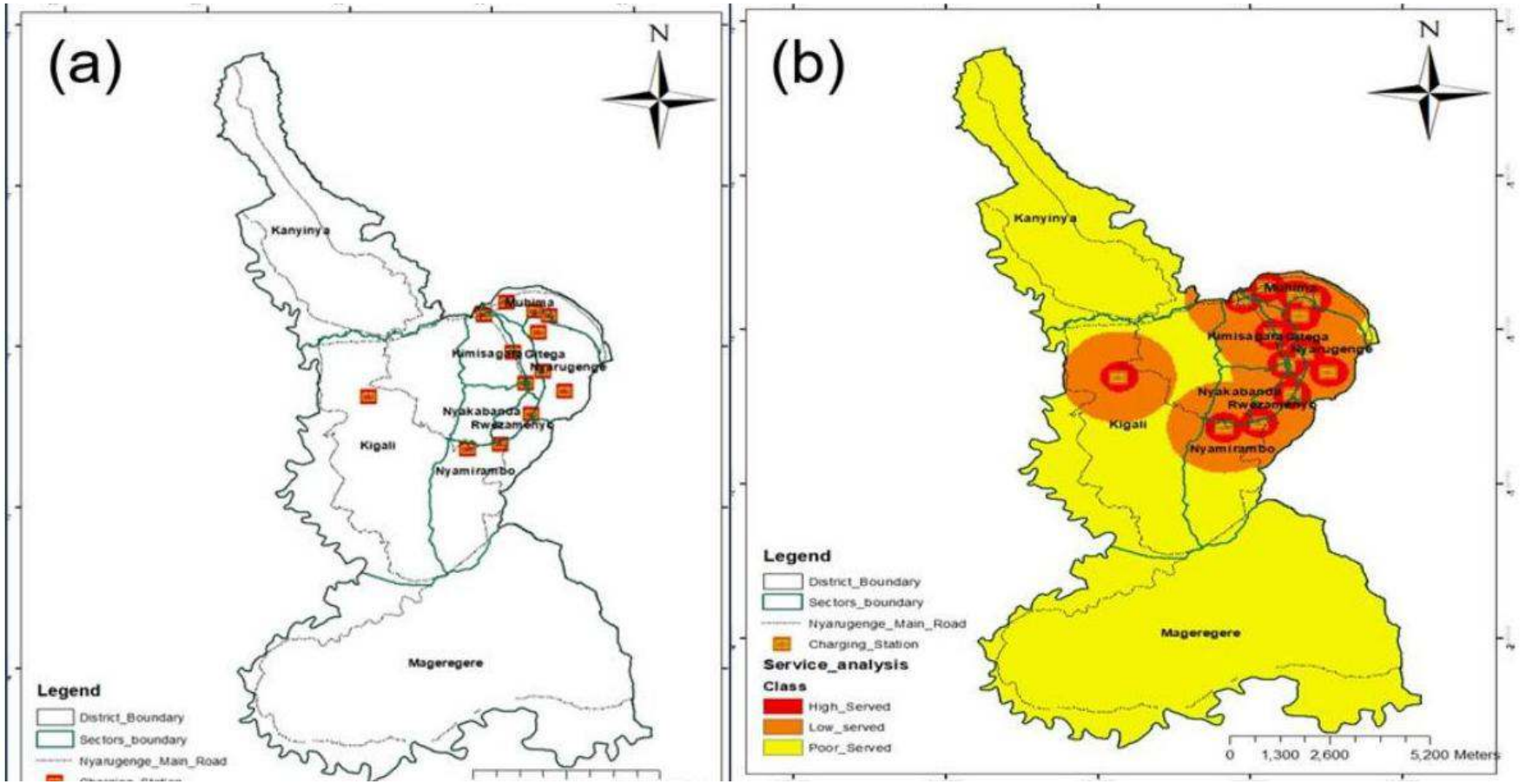
High awareness has not translated into ownership: e-motorbikes remain a small share of the registered fleet.



RURA registration data (2023–2025): 12,361 fuel motorbikes vs. 1,016 electric motorbikes in Nyarugenge District.

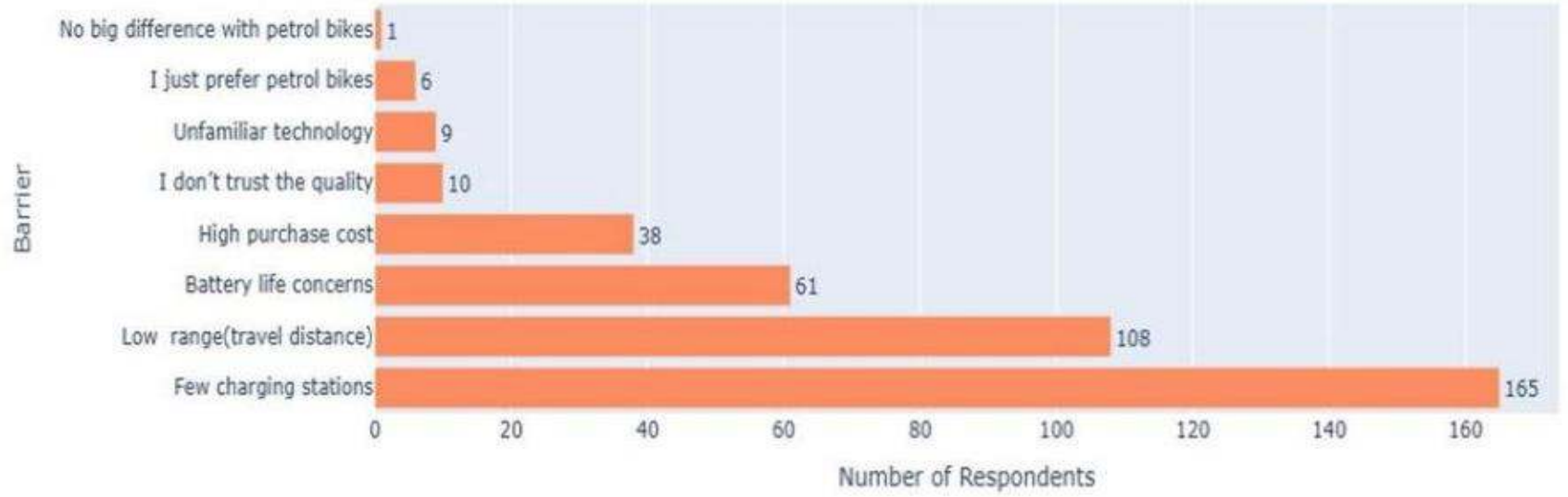
Charging Infrastructure Gap

Charging stations exist in only 8 of 10 sectors — and are heavily concentrated, leaving much of the district poorly served.



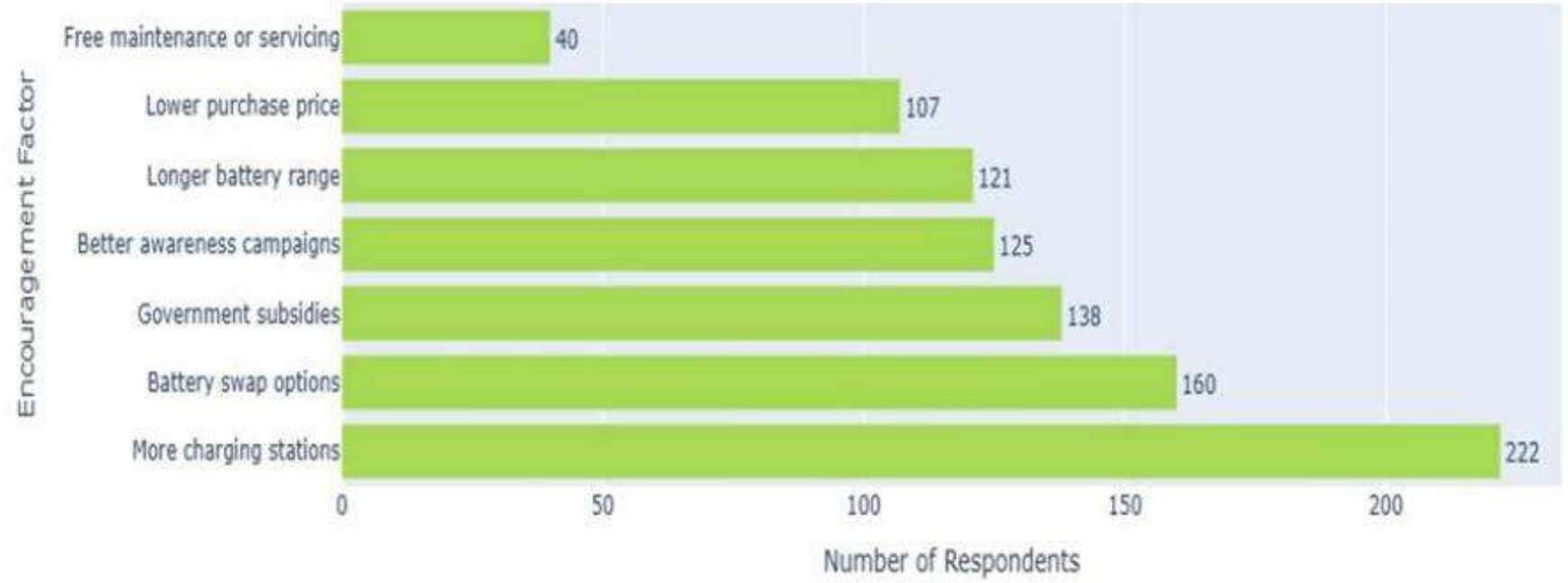
Barriers to Adoption

- **Few charging stations —** cited by 41% of respondents; the top-ranked barrier.
- **Low range / range anxiety —** battery range of only 50–90 km per charge (27%).
- **Battery life concerns** and unreliable technology (61 respondents).
- **High upfront purchase cost** with limited financing options.
- **Poor product quality —** e-motorbikes showing wear within 2 years vs. 12+ years for fuel bikes.
- **Scarce, expensive spare parts** (e.g. sprocket: 5,000 RWF electric vs. 1,000 RWF fuel) and poor mechanical services.
- **Restrictive company regulations** and delivery delays (up to 4 months).



Opportunities: Cost & Environmental Benefits

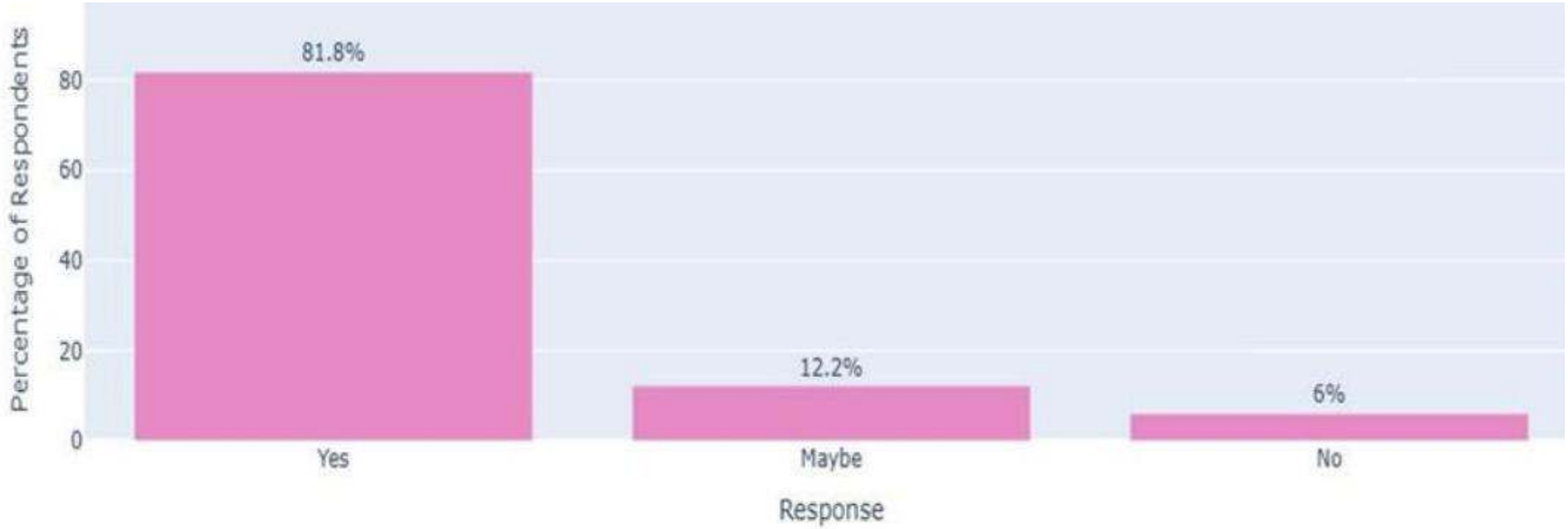
- **85.6%** of respondents say e-motorbikes help reduce air pollution.
- **Replacement parts are consistently cheaper** — a rear tyre costs 15,264 RWF (electric) vs. 50,000 RWF (fuel).
- **40.9%** of users save 1,000–5,000 RWF per trip in fuel costs; some report savings over 10,000 RWF.



Government Incentives & Willingness

81.8% of respondents would switch to e-motorbikes if the government offered incentives (tax exemptions, free parking, direct financial assistance).

City of Kigali hosts e-mobility stakeholder engagements; Rwanda Standard Board uses pricing incentives on standard products to boost demand.



Policy Recommendations

- **Strengthen incentives —** maintain tax exemptions, import duty reductions, and regulatory clarity.
- **Enhance public–private collaboration —** expand clean-energy charging stations in cities and rural areas.
- **Integrate policies into frameworks —** binding national and local regulations on infrastructure and standards.
- **Improve battery capacity —** encourage innovation to extend battery life and ease infrastructure pressure.
- **Regulate spare-part pricing —** transparent price controls to prevent exploitation.
- **Promote sustainability research —** recycling, circular economy, and long-term environmental impacts.

Conclusion

Nyarugenge District is in the early stages of e-motorbike adoption — constrained by infrastructure, affordability, and regulatory gaps, not by lack of awareness.

Coordinated action from government, private sector, and civil society can close this gap and advance Rwanda's NDC and NST2 sustainable mobility goals.

Thank you

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Published in Built Form Journal, Vol. 1, No. 2, 2025 | DOI: 10.63955/BuiltForm.25

C) URBANIZATION, INFRASTRUCTURE & ENERGY_VIRTUAL

Community Participation as a Pathway to Climate-Resilient Housing Development: Evidence from Bafoussam II, Cameroon

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Background & Context

- Rapid urbanization and population growth are straining housing, water, sanitation and waste systems in Bafoussam II, West Region, Cameroon
- Informal settlement expansion is visible in Djeleng and Koptchou neighbourhoods
- Cameroon's decentralization laws and urban planning regulations provide for community involvement in land use, housing and service delivery decisions
- Influx of internally displaced persons from the Northwest and Southwest Regions (Anglophone crisis) is reshaping housing demand

Statement of the Problem

- Housing projects are frequently implemented with limited input from the residents they are meant to serve
- Ghetto-settlement extension in Toungang Village signals weak participatory planning
- Socio-economic factors (poverty, low education) and cultural attitudes limit meaningful engagement, notably among migrant communities in Tchitchap
- Bureaucratic hurdles (MINDHU, MAETUR) and limited transparency from local authorities hinder genuine participatory mechanisms

Research Questions & Objectives

Main question: What is the nature of community participation in housing development in Bafoussam II Municipality?

- Objective 1 — Determine the current state of housing in Bafoussam II Municipality
- Objective 2 — Examine the current state of participation in housing development projects
- Objective 3 — Propose strategies to improve community participation in housing development

Research Hypotheses

Main hypothesis: Community participation positively influences housing development in Bafoussam II Municipality

- H1 — The current state of housing is inadequate in quality, accessibility and affordability
- H2 — Community participation in housing development is characterized by low engagement
- H3 — Targeted strategies would significantly increase community participation

Methodology

- Mixed-methods design combining quantitative and qualitative techniques
- Household questionnaires administered to 156 respondents, plus key informant interviews, focus group discussions and field observations
- Stratified random and purposive sampling across five neighbourhoods
- Study area: Djeleng II, Djeleng III, Toungang Village, Tchitchap and Koptchou
- Descriptive, quantitative and cartographic analysis of primary and secondary data

Study Area: Bafoussam II Municipality

- Located in the West Region of Cameroon; a regional commercial, administrative and trading hub
- Population grew from 121,282 (2005 census) to a projected 194,561 in 2025, at 2.6% annual growth
- Mountainous climate with a dry season (mid-November to mid-March) and rainy season (mid-March to mid-November)
- Predominantly Bamileké population, with a young age structure (15–34 years) concentrated in Djeleng, Toungang Ville and Koptchou

Current State of Housing: Types & Distribution

- Four dominant housing types: affordable, luxury, mixed-use and public housing
- Affordable housing dominates in Djeleng II (54.55%) and Toungang Village (40%) — reflects low-income demand
- Luxury and mixed housing dominate Tchitchap (39.39% / 30.30%) — market-driven, higher-income development
- Koptchou shows the most balanced housing mix across all categories
- Public housing is scarce municipality-wide (4.14%) — largely absent from Bafoussam II itself

Housing & Land-Use Dynamics (1990–2024)

- Built-up area grew from 765.99 ha (1990) to 1,741.32 ha (2013) — a 127% increase
- Cropland expanded over 400%, while bare ground fell by over 80%, as settlement replaced open land
- By 2024, urban sprawl reached previously agricultural and savannah land near the Baleng Forest Reserve
- Growth is driven by population increase, rural–urban migration and demand for affordable and luxury housing
- Trend reflects weak spatial planning and land-use regulation typical of rapidly urbanizing Sub-Saharan cities

Challenges in Accessing Affordable Housing

- High construction cost is the leading barrier — cited by 59.09% in Djeleng II and ~45% in Tchitchap and Koptchou
- Lack of financing options is most acute in Toungang Village (29.41%) and Koptchou (25%)
- Limited land availability weighs more heavily in Toungang Village (23.53%) and Djeleng III (20%)
- Insufficient government support and weak enforcement of building regulations compound these barriers

Current State of Community Participation

- **74.8% of residents have never attended a community meeting on housing development**
- Only 17.24% participate 1–2 times a year; just 1.38% attend more than 5 times a year
- Non-participation is highest in Tchitchap (25%) and Djeleng III (24.07%), lowest in Djeleng II (14.81%)
- Main reasons: lack of information about meetings, and limited time due to work commitments
- *Confirms Hypothesis 2 — community participation is characterized by low engagement*

Determinants of Community Participation

- Residents get housing-development information through a mix of word of mouth, in-person meetings and online/social media, varying by neighbourhood
- Motivations: sense of ownership, direct benefit from projects, and trust in local leadership
- Constraints: inaccurate/limited information, inadequate resources, and busy urban livelihoods
- Involvement is greatest in planning and design, and weakest in monitoring and evaluation

Proposed Strategies to Improve Participation

- A combined approach — regular meetings, public awareness, collaborative planning and feedback mechanisms — is preferred by residents across all five neighbourhoods
- Regular community meetings are most valued in Toungang Village (38.24%) and Koptchou (33.33%)
- Sensitize the population via social media and local radio; organize both formal and informal gatherings
- Include women, youth and marginalized groups; reward active participants; build partnerships with private investors

Policy & Practice Recommendations

- To local councils: establish inclusive consultation forums for marginalized groups, women and youth
- To government agencies (MAETUR): prioritize affordable social housing construction
- To policy makers: reinforce urban planning regulation to curb irregular land tenure and unregulated construction
- To financial institutions: expand flexible micro-financing for housing
- To NGOs & academia: run culturally-sensitive awareness campaigns and support participatory mapping/surveys

Conclusion

- Housing in Bafoussam II is diverse in type but constrained by cost, weak regulation and environmental pressure (H1 accepted)
- Community participation in housing development remains low across all neighbourhoods (H2 accepted)
- Targeted, multi-pronged strategies can significantly raise participation and improve housing outcomes (H3 accepted)
- Institutionalizing inclusive participation strengthens climate resilience, governance and sustainable urban development

Thank you!

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C) URBANIZATION, INFRASTRUCTURE & ENERGY

Assessing the impact of circular economy practices on construction and demolition waste management in kigali,Rwanda(2020-2025)

TUYISHIMIRE Bernard (Msc)
UNILAK
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Background of the Study

Globally

➢Construction industry is vital for economic development.
➢ It generates large quantities of waste globally.
➢ Construction and Demolition Waste (CDW) accounts for about 30–35% of global solid waste(Ghisellini et al., 2015) Poor waste management leads to environmental and economic challenges(Busch et al., 2017).)

KIGALI

➢Kigali is experiencing rapid urbanization.
➢Growth in infrastructure and housing development.
➢ Increased generation of construction and demolition waste(Kabera & Nishimwe, 2019).
➢ Need for improved waste management strategies.

PROBLEM STATEMENT

- CDW management in Kigali is largely disposal-oriented.
- Less than 20% of CDW is reused or recycled.
- Limited recycling infrastructure.
- Weak enforcement of regulations.
- Lack of empirical evidence on CE effectiveness in CDW management.
- Need for sustainable waste management solutions.

Objectives

To assess the impacts of Circular Economy practices on Construction and Demolition Waste management in the City of Kigali.

1.To examine current circular economy practices in the construction sector.

2.To evaluate effectiveness of CDW management systems.

3. To analyze relationship between CE practices and CDW management efficiency.

Sampling ,Data Collection &Analysis Methods

- Study population :691
- Sample Size: 282 respondents
- Sampling methods:
  - Stratified sampling
  - Purposive sampling
  - Snowball sampling
- Data collection: Questionnaires, interviews, observations
- Quantitative Analysis:
  - Descriptive statistics
  - Correlation
  - Regression

DATA PRESENTATION, ANALYSIS AND DISCUSSION

1. Existing Circular Economy Practices in Construction and Demolition Sector(OBJECTIVE 1)

Waste Minimization Practice	Yes (%)	No (%)
Accurate material estimation	68.4	31.6
On-site waste segregation	52.1	47.9
Reuse of off-cuts	46.8	53.2
Design optimization	39.7	60.3

2. Material Recovery and Reuse Practices

Type of Material	Reused (%)	Recycled (%)	Disposed (%)
Concrete & masonry	28.4	31.9	39.7
Metals	67.8	22.1	10.1
Timber	41.2	18.6	40.2
Plastics	12.4	19.3	68.3

3. Policy and Regulatory Support for Circular Economy Practices (key informant responses)

➢**Awareness of policies**
Most respondents acknowledged the existence
of national sustainability and circular economy policies
➢**Weak enforcement**
▪Policies are not strongly enforced
▪Compliance is often treated as a formality rather than actual
performance
➢**Limited monitoring**
▪Inadequate systems to track CDW generation and management
Lack of specific regulations
▪Absence of CDW-specific guidelines and standards

➢**Institutional challenges**
▪Limited staffing in regulatory bodies
▪Overlapping roles among institutions
➢**Gap between policy and practice**
Strong policy commitments exist, but implementation is weak
➢**Lack of incentives and penalties**
▪No clear rewards or sanctions, making compliance largely voluntary
➢**Low contractor motivation**
▪Weak regulatory pressure reduces adoption of circular economy practices

4. Stakeholder Engagement and Collaboration in CE Implementation (key findings)

➢**Limited coordination**

Weak collaboration among construction firms, waste collectors, recyclers, and regulators

➢**Informal engagement**

▪Stakeholder interaction is **project-based and**

▪**ad hoc**

▪Minimal **information sharing or joint planning**

➢**Insufficient training**

▪Limited awareness and training on circular economy (CE) practices

➢**Weak collaboration with recyclers**

▪Partnerships occur **occasionally**, not systematically

5. Waste Collection, Transportation, and Disposal Methods

Waste Management Method	Percentage (%)
Landfilling	55
Recycling	22
Reuse (on-site or off-site)	15
Informal dumping / backfilling	8
Total	100

- **Landfilling dominates (55%)**
  - Main method of waste management Indicates a **disposal-oriented system**
- **Low recycling and reuse**
  - Shows limited adoption of **circular economy practices**
- **Organized collection system**
  - Use of private waste collectors
  - Reflects structured **waste transport and collection**

6. CDW Management Efficiency by Project Scale

- **Large-scale projects: 60% efficiency**

Highest performance

Due to:

  - Strong management systems
  - Better technical expertise
  - Access to resources and sustainability knowledge

- **Medium-scale projects: 45% efficiency**

- Moderate performance
- Limited consistency in applying best practices

- **Small-scale projects: 30% efficiency**

- Lowest performance
- Characterized by: Informal practices
  - Limited oversight
  - Financial constraints

7. Descriptive Statistics of Circular Economy Practices and CDW Management Efficiency (n = 282)

Waste Minimization

➢**61.3% use basic practices** (estimation, procurement) only **23.4% use advanced strategies** (design for deconstruction)

·Higher adoption → **lower waste generation (58.7%**

Policy & Regulation

➢**69.1% aware of policies**

And only **34.8% see enforcement as effective**

➢Strong enforcement → better compliance (**57.6% segregation**)

Material Recovery & Reuse

➢High recovery of: **Metals (72.5%) And timber (64.2%)**

➢Low recovery of:

·**Concrete & masonry (28.6%)**

·Leads to: Reduced landfill (**55.1%**) and Lower costs (**47.8%**)

Stakeholder Collaboration

Only **26.9% report strong collaboration**

Indicates weak coordination across the sector

However, **weak enforcement, low adoption of advanced strategies, and poor coordination** limit full sustainability benefits

8. Recommendations

Circular economy (CE) practices show a strong positive impact on construction and demolition waste (CDW) management efficiency in the City of Kigali. However, a significant gap remains between national policies like the Circular Economy Action Plan (2022–2035) and on-the-ground implementation due to weak enforcement, data gaps, and inadequate infrastructure

➢**Ministry of Infrastructure (MININFRA)** should strengthen the following:

Green Building Codes: Integrate mandatory design-for-deconstruction principles into national building regulations.

Public Procurement Rules: Mandate minimum percentages of recycled aggregates in public infrastructure contracts.

Standardization Frameworks: Collaborate with standards bodies to certify the quality of secondary construction materials.Pilot Program Funding: Subsidize large-scale demonstration projects showcasing advanced material circularity.

➢**(REMA)** should strengthen the following:

Enforcement Mechanisms: Strengthen penalties for illegal dumping of construction debris.

Permitting Requirements: Require detailed waste management and minimization plans before approving Environmental Impact Assessments (EIAs).

Data Tracking Systems: Establish a centralized digital database to monitor city-wide CDW generation and recovery rates.

Material Audits: Conduct mandatory post-construction compliance audits for large-scale developments.

- **City of Kigali** should strengthen the following :

Recycling Infrastructure: Invest in municipal sorting hubs and specialized crushing facilities for concrete waste.\
Zoning and Logistics: Designate specific collection zones to prevent CDW from mixing with municipal solid waste streams.
Capacity Building: Provide technical training programs on source segregation for site managers and contractors.
Informal Sector Integration: Formally incorporate informal material recovery workers into the city's waste management framework.\

- **Rwanda Development Board** should strengthen the following

Economic Incentives: Offer tax exemptions or deductions to construction firms that achieve high recycling rates
Market Development: Provide financial grants to startups focusing on high-value recycling technologies.
Investment Promotion: Actively market Kigali’s eco-industrial sector to attract foreign green tech investors.

9. Conclusions

Rapid urban expansion in the City of Kigali creates critical waste challenges. Traditional linear disposal methods are no longer environmentally sustainable. This research proves that circular principles significantly optimize resource efficiency. Resolving the gap between policy and practice remains highly vital. Coordinated institutional enforcement will ensure a sustainable urban transition.

C) URBANIZATION, INFRASTRUCTURE & ENERGY

22 September 2025, 14:15 – 15:30, Breakout Room II

""The Floods are Moving with Us": Vulnerability Transferability and the Limits of Relocation-Based Adaptation in Urban Informal Settlements

Edith Kemunto Rosasi
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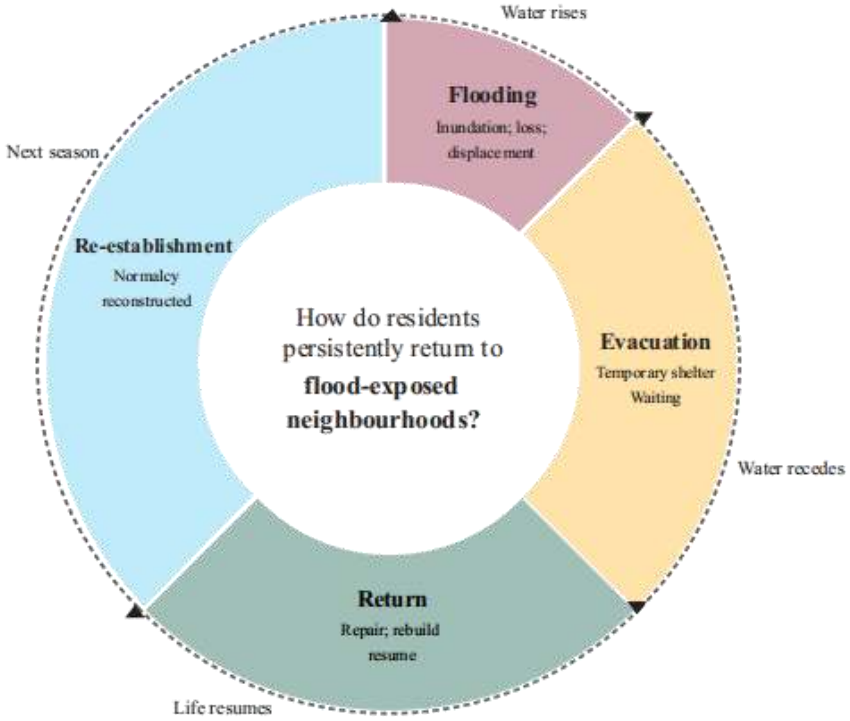
Rethinking the mobility bias in flood adaptation

THE DOMINANT RESPONSE

- When settlements flood, the policy response is to move people — relocation, managed retreat *(Black et al., 2011; Schewel, 2020 — "mobility bias")*
- It assumes vulnerability is a property of location: remove people from the hazard and risk falls *(Wisner et al., 2004)*
- Vulnerability is treated as a property of place

WHAT RESIDENTS ACTUALLY DO

- Across successive flood cycles, residents evacuate and return
- This cyclical return is the study's core puzzle

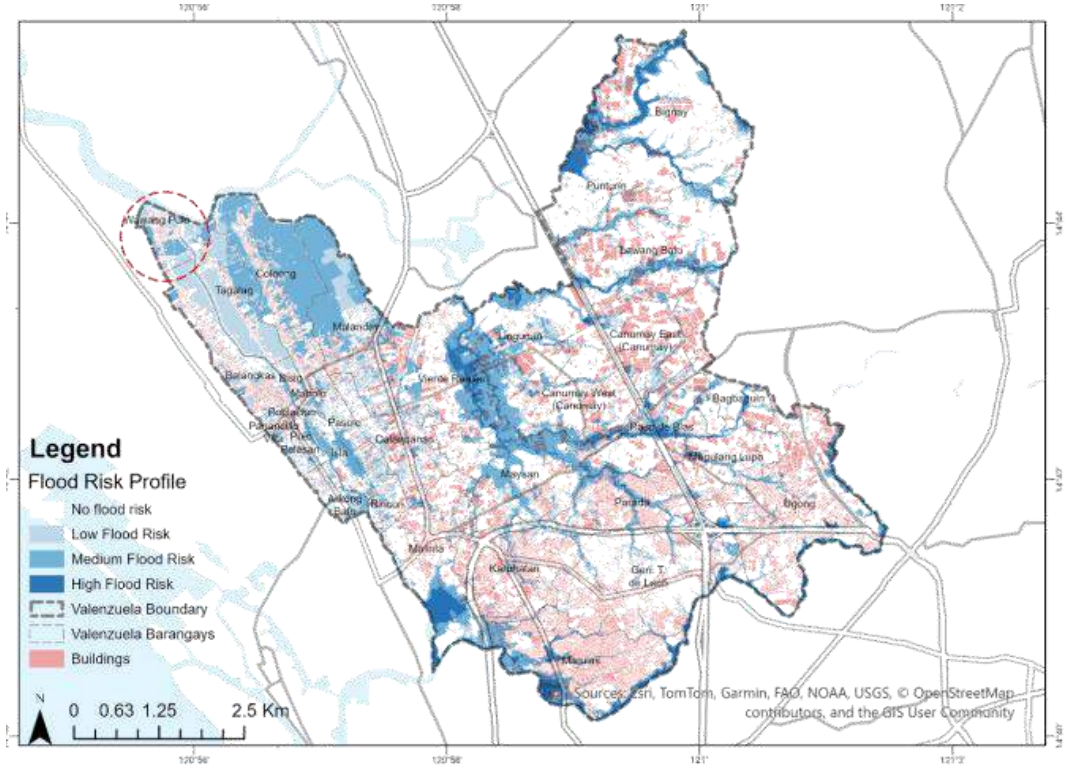


If people keep returning, is the place really the problem?

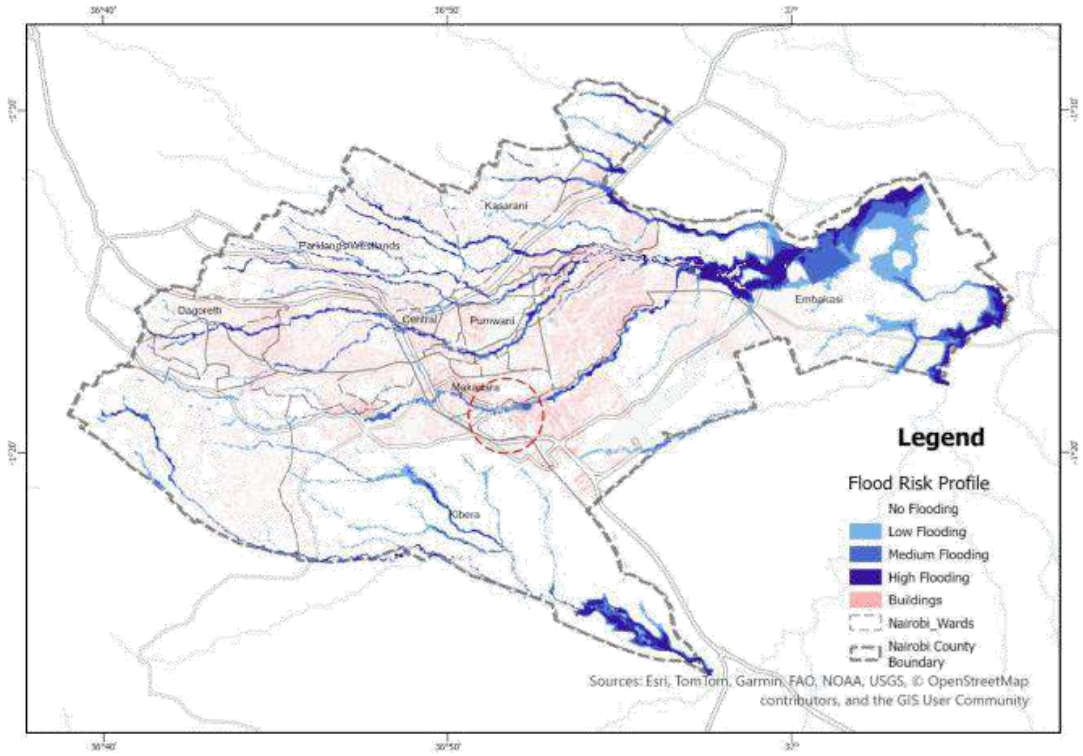
Two cities, one question

How do residents remain in or return to flood-prone urban neighbourhoods across successive flood cycles, and what does this reveal about the limits of relocation as flood adaptation?

Wawang Pulo · Valenzuela, Metro Manila



Mukuru · Nairobi



Two cities, one question

Comparative case design: two different institutional contexts allow examination of whether similar processes recur across settings.

	Mukuru Kwa Reuben & Mukuru Kayaba Nairobi, Kenya	Barangay Wawang Pulo Valenzuela City, Metro Manila
Governance	Fragmented; demolition & eviction	Formalised; investment & aid
Tenure	94% tenants; precarious (*Corburn et al., 2022)*	Formalising via ECMP mortgage Programme
Institutional trust	Compromised - 2024 demolition ruled illegal by High Court, Nov 2024	Contested but protective in intent
Shared	**Chronic flood exposure · cyclical evacuation & return · livelihood embeddedness**	

How the study was done?

Qualitative · multi-instrument · critical-realism stance · fieldwork April 2026

29
FGD participants
Focus group discussions · 20 Wawang Pulo · 9 Mukuru

7
In-depth resident interviews
4 Wawang Pulo · 3 Mukuru

3
Key informant interviews
City Planning & DRRM officers (Valenzuela) · community organisation rep (Nairobi)

1
Threshold simulation
Relocation-threshold exercise run inside the FGDs

2
Sites under field observation
Direct observation of flood exposure and in-situ adaptation

Analysis: thematic analysis across both sites to identify convergent processes
Transferability is claimed as **analytical, not statistical**

Vulnerability Transferability

> *"These floods... are moving with us."*
>
> Mukuru resident and community organisation representative, 13 April 2026

DEFINITION

Vulnerability is produced through the relationship between households and their spatial, social and economic conditions. Relocation can change physical exposure without changing the conditions that produce vulnerability.

Why the risk travels

1. Relocation sites are themselves on marginal land
2. The conditions that produce vulnerability travel with people: unaffordable formal housing, insecure tenure, absent infrastructure
3. Moving the household does not change its position
4. So, the risk reappears in the new location

Physical exposure ≠ vulnerability *(Wisner et al., 2004)*

The housing market returns them to the same conditions

92%
of Mukuru residents are tenants, typically in 10 × 10 ft sheet-metal structures *(Andersen et al., 2023)*

30–50%
of monthly household income goes to rent *(Habitat for Humanity Kenya, 2025)*

4×
the returns investors realise in low-cost rentals versus formal housing *(Mwau & Sverdlik, 2020)*

The mechanism: Within the rent range accessible to many low-income households, affordable alternatives are concentrated in similarly exposed settlements, at densities near 280,000 people per km² *(Habitat for Humanity Kenya, 2025)*

NEIGHBOURHOODS IN THE SAME RENT BAND — AND THE SAME FLOOD SITUATION



Mathare : Mathare River corridor; 7,000+ displaced, April 2024



Kibera: Ngong River corridor; surveyed alongside Mukuru Viwandani



Korogocho : Nairobi River corridor; flooded May 2024

Nairobi's flood vulnerability cannot be explained by location alone

Nairobi's drainage depends on wetlands and riparian corridors the city has progressively lost *(ACRC, 2026)*

THE PHYSICAL SET-UP

- Settlements sit along the Nairobi, Ngong and Mathare river corridors, in low-lying floodplains with limited drainage *(WRI, 2025)*
- Rain runs from the higher western city towards lower eastern neighbourhoods *(WRI, 2025)*
- Degraded wetlands and buffers, spreading impervious surfaces, blocked drains and uncollected waste amplify every event *(WRI, 2025)*

AND YET THE RESPONSE IS REMOVAL

- After the May 2024 floods a 30-metre riparian corridor was enforced, evicting thousands of residents *(IIAS, 2025)*
- In Kibera, more than 22,000 people live along the Ngong River and over half report being flooded since 2015 *(Mulligan et al., 2019)*
- The same drainage failures now flood densifying middle-income neighbourhoods — this is not only a settlement problem *(WRI, 2025)*

Drainage, riparian restoration and tenure change exposure. Moving households does not.

Sources: WRI (2025) · ACRC (2026) · IIAS (2025) · Mulligan et al. (2019)

How households respond when relocation is not viable

Alongside Vulnerability Transferability, two further findings reshape how we think about staying

01

Vulnerability Transferability

- Vulnerability can persist when relocation changes exposure but leaves underlying social and economic conditions unchanged.

02

Vertical Refuge

- Households build second floors and raised floors to stay more safely
- A “third position” stay-or-leave planning cannot see: investing in staying better
- Metro Manila survey ranked adding floors the top desired intervention *(Du et al., 2025)*

03

Provisional Framing

- Residents sustain permanent flood-zone residence by narrating it as temporary
- Explains why relocation programmes stay underused even where alternatives exist

“When you calculate your income, your children, school here… it’s better to endure because it’s something temporary, and life goes on.” **- Resident, Mukuru**

The real question is not "move or stay"

Location-based relocation logic(current): is the new location safer?	Position-sensitive adaptation logic (proposed): Did the intervention change the conditions that produce vulnerability?
Vulnerability is in the floodplain	**Vulnerability is in social & economic position**
Solution: move people out	**Solution: change the conditions that produce it**
Relocation as the default	**In-situ adaptation recognised as legitimate**
Ignores adaptation already happening	**Supports what residents already do (vertical refuge)**

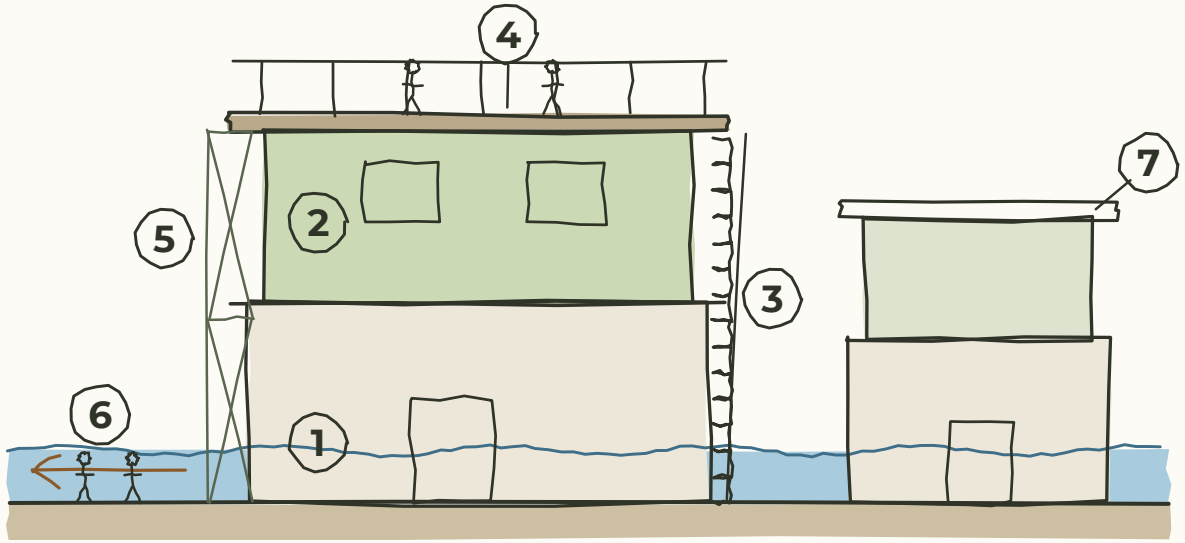
Adaptation is already happening in place





Households invest in staying more safely, evidence that in-situ adaptation is real and rational

Vertical refuge is an established adaptation practice



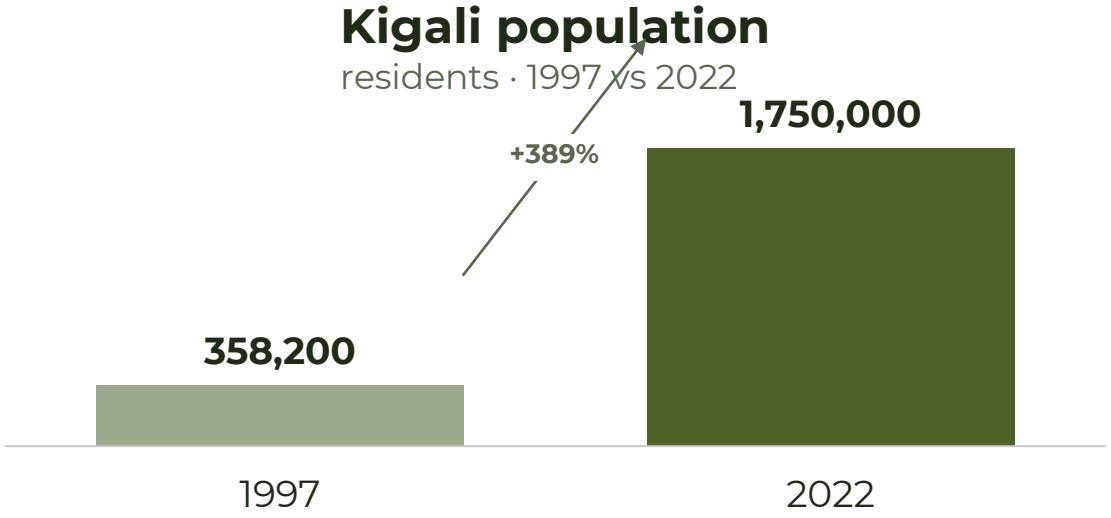
1. Existing structure retained
2. One more floor, added incrementally
3. External stair, non-corrosive material
4. Railed rooftop refuge doubles as rescue platform
5. External frame braces typhoon and quake loads
6. Alley kept clear for evacuation
7. Planned densification via reblocking

IN-SITU ADAPTATION IS ALREADY IN THE PLANNING RECORD

- LIRLAP explicitly includes on-site retrofitting of settlements to avoid relocation *(IREUS, University of Stuttgart)*
- Guidebooks on Resilient Retreat and Resilience Upgrading drawn from pilots in Valenzuela, Quezon City and Manila *(MGB, 2025)*
- Built precedent: the Manggahan Low Rise Building Project, Pasig *(Reach Alliance, 2026)*

What does this mean for Kigali?

Disclaimer: Policy Reflection, Kigali was not a study site



79% live in unplanned housing, many on high-risk slopes and wetlands

RWANDA'S RESPONSE

Kigali Master Plan 2050 and the Informal Settlements Upgrading Strategy: relocate from high-risk zones and upgrade

2025 EVIDENCE

Redevelopment introduced new vulnerabilities: affordability, employment and community cohesion *(Chiromo et al., 2025)*

The drivers this study identifies reappear in Kigali's own experience

Rwanda is already testing both approaches

Busanza - the relocation model	Mpazi - the in-situ model
Planned resettlement zone on Kigali's outskirts	Redevelopment within the existing flood-prone community
Residents moved out of high-risk settlements: experiences of financial strain, job disruption, social isolation	Formal housing built in place, keeping people and livelihoods rooted
Position destroyed	**Position preserved**

Relocation reduced exposure but disrupted livelihoods and social networks; in-situ redevelopment preserved these spatial relationships.

The floods keep moving with us

01

Vulnerability is produced by position

02

Relocation can reduce physical exposure without reducing the conditions that produce vulnerability.

03

Adaptation must address tenure, infrastructure and livelihoods, wherever people live

"Until we change the conditions that produce vulnerability, the floods keep moving with us."

Thank you

Edith Kemunto Rosasi · TU Dortmund & University of the Philippines Diliman · edith.rosasi@tu-dortmund.de

C) URBANIZATION, INFRASTRUCTURE & ENERGY

22 September 2025, 14:15 – 15:30 PM, Breakout Room II

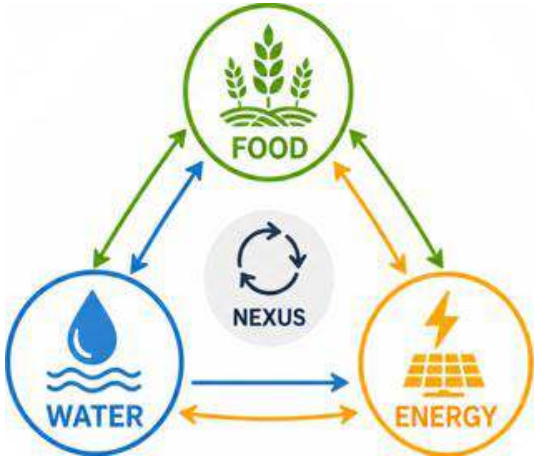
Planning Irrigation Electrification and its Impact on Electric System

Pierre Damien Uwitije[1,2], Jimmy Ehnberg[1], J.M.V. Bikorimana[2], and Umutoniwase Ernestine[2]

[1]Department of Electrical Engineering, Chalmers University of Technology, Sweden

[2]School of Engineering, College of Science and Technology, University of Rwanda, Rwanda

Contextual background



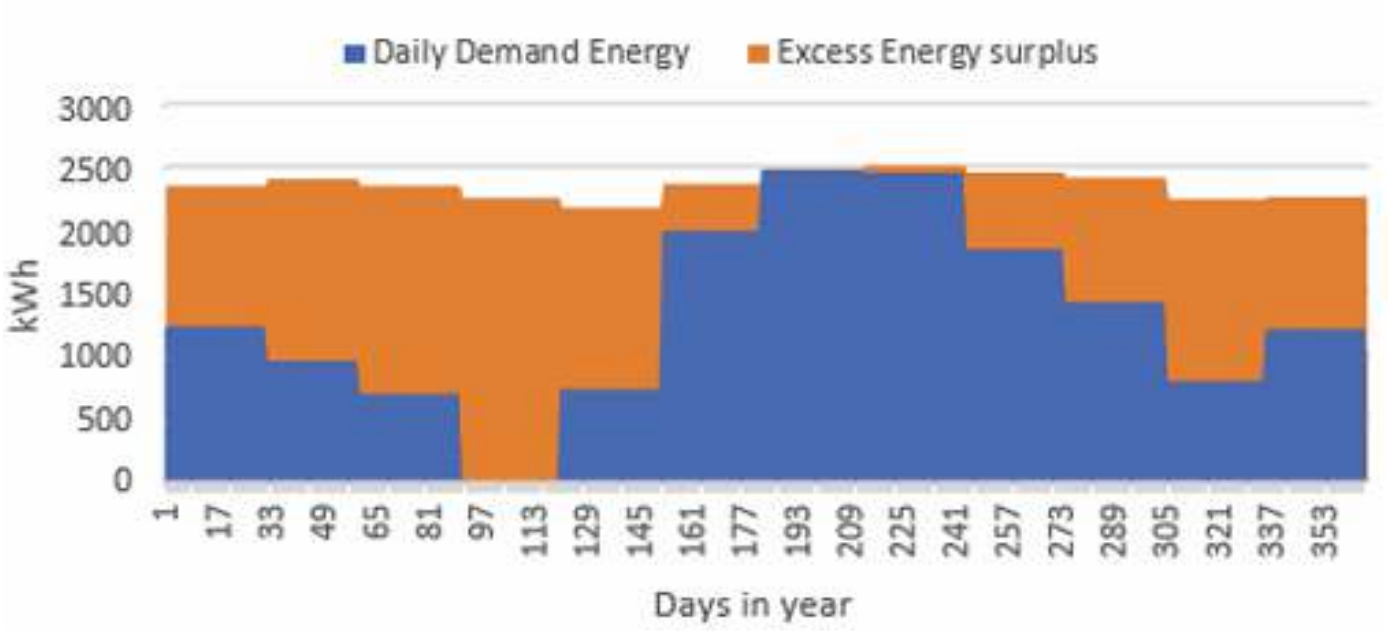




Need for a bridging study



Small-scale: Preliminary results

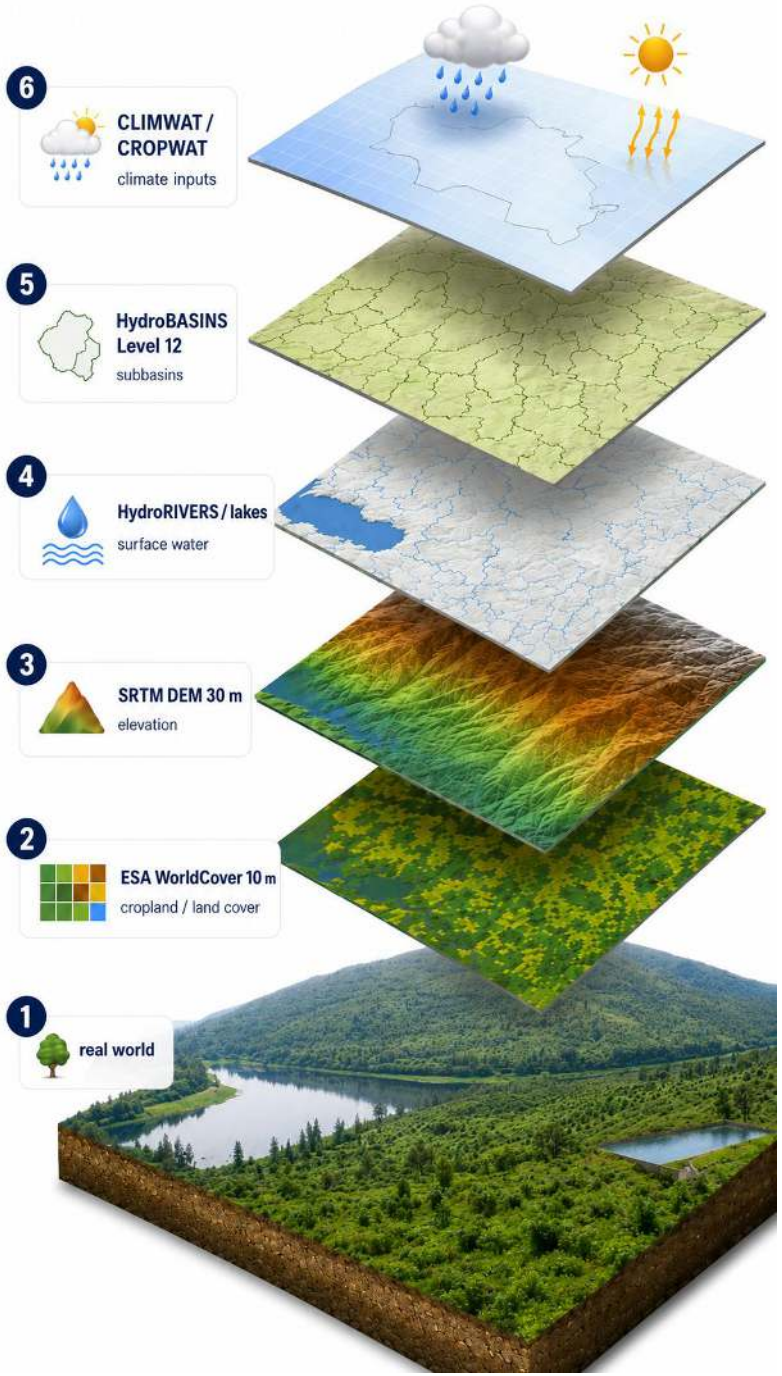


- Low power plant factor.
- If powered by on-farm PV, Excess valuation.
- Gravity storage is not systematically sized.

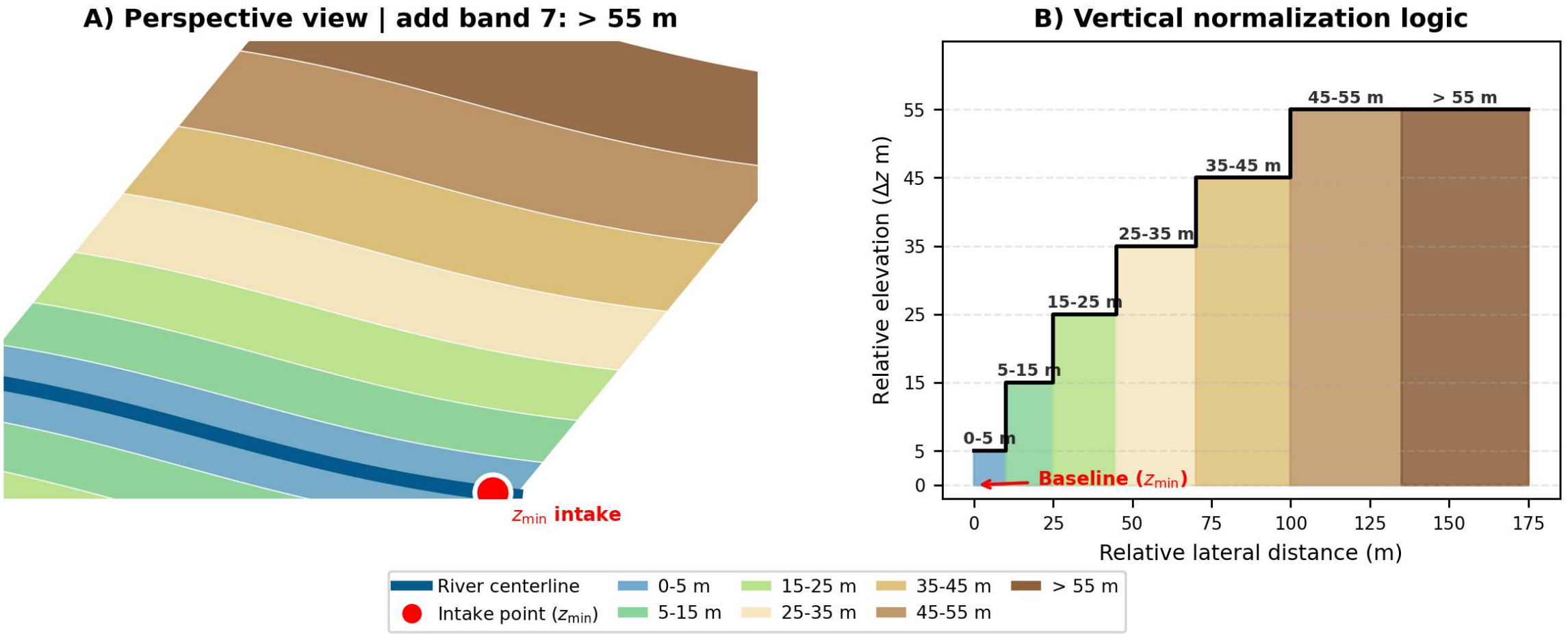
Large-scale: Methodology

What is cropland area?; lift?; flowrate?

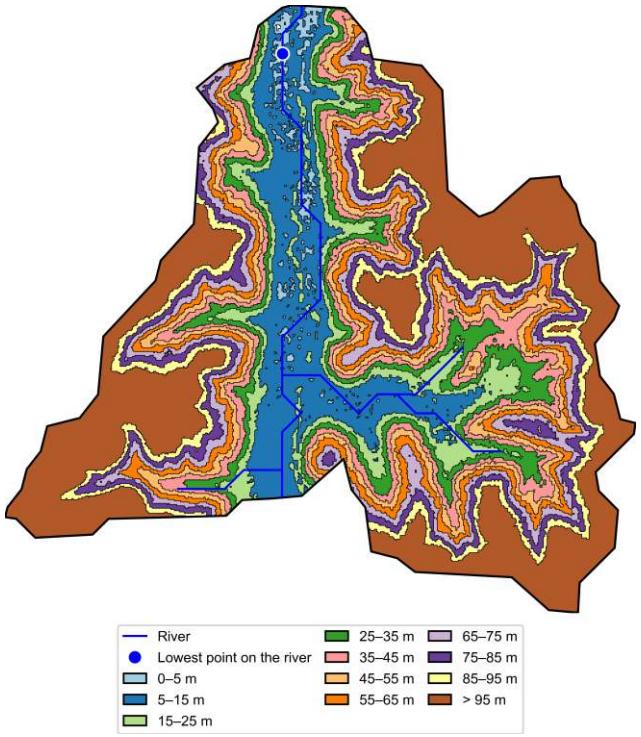
- Cropland is derived from ESA world cover.
- Water intake is geolocated from HydroRivers/ lakes dataset
- Lift is derived from SRTM DEM dataset.
- Hydro-Basins and CLIMWAT datasets are used to define the planning envelopes

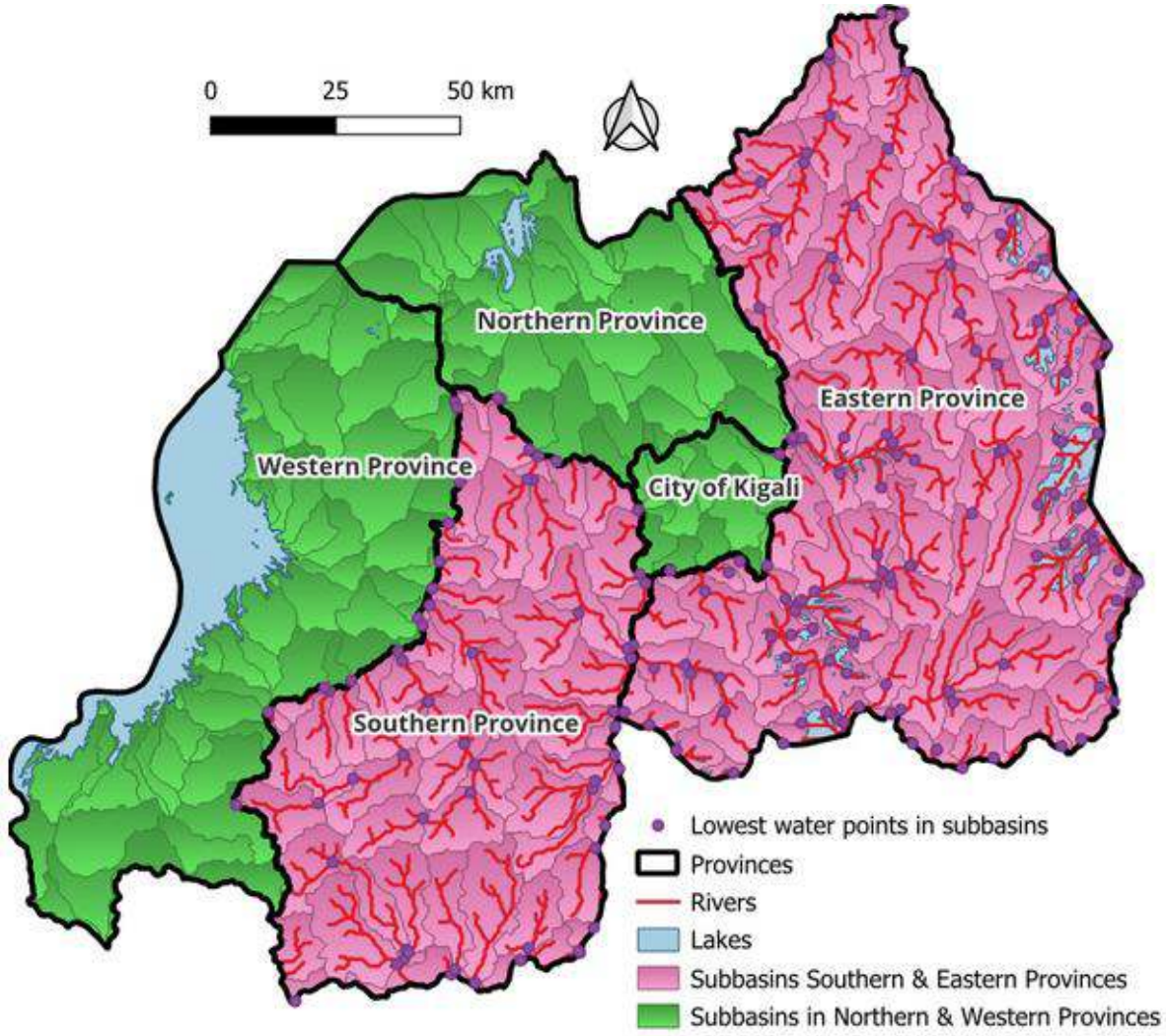


Intake abstraction and cropland grouping by relative elevation

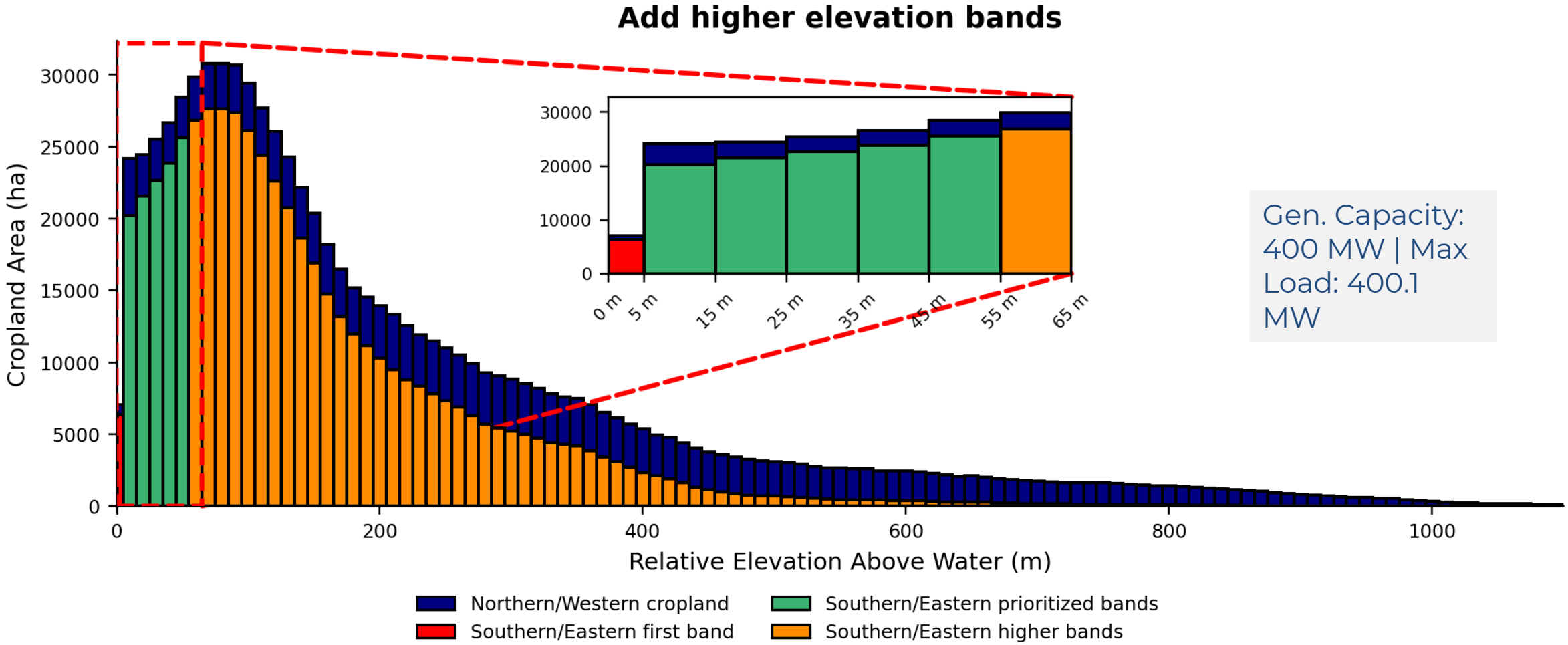


Large-scale: Area of interest





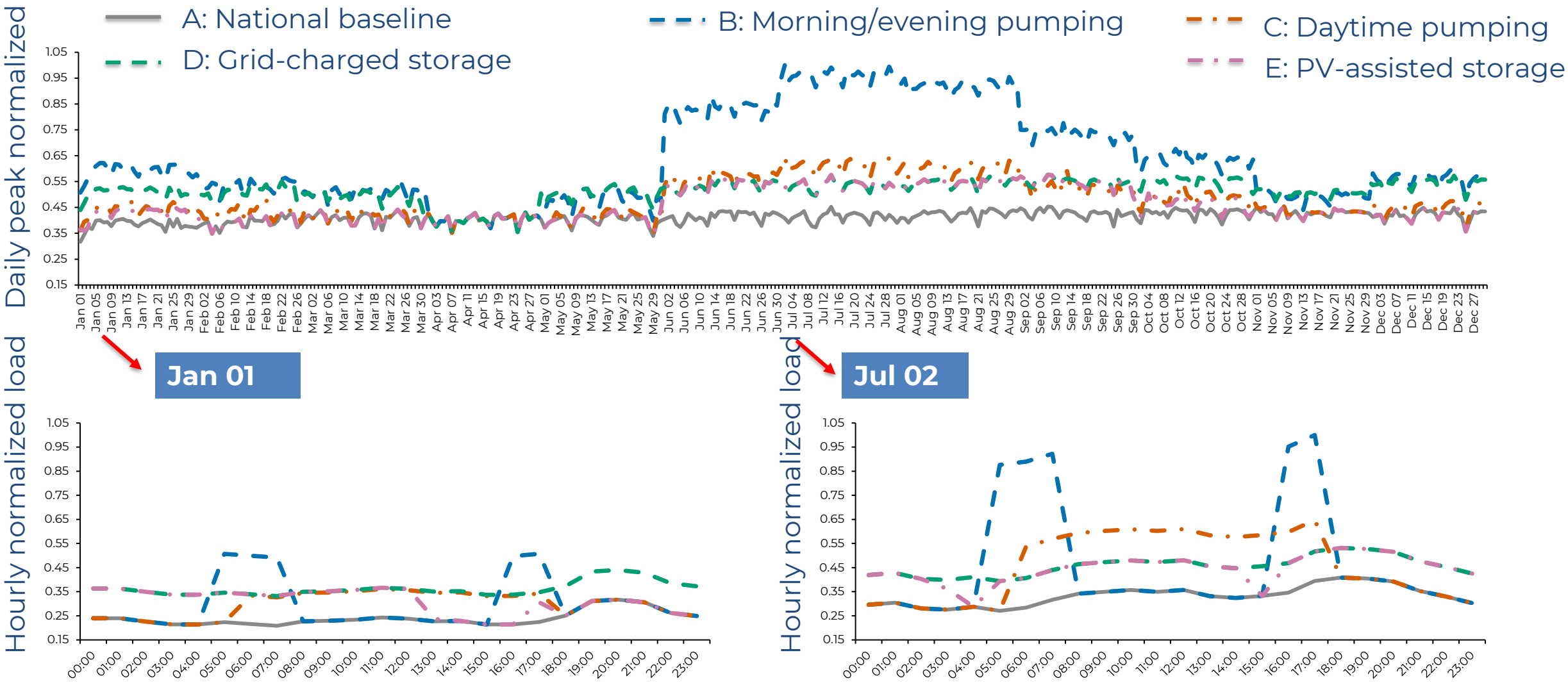
Results 1 : Where irrigation become systems-relevant?



Gen. Capacity: 400 MW | Max Load: 400.1 MW

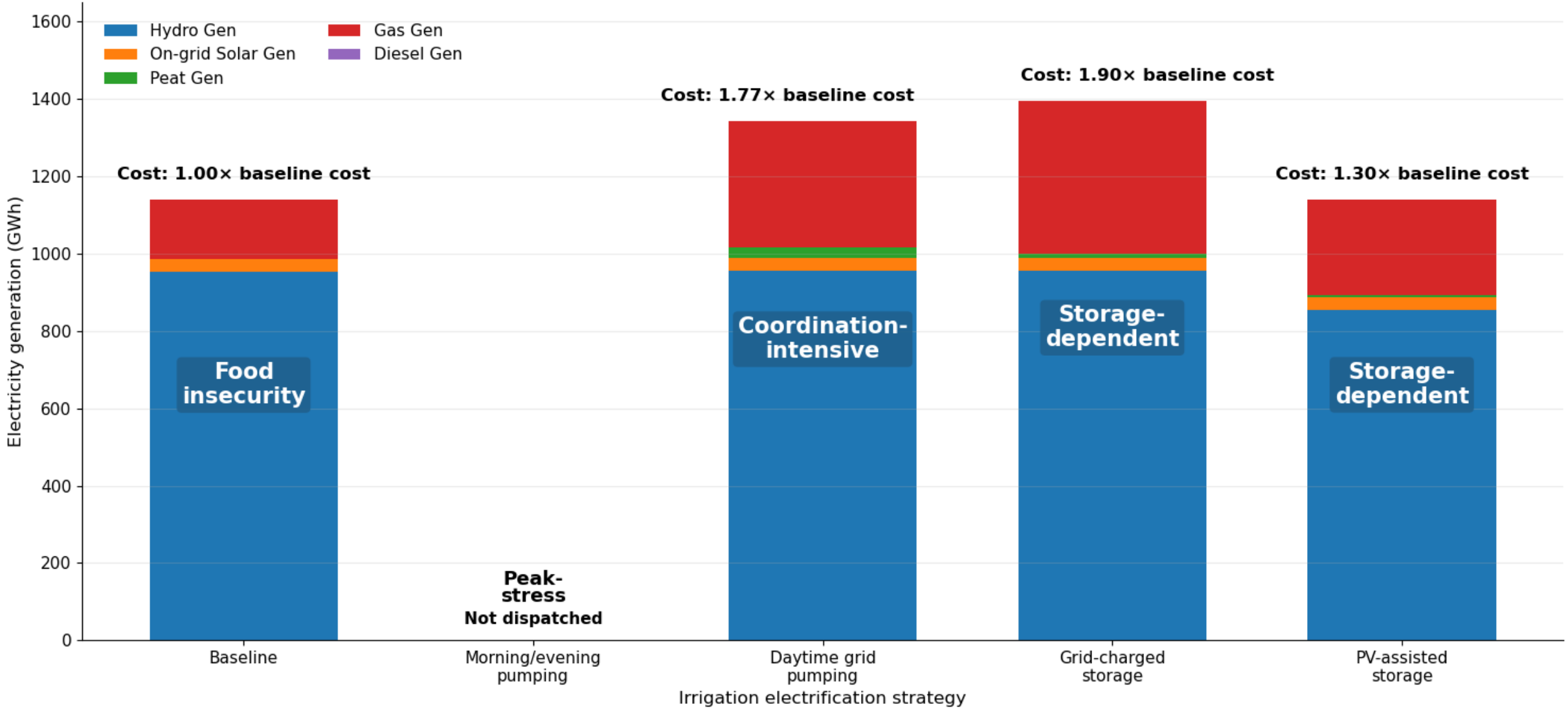
RWANDA CLIMATE SCIENCE SYMPOSIUM 2026

Results 2: How irrigation service becomes grid demand

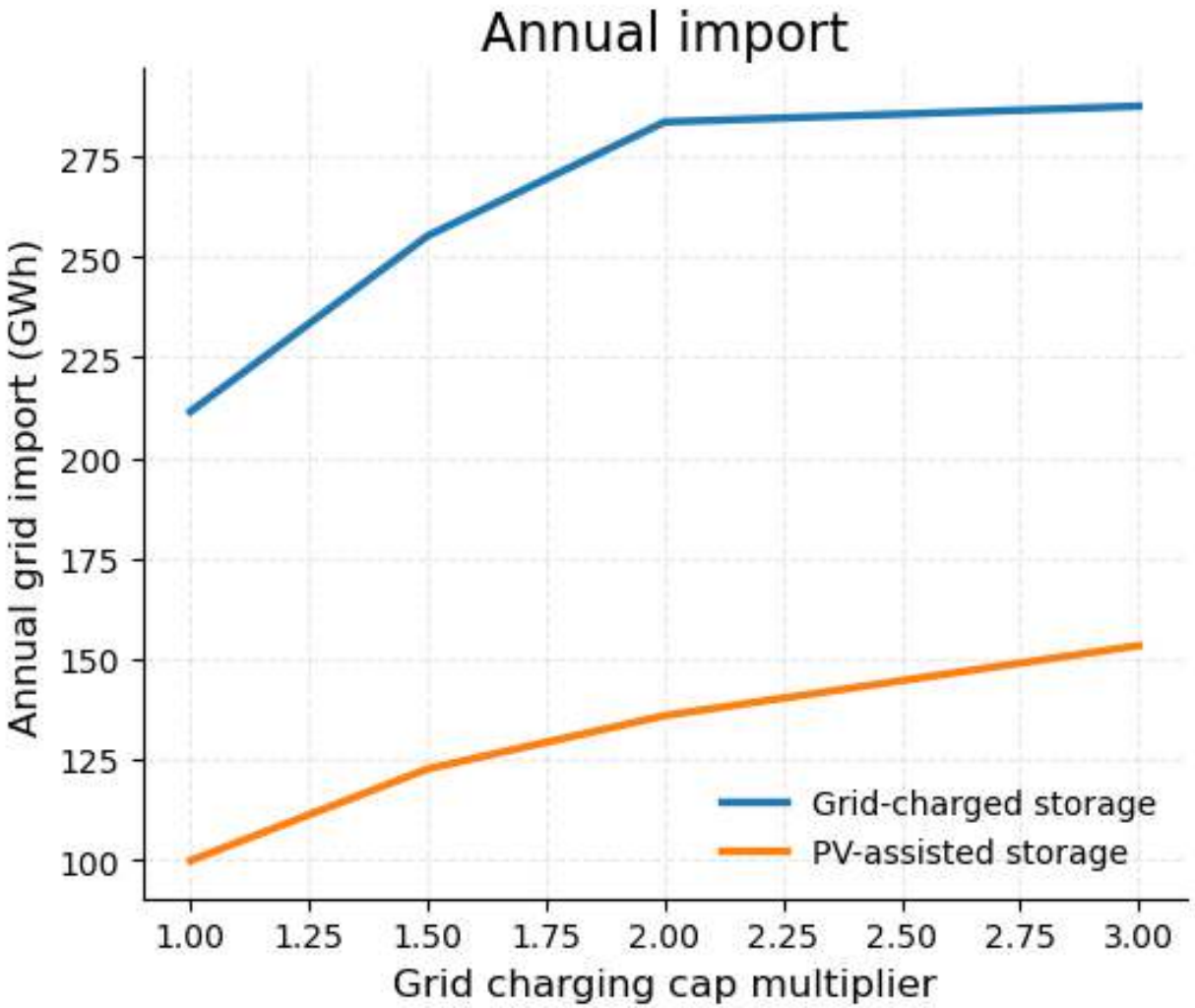


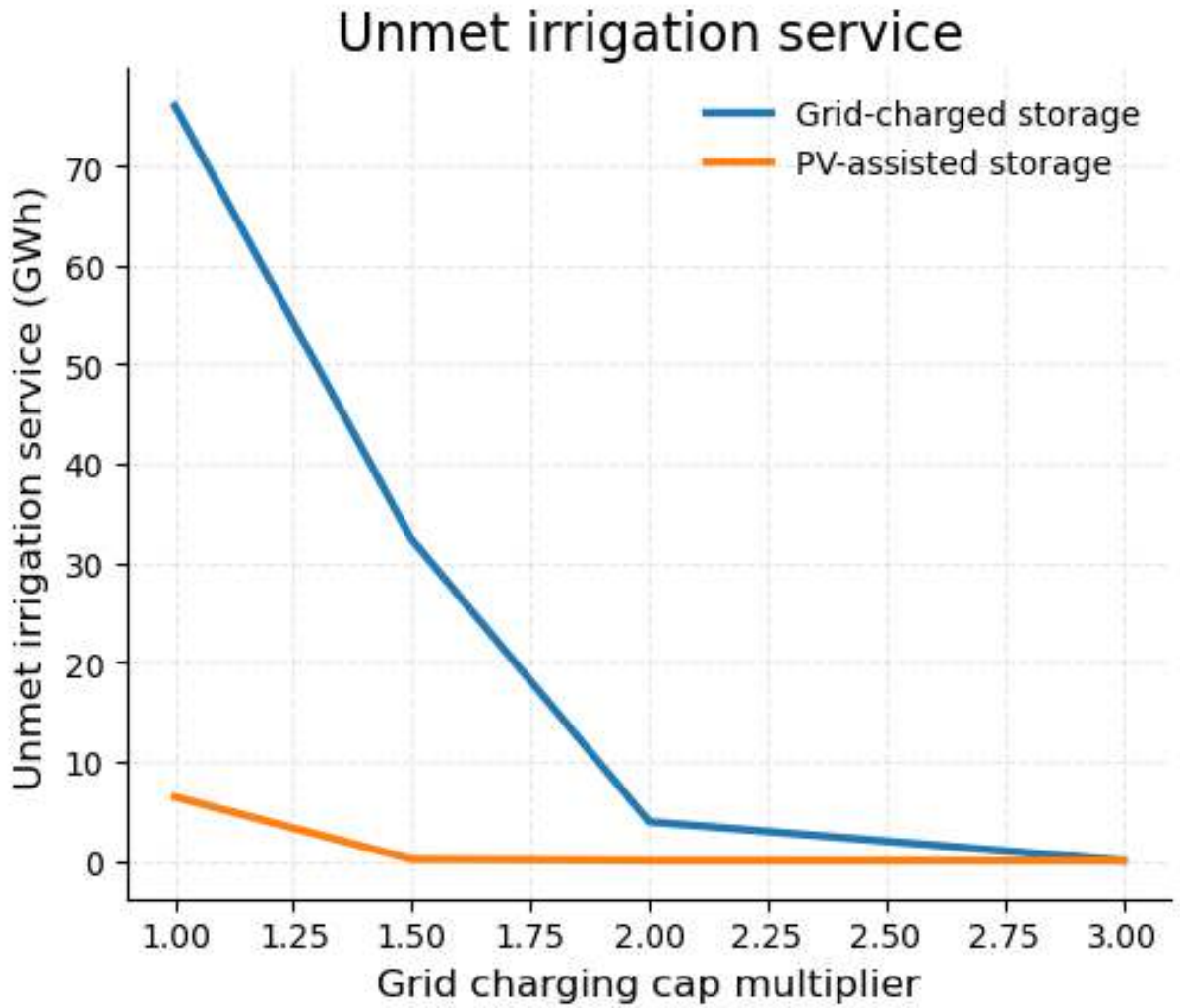
Farm-side pumping	Delivery logic	Grid signature	Cost implication
PV + grid pumping to storage	Delivery depends on PV, storage, and grid support	Lower imports, possible exports	Cost depends on PV size, storage and FiTs rules

Results 3: Cost effective strategies

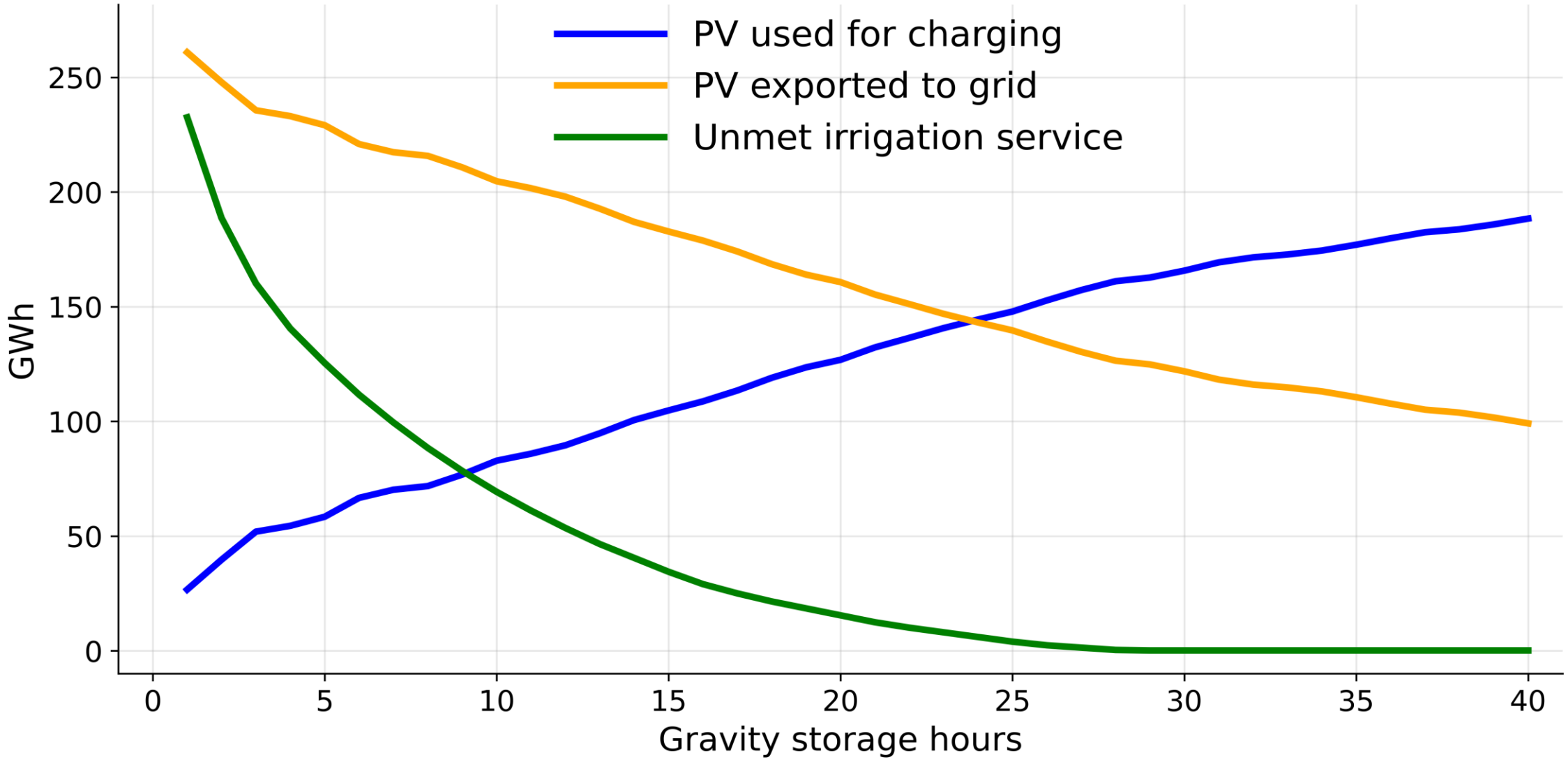


Results 4: Grid-charged only is not reliable

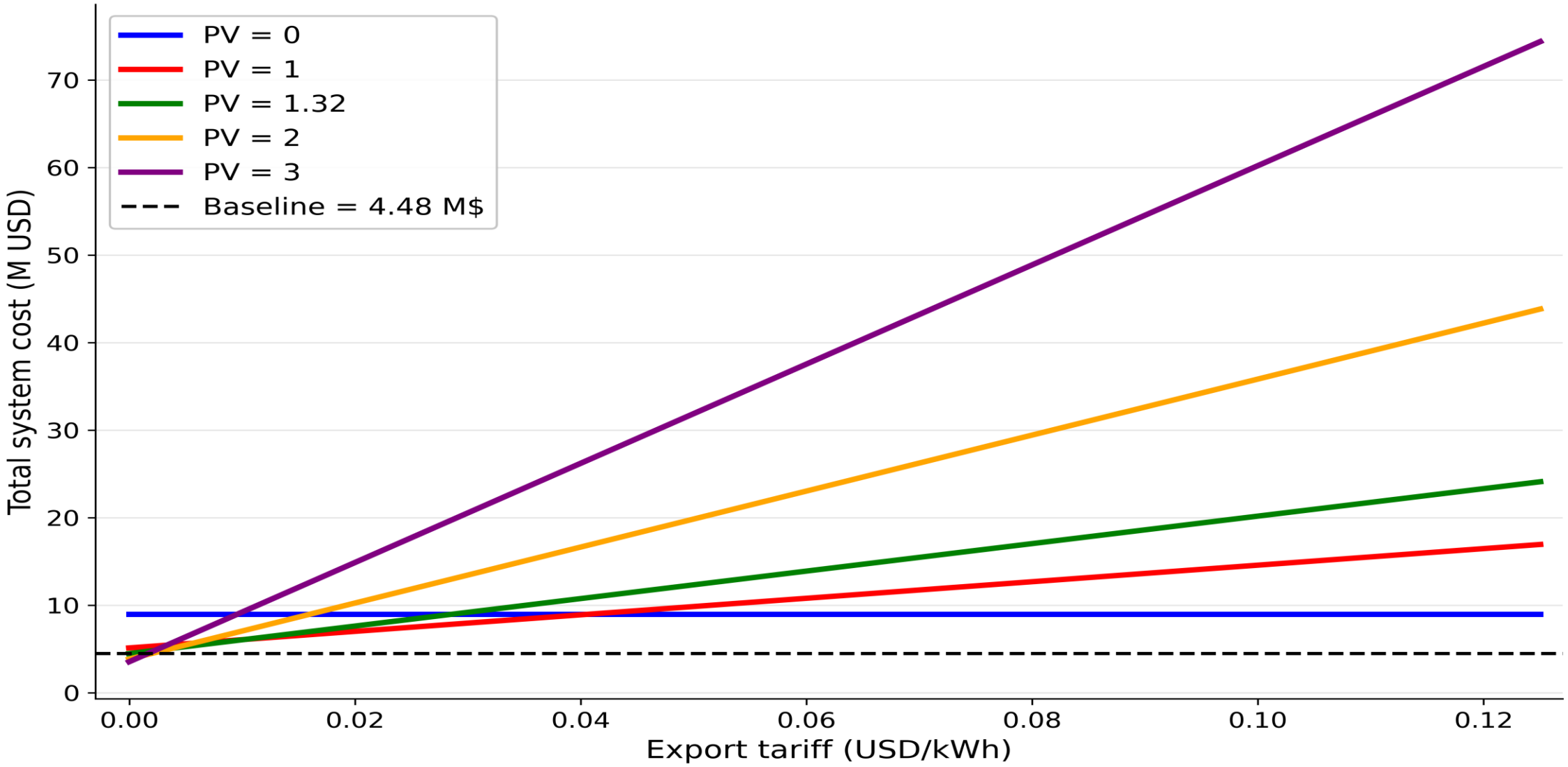




Results 5: storage size behavior decides usage, exports and unmet irrigation service

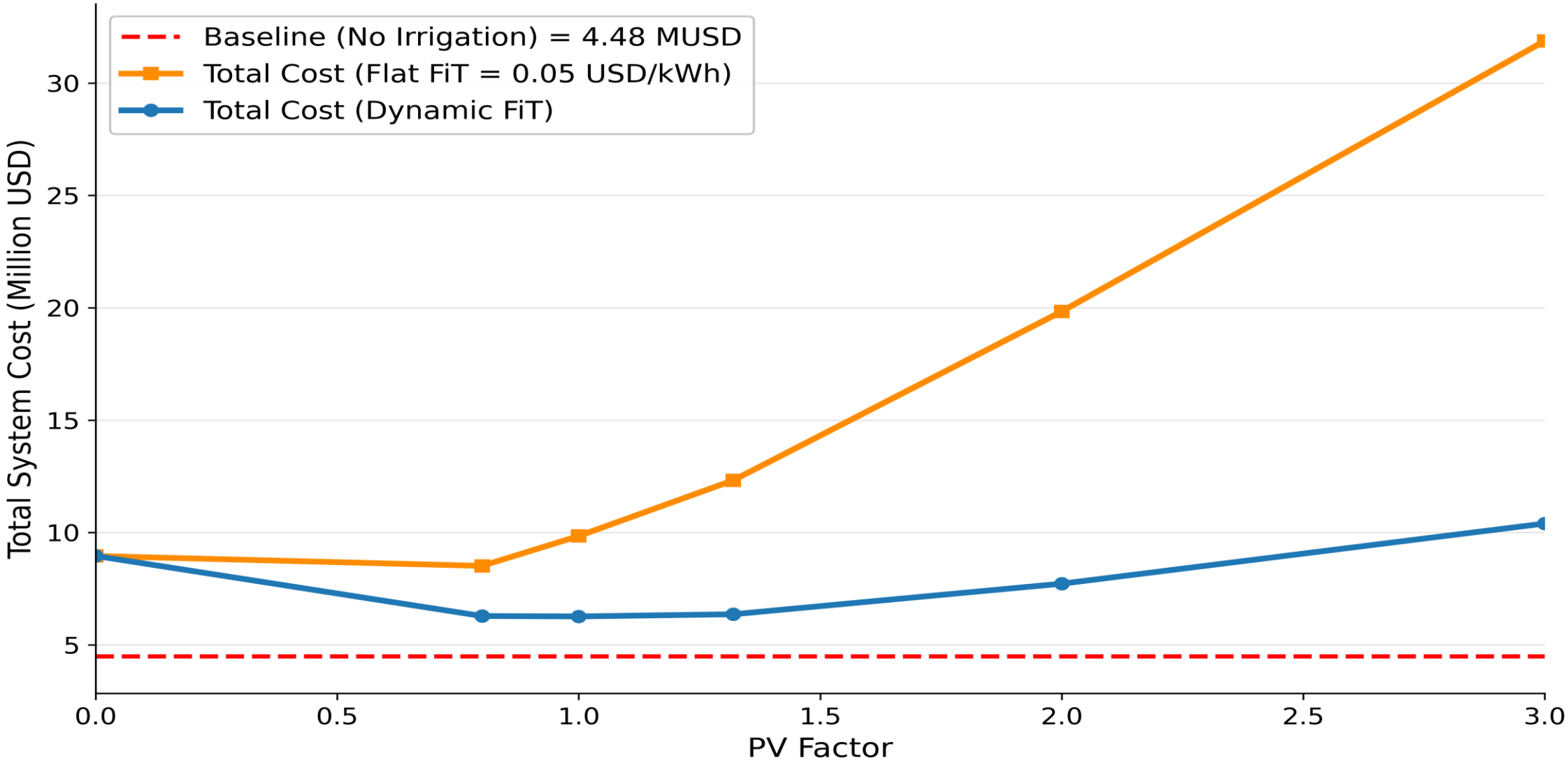


Results 6: Tariff ought to be revised with more on-farm PV



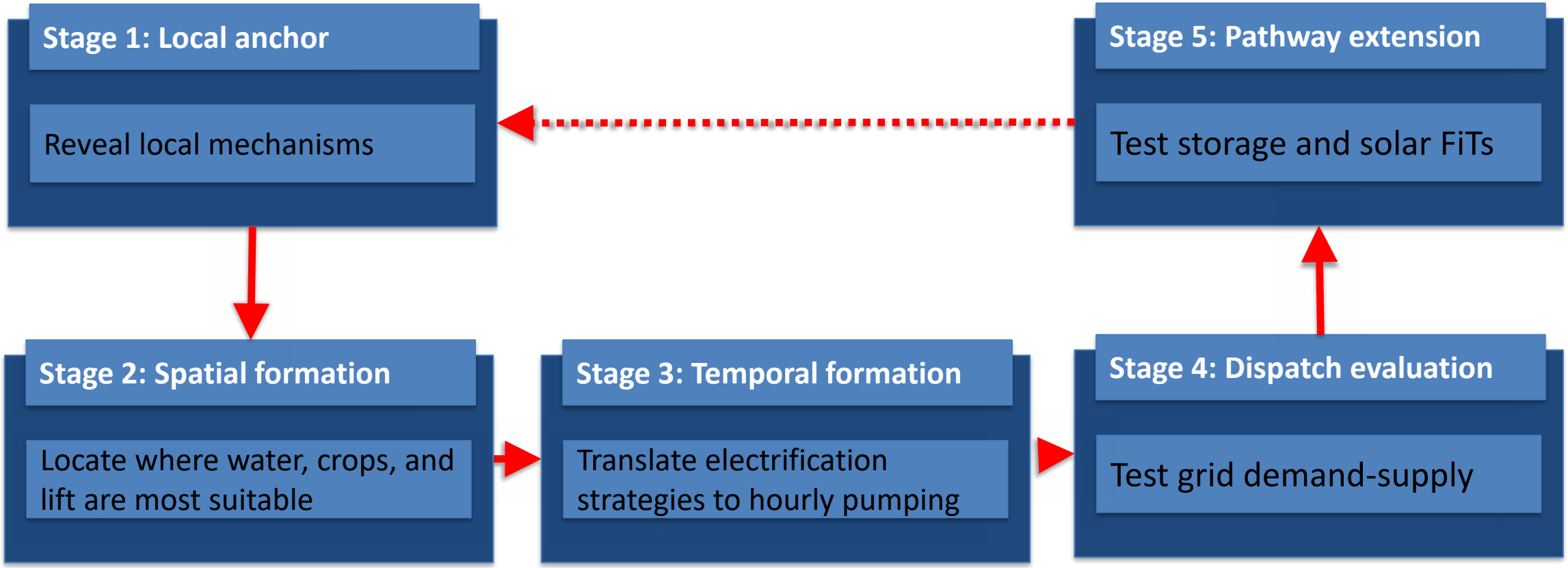
If exported PV electricity is paid at different fixed tariffs, how does total system cost change for different PV factors?

Results 6: Tariff ought to be revised with more on-farm PV



Dynamic FiT analysis; flat FiT used for comparison = 0.05 USD/kWh

Integrated Framework and Policy intervention



Conclusion

- Irrigation electrification is demanding formation problem.
- Irrigation is a system shaping productive use activity.
- Storage improves reliability, but shifts constraints toward charging cap, and storage capacity.
- Hillside irrigation is both a constraint and a storage-flexibility opportunity.
- FiT policies should balance utility cost recovery with farmer incentives.
- Planners need a shared land-water-energy-tariff interface.

D

NATURE-BASED SOLUTIONS & ECOSYSTEMS

D) NATURE-BASED SOLUTIONS & ECOSYSTEMS

Exploring Plant -Microbe Relationships in the Rhizosphere of Native Tree Species under Metal-Contaminated Soils: Basis for Microbial-Assisted Phytoremediation

Ms. Agnes Uwimbabazi- PhD Candidate (a, b), Prof. R. Subbaiya (a ,e),
Dr. T. Mwamba (a, c), Prof. S. Syampungani (a, e)

a	Copperbelt University, Zambia
b	Rwanda Polytechnic-Kitabi College
c	Lubumbashi University, DRC
d	University of Pretoria, South Africa
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Outline

- Introduction
- Problem statement
- Objective
- Materials and Methods
- Results
- Discussion
- Implications and Conclusion

1 Introduction

- Mining activities have released large amounts of heavy metals such as copper (Cu), cobalt (Co), zinc (Zn), cadmium (Cd), and chromium (Cr) into soils (Robyn et al. 2021).

- Ecosystems bear the scars of metal pollution from mining activities (Zhou et al., 2024)

  - Poor plant reestablishment
  - Poor soil health
  - Degraded land

- Metal pollution is critical in Sub-Saharan Africa (Chileshe et al. 2022; Mutika et al.2024)



Field photos of tailings dams, Copperbelt Province, Zambia
Photo by Uwimbabazi, October 2025

1 Introduction

Zambia's Copperbelt region only

Over 2.8 billion tons of mine waste across ~30,000 ha.

- Vast amounts of metal waste deposits in poorly managed tailings dams (Festin et al.,2019; Mutika, 2024)

- **Tailings**: 791 million tons (9,125 ha)
- **Overburden**: 1,899 million tons (20,646 ha)
- **Waste rock**: 77 million tons (388 ha)
- **Slag**: 40 million tons (279 ha)

- Expected continuous accumulation
- Ongoing build-up
- Long-term impact

(Festin et al.,2019)

- **There is an urgent need for sustainable action to mitigate these impacts (Uwimbabazi et al., 2026a, b)**

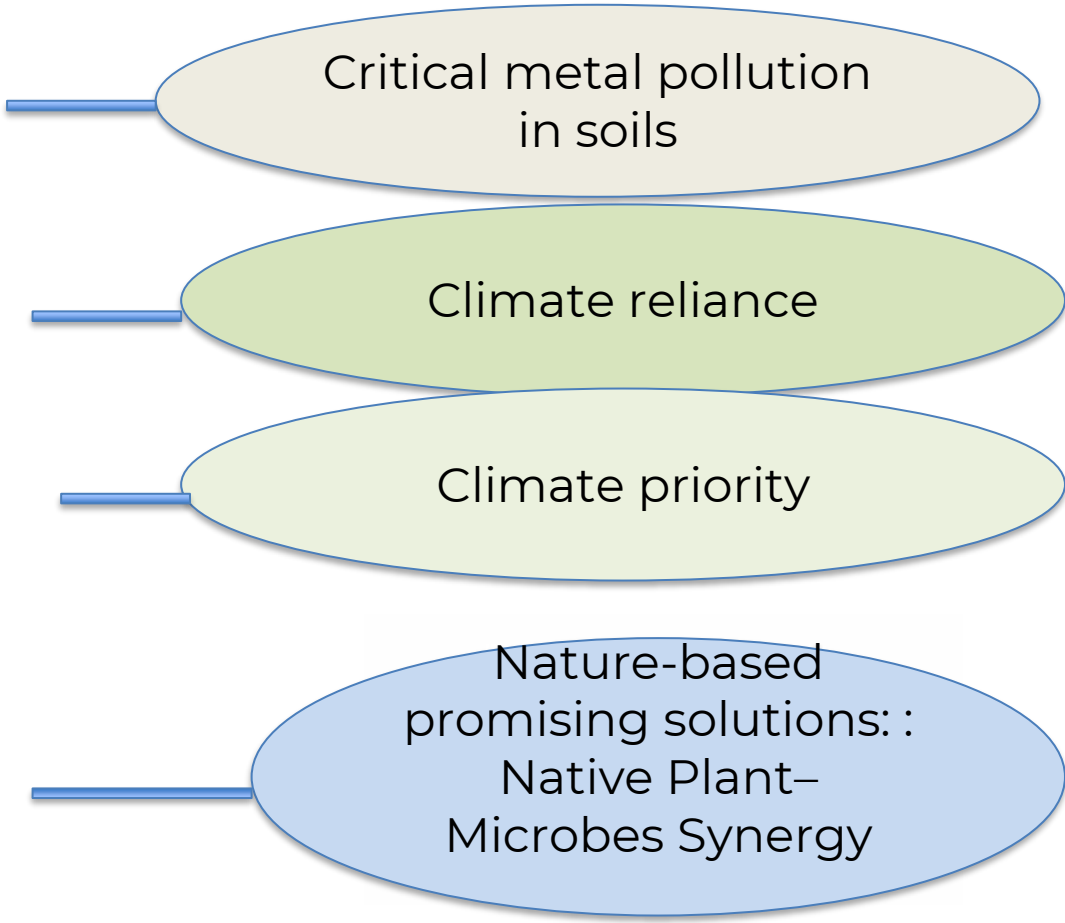
Critical continuous source of metal pollution

- Leaving soils, waters, and air heavily contaminated and threatening ecosystem life

2 Problem statement

Why does restoration of metal-contaminated soils urgently matter in SSA?

- Contamination undermines land productivity and food security (Octavia et al., 2023)
- Communities depend heavily on resilient ecosystems (Singh and Rigaud, 2023)
- Restoring polluted soils is both an environmental necessity and a climate resilience strategy (Nabiyeva and Wheeler, 2024)
- **Sustainable solution :** Microbial-assisted phytoremediation offers a nature-based pathway to remediation compared to other approaches (Nkongolo et al. 2023; Inobeme 2021; Uwimbabazi et al. 2026a)



3 Research Gap

Unlocking Microbial-Assisted Phytoremediation Potential

- ⚠️ **Limited knowledge** → Current studies rarely explore plant–microbe–metal interactions in SSA soils
- 🌱 **Native rhizosphere** → Limited research on native tree species and their root microbiomes in contaminated environments
- 🔬 **Mechanistic understanding** → Insufficient insight into how microbes and metals interact within the rhizosphere
- 🌼 **Climate priority** → Without deeper knowledge, microbial-assisted phytoremediation cannot be fully optimized as a climate-smart solution

(Matakala et al. 2023 ; Bruneel et al. 2022; Adu-Baffour et al. 2023)

objective

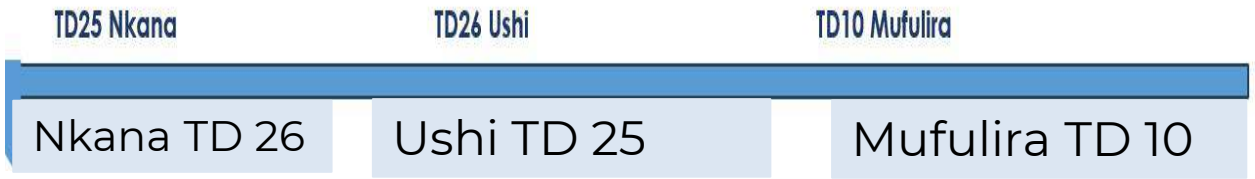
To evaluate how native tree species' rhizospheres shape microbial community structure, activity, and metal bioavailability in metal-contaminated soils

Material and methods









- A purposive sampling of soil in the rhizosphere and bulk of woody species
- *Rhus longipes*, *Senegalia Polyacantha*, *and Syzygium guineense* were selected
- Soil sampling in the bulk at 20 cm depth

Sampling and woody species selection

Selection criteria for individual tree species(Yengwe et al. , 2018; Addison et al., 2023)

- Mature trees with DBH≥ 15 cm
- Health status(physically health tree)
- Spacing: individuals located at least 5-10 meters apart to avoid root overlap
- Comparable tree height class (5-9 m)
- Absence of nearby disturbances

4 Material and methods

Soil preparation and laboratory analysis



Soil sample collection and transport



Air drying of soils



Soil sieving with a 2 mm sieve



Heavy metals analysis



Incubation in NaOH and Titration for Soil Respiration



Biomass, abundance of microorganisms



Titration for Total Organic Carbon

4 Material and methods

Laboratory methods

microBIOMETER® Pro Test Kit	F:B ratio, % Fungi, % Bacteria and microbial biomass
Alkali absorption method	Soil respiration (Microbial activity)
Ammonium Acetate–EDTA extraction	Extraction of bioavailable heavy metals
Atomic Absorption Spectrophotometer	Reading bioavailable heavy metal concentration
CaCl2 suspension method	Soil pH and electrical conductivity
Ammonium Acetate method	Cation exchange capacity
Walkley–Black method	Total organic carbon

(Bolo et al. 2023; Meena & Rao 2022; Szili-kov (2024) ; FAO 2022)

5 Results

Reduction of Bioavailable Metal in rhizosphere compared to bulk soil under contamination

Species	Metal	Bulk Soil (ppm)	Rhizosphere (ppm)	Trend in variation (p<0.05 from Kruskal-Wallis test)
Rhus longipes	Co	15.85 ± 3.86	7.98 ± 3.29	↓ Significant
	Cu	108.30 ± 2.28	98.05 ± 2.03	↓ Significant
	Fe	2388.71 ± 151.30	1979.75 ± 43.98	↓ Significant
	Mn	45.10 ± 5.55	31.22 ± 2.02	↓ Significant
Senegalia polyacantha	Co	23.71 ± 2.46	13.12 ± 1.15	↓ Significant
	Fe	2626.71 ± 276.34	2049.75 ± 75.01	↓ Significant
	Mn	40.90 ± 3.50	24.25 ± 4.84	↓ Significant
	Pb	0.19 ± 0.08	0.03 ± 0.05	↓ Significant
Syzygium guineense	Co	17.55 ± 0.99	5.11 ± 1.75	↓ Significant
	Cu	105.65 ± 4.42	77.47 ± 1.74	↓ Significant
	Fe	2371.39 ± 367.87	1563.62 ± 345.58	↓ Significant
	Mn	44.27 ± 2.85	34.94 ± 3.27	↓ Significant

Average recovery across all metals ranged from 96-98%, indicating reliable accuracy relative to certified values (BSG 102 and BSG 118

The concentration of bioavailable metals in rhizosphere soils under contamination was higher compared to the Control soils

5 Results

- Rhizosphere soils varied strongly relative to bulk soils, with significant **tree-species-specific differences in SR and MBC variables (TD10, TD25)**
- Most other parameters remained non-significant across tree species in rhizosphere soils.

- **SR**: Soil Respiration
- **MBC**: Microbial biomass
- **%Bacteria**: Abundance of Bacteria
- **%Fungi**: Abundance of Fungi

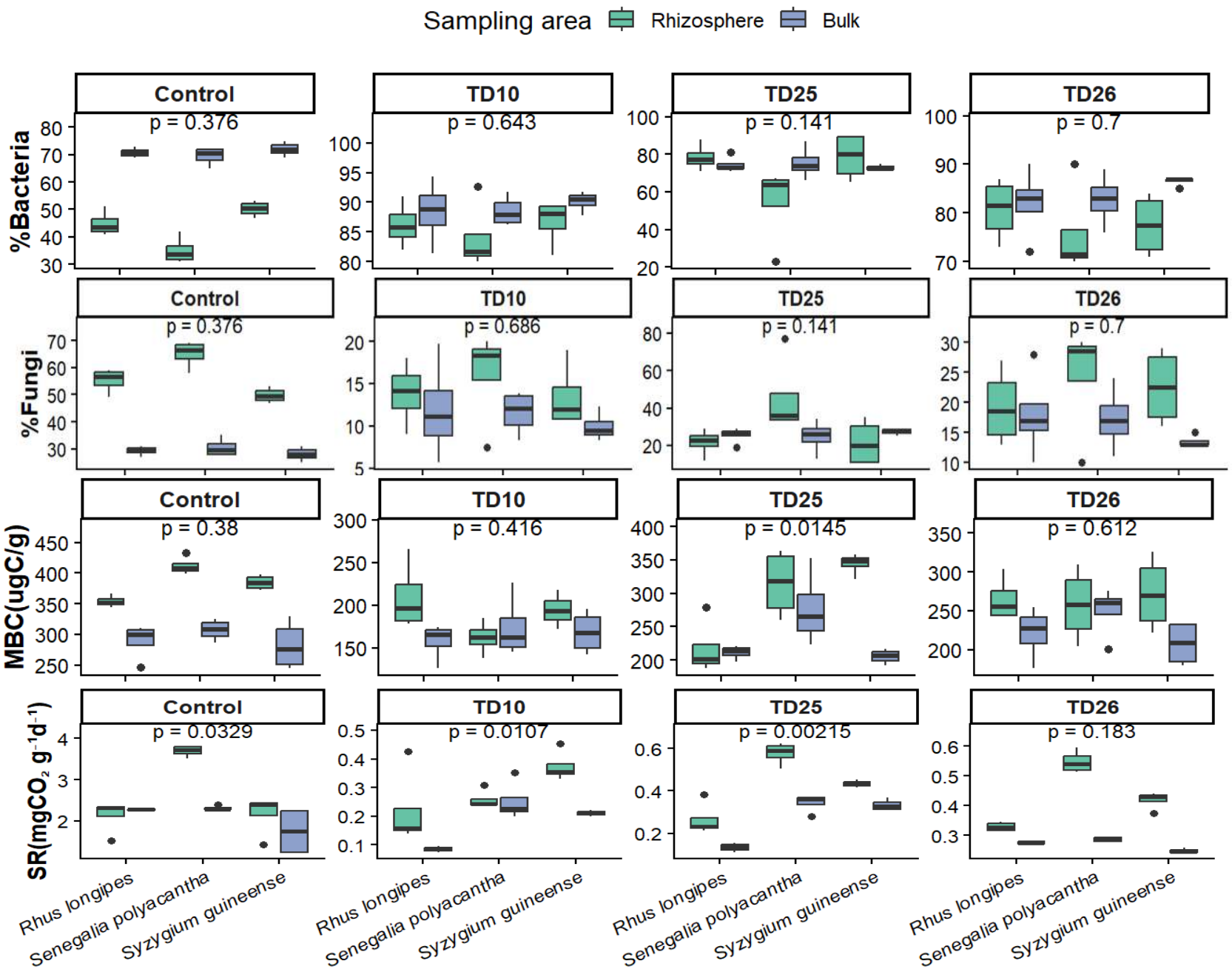
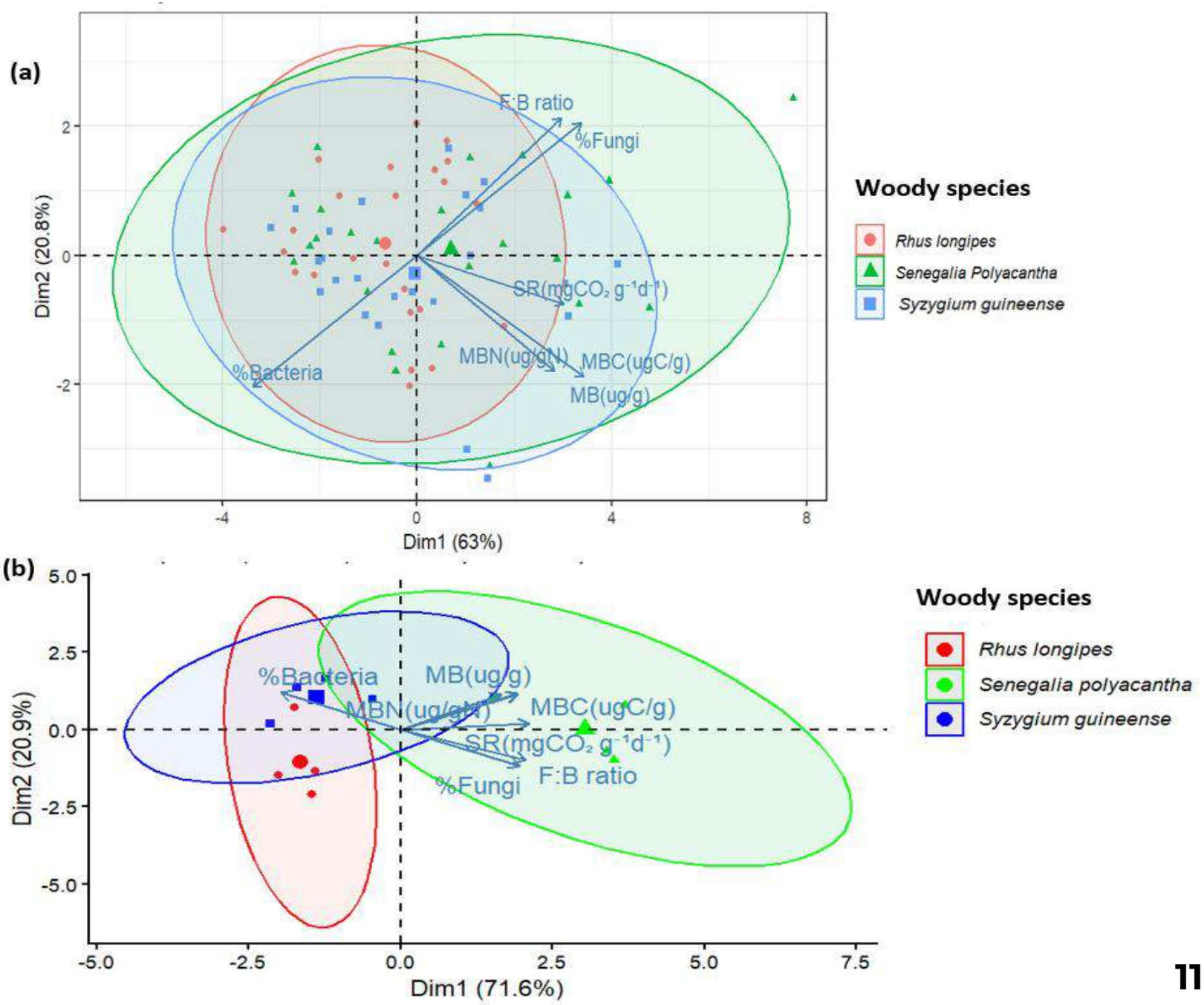


Fig.1 Microbial variation in species rhizosphere and bulk soils

5 Results

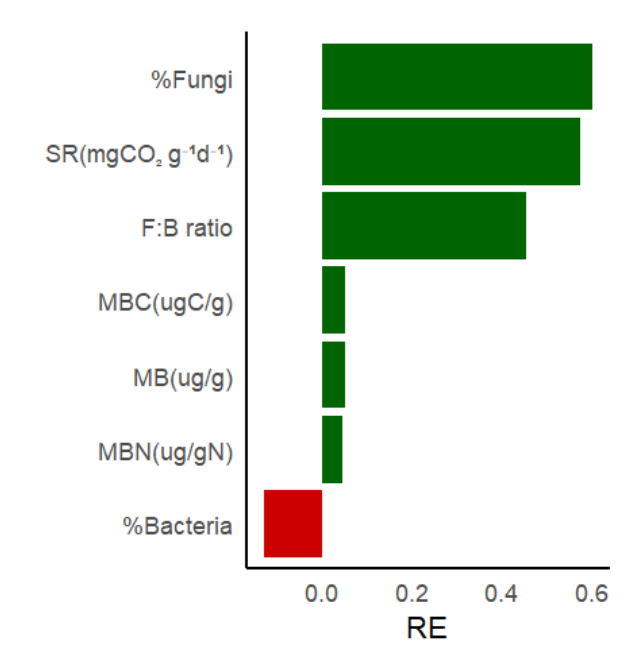
Fig.2 PCA biplots showing species-specific microbial separation in the rhizosphere soils under (a) metal contamination and (b) control (Mwekera Forest Reserve).

Ellipses indicate distinct clustering by tree species, with microbial biomass (MB, MBC, MBN) and soil respiration (SR) driving separation under metal contamination and fungal-bacterial balance(% bacteria, % fungi, and F: B ratio) driving separation under control.

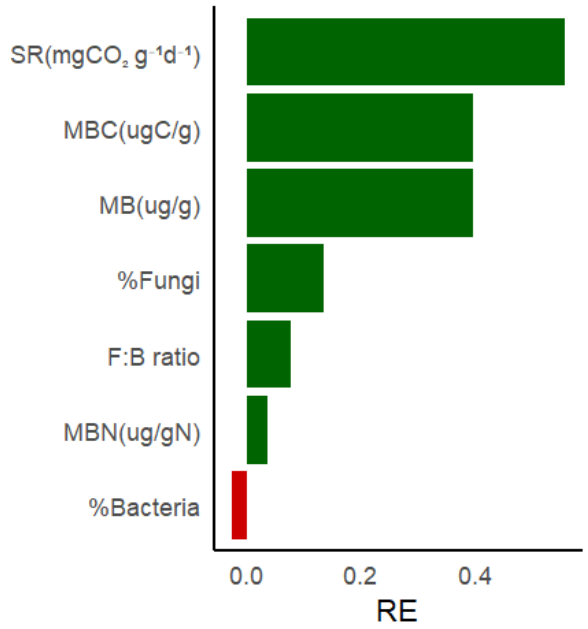


5 Results

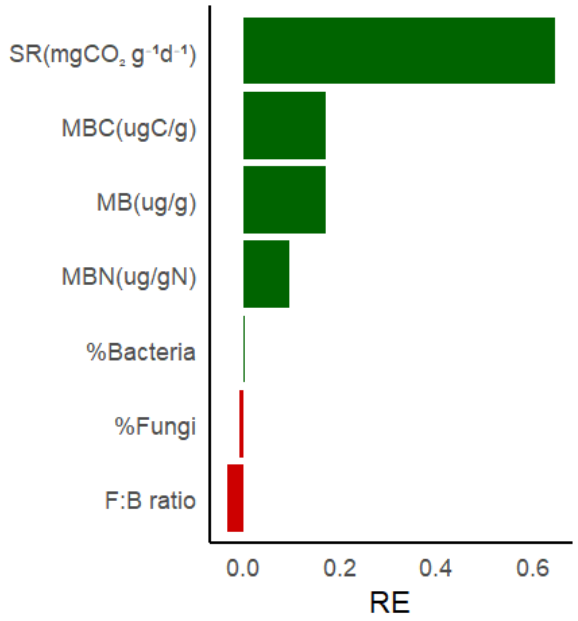
Fig. 3. Rhizosphere effect (RE) for the measured variable under contamination. Positive RE=rhizosphere enrichment; negative RE=Rhizosphere depletion



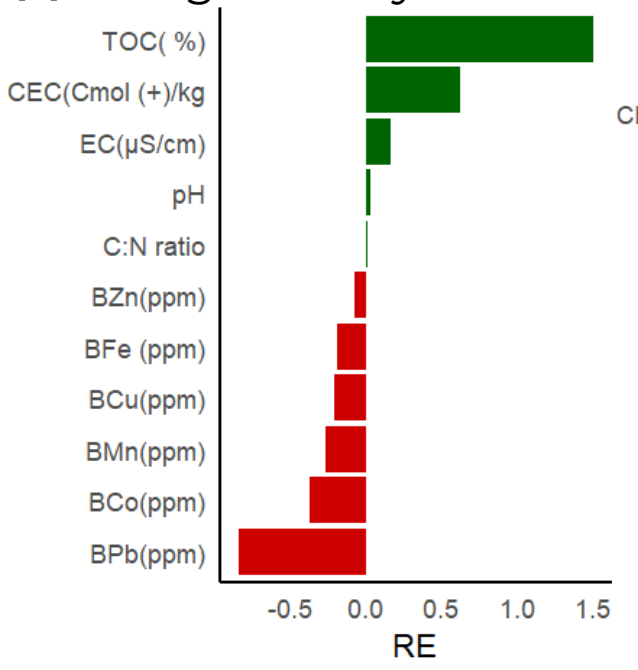
(a) *Senegalia Polycantha*

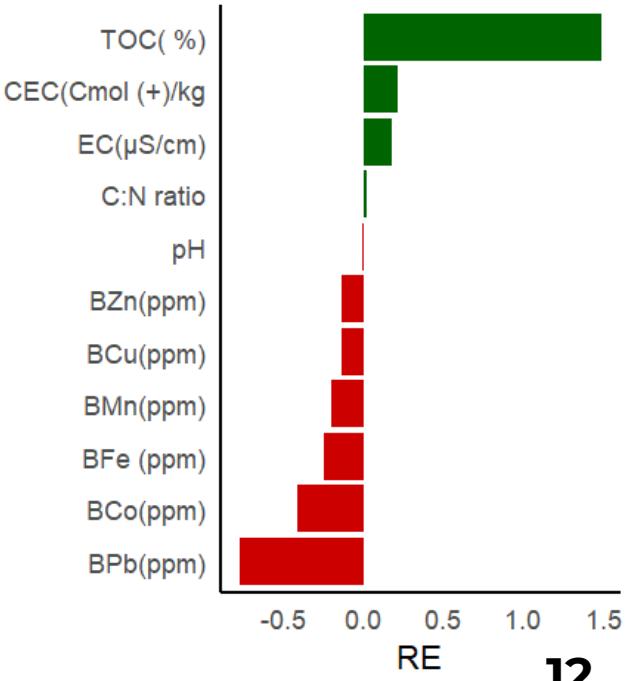


(b) *Rhus longipes*



(c) *Syzygium guineense*

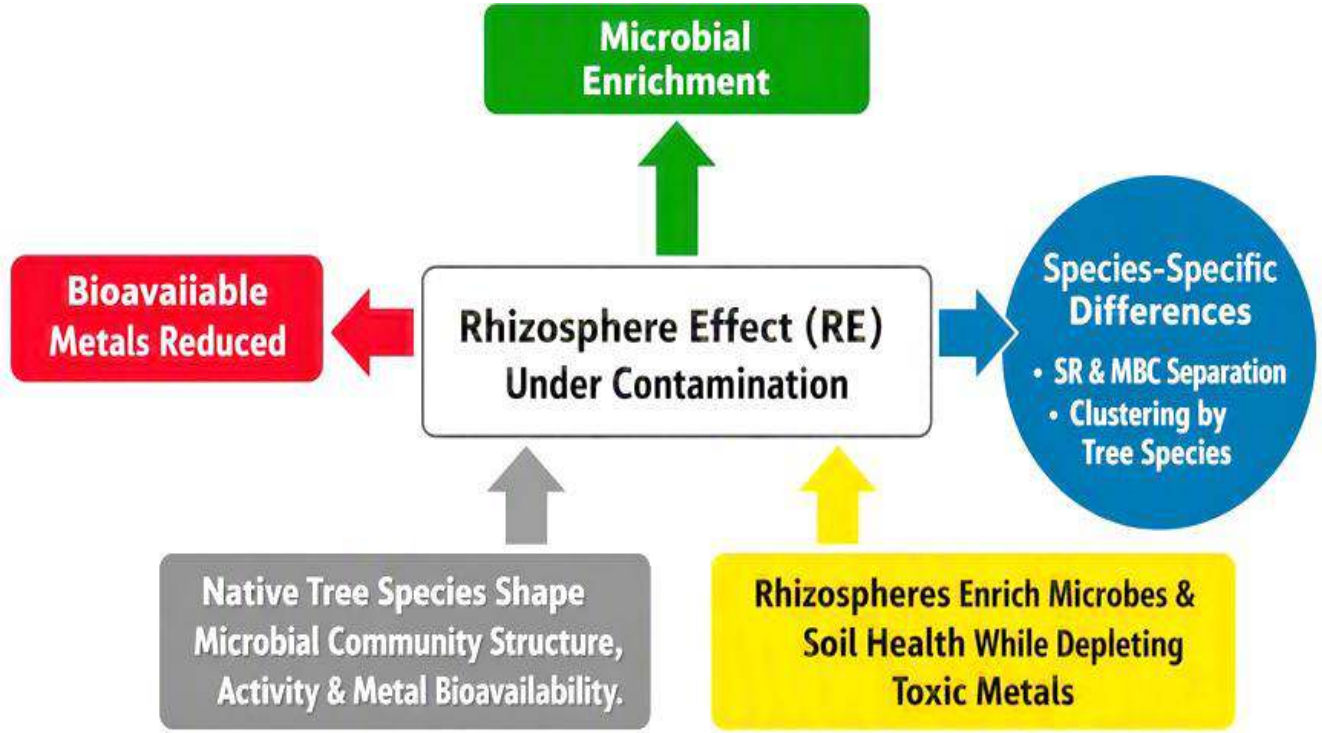




Rhizosphere effect Enrichment in microbial parameters and soil health parameters, bioavailable metal reduction with species-specific rhizosphere effect

6 Discussion

- Rhizosphere soils showed **depletion of metals** despite higher concentrations than control soils, indicating the role of tree roots in metal transformation (Caracciolo and Terenzi 2021; Hnini et al. 2025)
- Microbial parameters (MB, SR)and soil health indicators (TOC, CEC, pH) were **enriched in rhizosphere soils**, highlighting root-driven resilience (Sun et al. 2025; Yu et al. 2025).
- Tree species showed distinct rhizosphere effects, highlighting the differential strategies by which root microbe interactions shape soil processes under contamination (Hongyang et al. 2024; Wang et al.2026)



7 Implications and Conclusion

- **New evidence:** rhizospheres can simultaneously enrich microbial activity and soil health while depleting toxic metals, revealing species-specific protective effects not widely reported in prior literature (Jiang et al. 2026; Arantza et al. 2022).

- Native tree rhizospheres –microbe interaction can be used in microbial-assisted phytoremediation programs to restore metal-contaminated soils (Matakala et al.2023)

- Tree species rhizospheres naturally enhance soil health and reduce toxicity, offering a low-cost, nature-based solution (Festin et al. 2019 ; Matakala eta al.2023)

- Supports community-driven restoration in metal-contaminated soils across Sub-Saharan Africa (Adu-Baffour et al. 2023)

- These findings confirmed the capacity of native tree rhizospheres to shape microbial community structure, activity, and metal bioavailability, supporting their role in nature-based restoration of contaminated soils, aligning with **4 SDGs (13,3,6,15)**

Integrated Nature-Based Restoration Approach

13 CLIMATE ACTION

Builds Climate Resilience

Adapts to Climate Change

3 GOOD HEALTH AND WELL-BEING

Limits Toxic Exposure

Reduces Health Risks

6 CLEAN WATER AND SANITATION

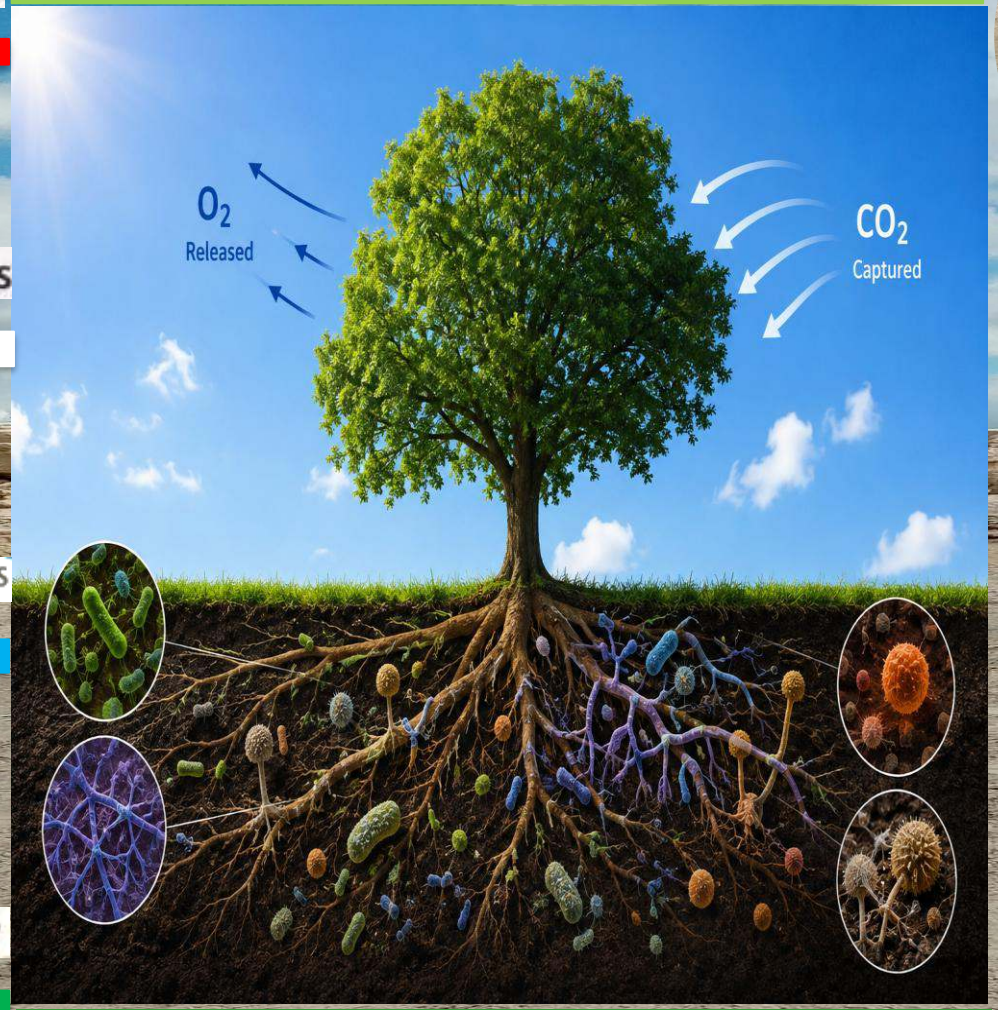
Reduces Contamination

Protects Water Resources

15 LIFE ON LAND

Restores Ecosystems

Revitalizes Biodiversity





Microbial-Assisted Phytoremediation of Metal Waste

ORTARChI
O.R. Tambo Africa Research Chairs Initiative

Acknowledgement

We acknowledge the **Financial support** of the Oliver R. Tambo African Research Chair Initiative of Environment and Development **(ORTARChI)** project at **The Copperbelt University,** Zambia. ORTARChI is led by South Africa's National Research Foundation **(NRF)** and Department of Science and Innovation **(DSI)** in partnership with the Oliver & Adelaide Tambo Foundation **(OATF),** Canada's International Development Research Centre **(IDRC),** and the National Science and Technology Council, Zambia **(NSTC)**

Thank you for your attention

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D) NATURE-BASED SOLUTIONS & ECOSYSTEMS

23 September 2025, 14:15 – 15:30 PM, Plenary

Climatic origin shapes photosynthetic sensitivity to water limitation in tropical tree species

Brigitte Uwajeneza[1,2] | Myriam Mujawamariya[1] | Camille Ziegler[3] | Donat Nsabimana[1] | Göran Wallin[1,2] | Johan Uddling[2]

[1]University of Rwanda, [2]University of Gothenburg (Sweden), [3]University of Bordeaux (France)

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Introduction

- Projected increases in global mean temperature of 1.5–4.7°C by 2100 (IPCC, 2021)

↓

Water stress in tropical regions.

- Moist and seasonally dry tropical forests, are particularly vulnerable to shifts in temperature and moisture availability.

↓

Loss of forest cover

Rwanda

- 110 ha of Rwandan forests were lost driven by wildfire (Global Nature Watch)

- Driven by Bonn Challenge initiative, Rwanda forest cover was boosted to the target of 30.4%

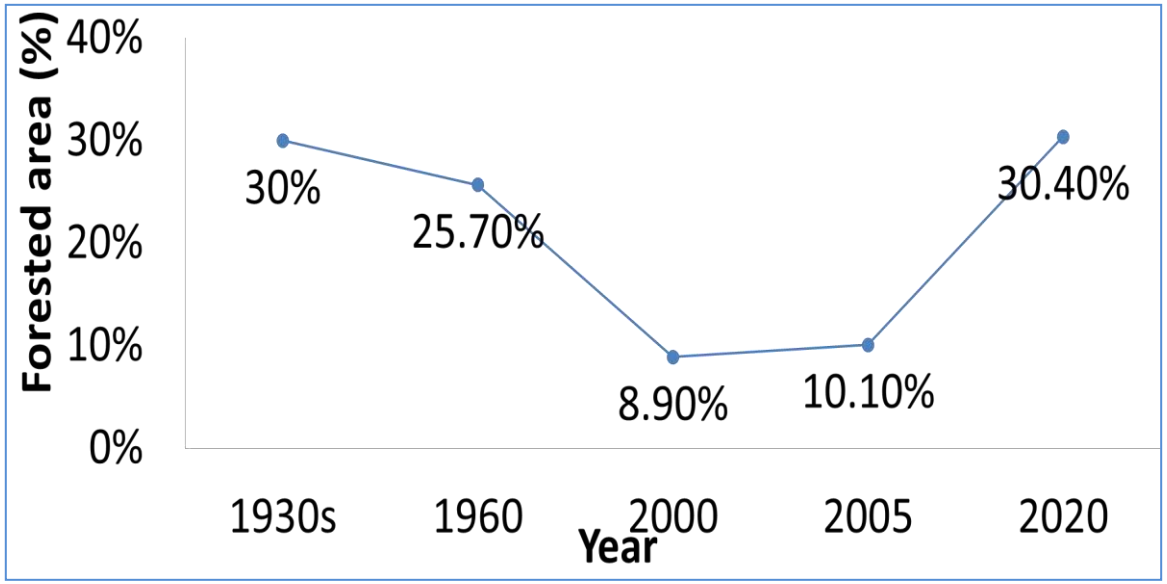


Figure 1: Status of forested area in Rwanda from 1930s to 2020

Problem statement

- The dominance of exotic monoculture specifically Eucalyptus spp (89%)

Soil erosion, allopathic effects, pests and diseases attraction and depleting soil nutrients

- Rwanda new Forest Policy (2018) focus on native tree species to increase tree diversity in forest restoration.

- Low survival rate of tree seedlings

Challenges:

- Many trees are not planted in the right places, or are not cared for properly

- Knowledge gap about the adaptation strategies of native tree species in differing environmental conditions
- Role of physiological adaption to warmer and drier conditions in the overall tree growth is less studied

Problem statement

- Some studies suggest that species capable of maintaining photosynthesis under warming and water limitation may gain a competitive advantage as climate change progresses.
    - *Limited empirical evidences **linking physiological** responses to warming and water limitation **with tree growth** and community-level shifts in tropical forests*
    - *This knowledge is still lacking in East-African native tree species*

Research objective

- Assess the impact of warming and drought on net photosynthesis (A_n) and its underlying components in native tree species along an elevation gradient in Rwanda

Research questions

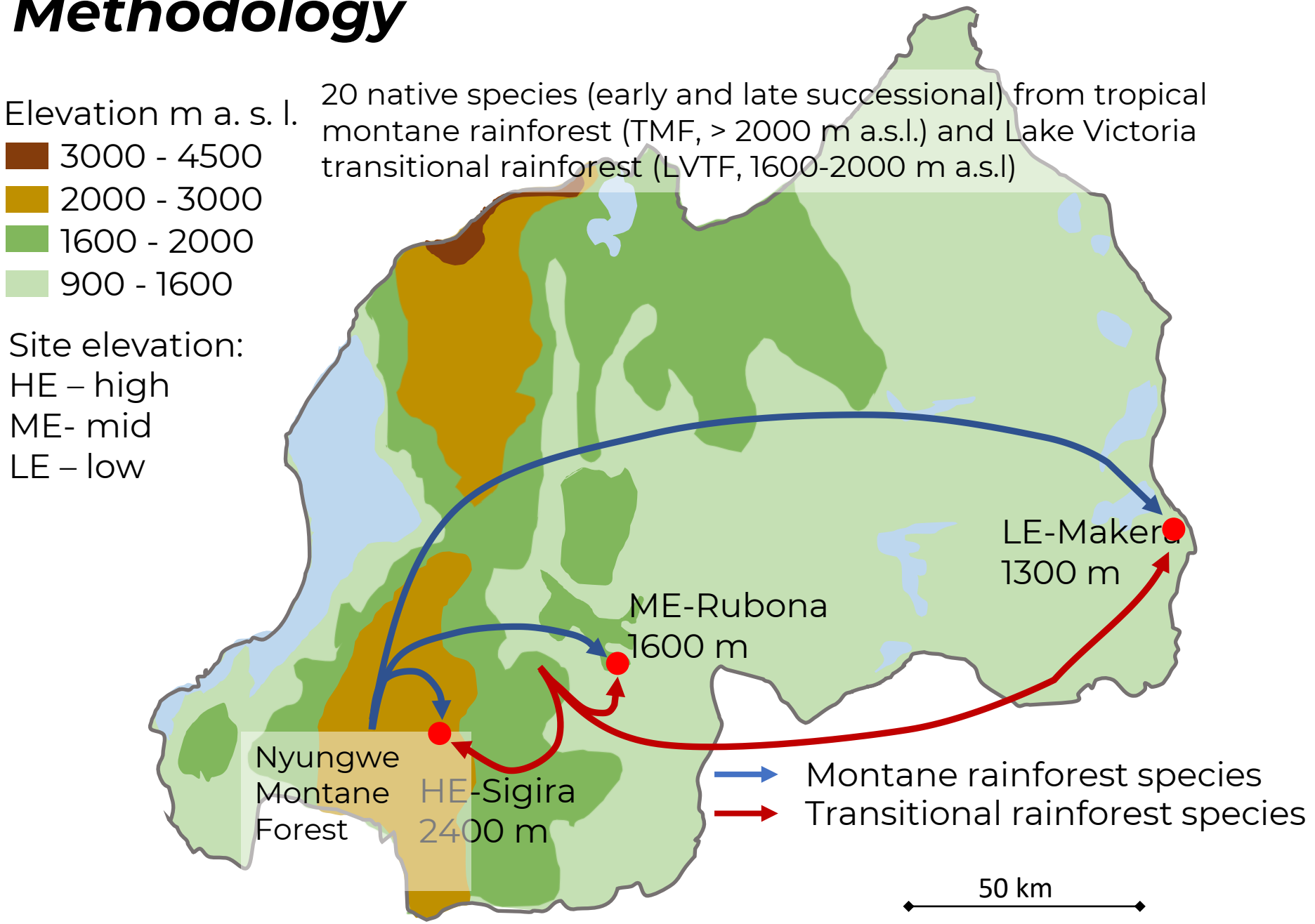
1. How do warming and water limitation influence A_n , stomatal conductance (g_s) and intrinsic water use efficiency (iWUE) native tree species

2. To what extent do climatic origin and successional strategy mediate these responses?

3. How do responses of photosynthesis to warming and water limitation compare with those of tree growth?

Methodology

20 native species (early and late successional) from tropical montane rainforest (TMF, > 2000 m a.s.l.) and Lake Victoria transitional rainforest (LVTF, 1600-2000 m a.s.l)



Tropical montane forest

Early succesional

- *Bridelia brideliifolia*
- *Harungana montana*
- *Macaranga kilimandscharica*
- *Maesa lanceolata*
- *Polyscias fulva*

Late successional

- *Afrocarpus falcatus*
- *Carapa grandiflora*
- *Faurea saligna*
- *Prunus africana*
- *Syzygium guineense*

Transitional forest

Early succesional

- *Bridelia micrantha*
- *Croton megalocarpus*
- *Dombeya torrida*
- *Harungana madagascariensis*
- *Markhamia lutea*
- *Albizia gummifera*

Late successional

- *Chrysophyllum gorungosanum*
- *Entandrophragma excelsum*
- *Ficus thonningii*
- *Newtonia buchananii*

Methodology

Mean daytime *T* difference is 6.9 °C
Annual precipitation difference is ~500 mm per elevation step
3 water x 2 nutrient levels = 6 treatment combinations

High Elevation - Sigira
2400 m. a. s. l.
17.1/23.1 °C, 2100 mm

Mid Elevation – Rubona
1600 m. a. s. l.
22.4/28.3 °C, 1600 mm

Low Elevation - Makera
1300 m. a. s. l.
24.0/31.3 °C, 1100 mm

Treatments:

	HW	MW	LW
LN	Control	Shelter -500 mm	Shelter -900 mm
HN	Fertilizer	Shelter -500 mm -& Fertil.	Shelter -900 mm -& Fertil.

Treatments:

	HW	MW	LW
LN	Irrigation +500 mm	Control	Shelter -400 mm
HN	Irrigation +500 mm & Fertil.	Fertilizer	Shelter -400 mm -& Fertil.

Treatments:

	HW	MW	LW
LN	Irrigation +900 mm	Irrigation +400 mm	Control
HN	Irrigation +900 mm & Fertil.	Irrigation +400 mm & Fertil.	Fertilizer

LN = low nutrient (control)
HN = high nutrient (fertilized)
LW = low water supply
MW = medium water supply
HW = high water supply

Methodology

- Gas exchange measurements were made during the dry season of 2022 at HE and LE sites

- Trees were sampled randomly from two treatments (HW and LW)

- Sample size= 2 treatments x 3 replicate plots x 20 species x 2 leaves= 240 leaves
- Instrument: Infrared Gas Analyzer (LICOR 6400)

Variables

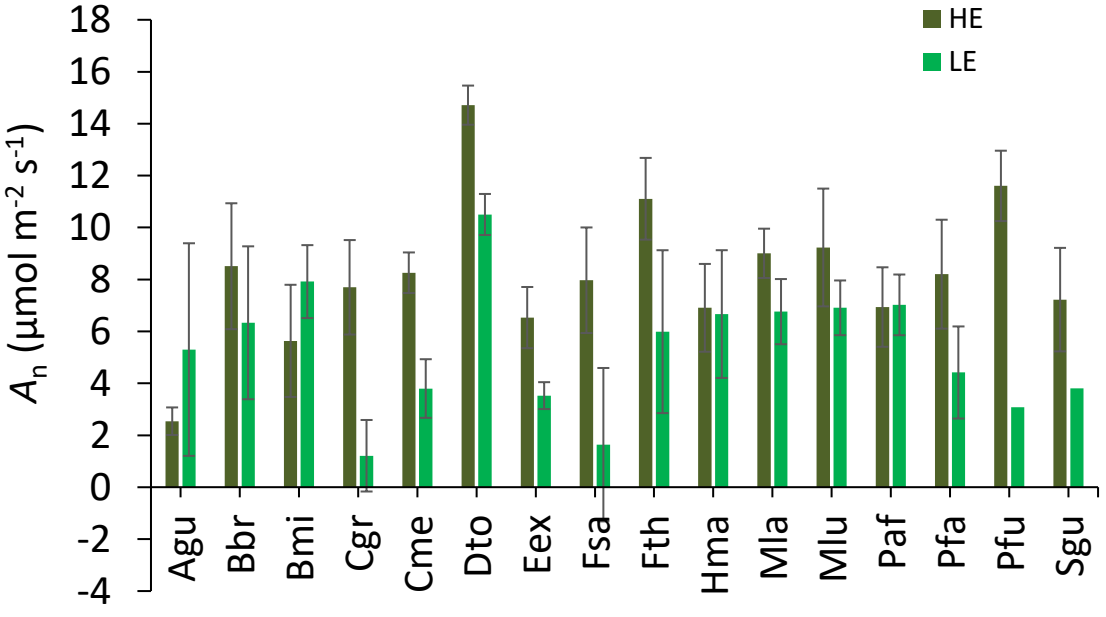
- A_n: net photosynthesis
- g_s: stomatal conductance
- iWUE: intrinsic water use efficiency

$$iWUE = {A_n}/{g_s}$$

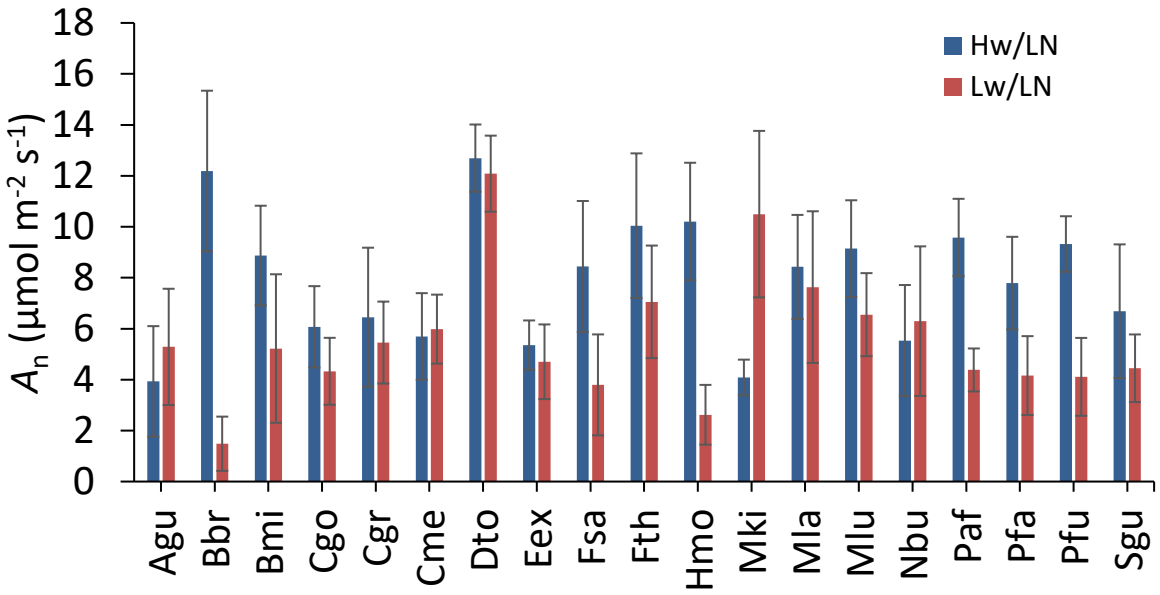
Results and Discussion

Q1. *Effect of warming and water limitation on A_n*

A_n significantly declined at LE compared to HE sites



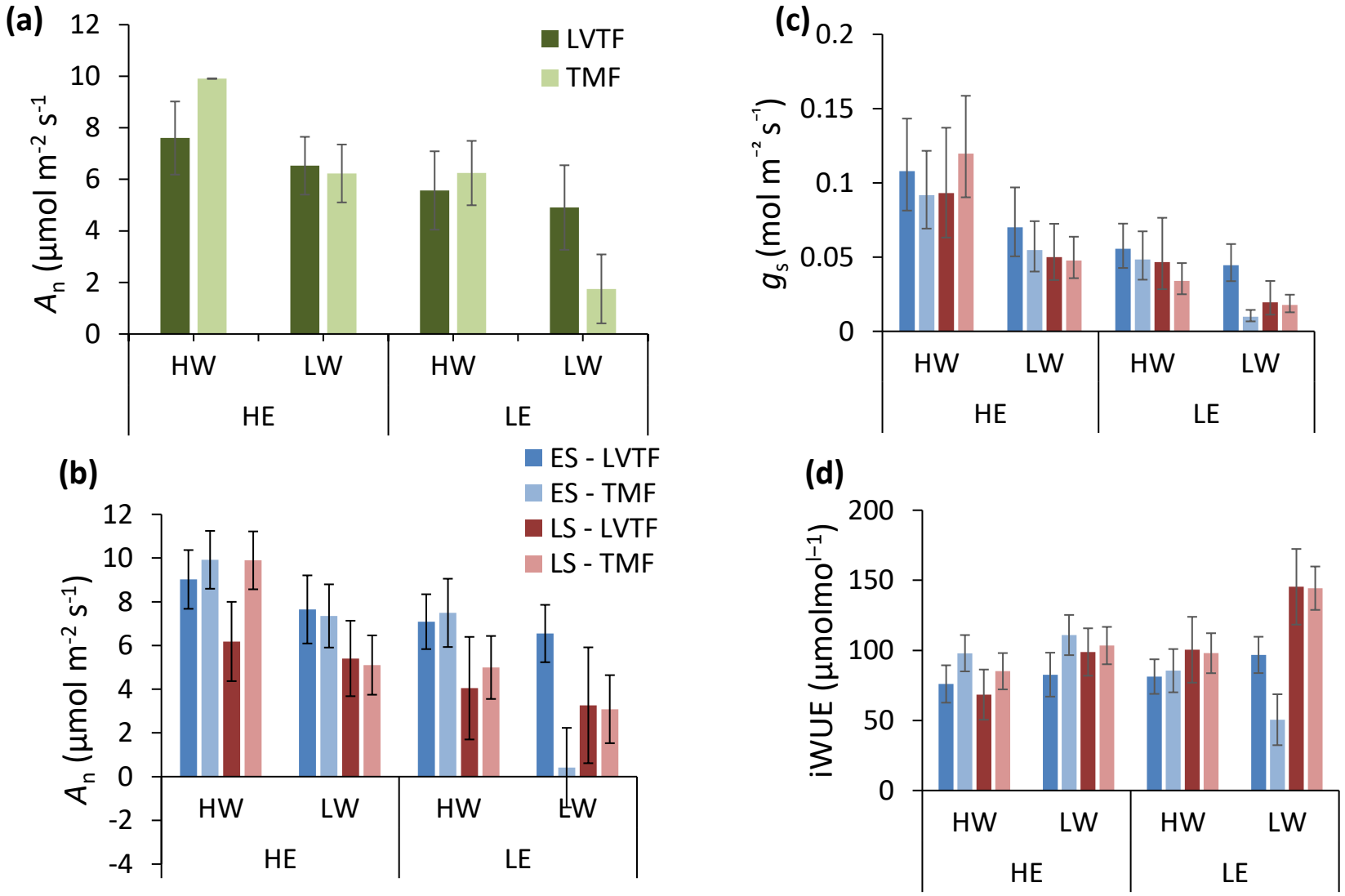
A_n low compared to high water availability



Results and Discussion

Q2. *Climatic origin and successional strategy mediate A_n responses*

- *Effects of water availability depended on species' climate of origin (p = 0.026)*
- *Effect of low water availability was strong at LE site*
- *Fast growing TMF species were highly affected by low water availability*



Results and Discussion

- The decline of A_n at LE site can be explained as a result of the reduction in the availability of CO_2 due to the decline in g_s.
- Temperature increase leaf stomata closes partially to reduce water loss.
- LVTF species shows greater physiological resistance to drought as they are more adapted to warmer and dryer conditions
- Fast-growing species invest more in rapid carbon gain than in drought tolerance mechanisms making them vulnerable under low soil water availability

Results and Discussion

Q3. *Responses of photosynthesis and tree growth response to warming*

- *There was a positive relationship warming-induced response of A_n and D_{base} under both water conditions (R^2 = 0.29 p = 0.016).*
- *The relative A_n declined with the increase in D_{base}*
- *Indicating negative effects of warming on species that attain larger size at HE site.*
- Temperature may be above the optimum for photosynthesis, leading to:
  - *Increased photorespiration*
  - *Reduced Rubisco efficiency*
  - *Reduced net carbon assimilation*

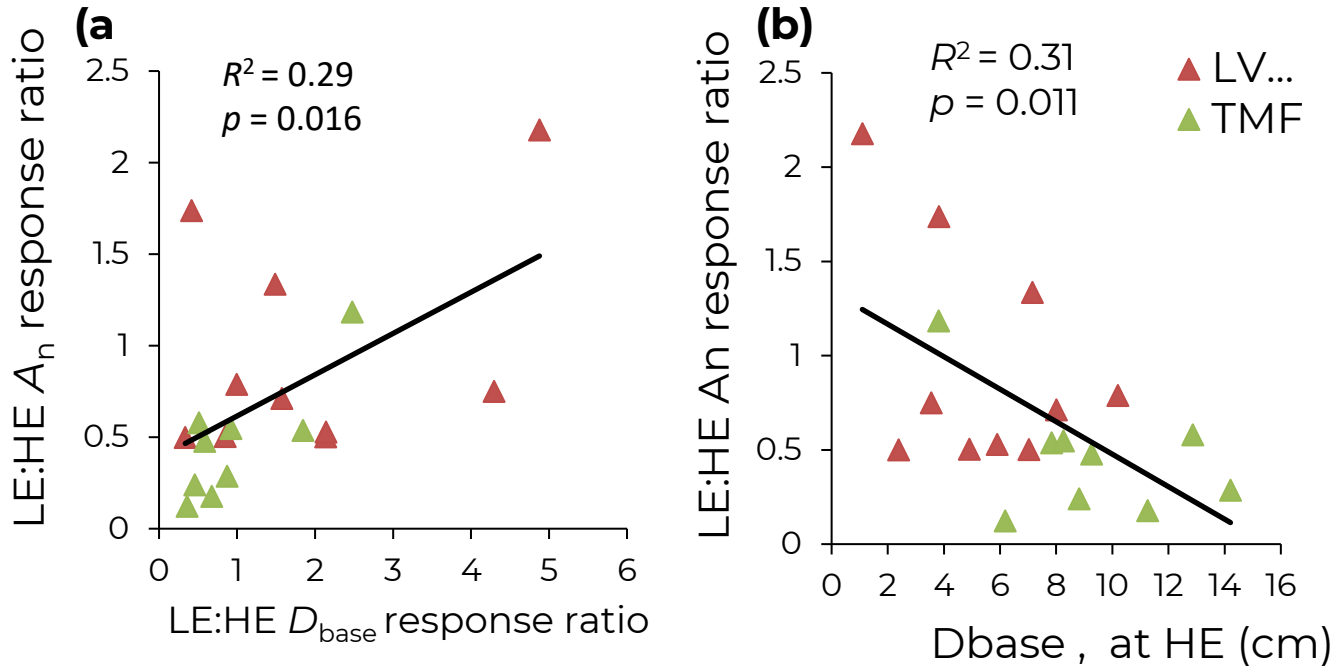


Figure: Relationships between (a) warming responses of net photosynthesis (A_n) and tree stem base diameter (D_{base}) and between (b) D_{base} at the high-elevation (HE) site and warming responses of A_n. Warming responses were defined as the ratio of A_n or D_{base} at low-elevation versus high-elevation sites (LE/HE)

Take home message

- Warming enhance the impacts of low water availability to A_n
- Both climatic origin and successional strategy mediate plant responses to water availability
- TMF species were particularly sensitive to water limitation, whereas LVTF species maintained more stable physiological performance
- Warming impacts is more pronounced in species that attain bigger size under their favorable conditions
- These findings suggest that future increases in drought frequency may disproportionately affect TMF species, potentially altering species composition, competitive interactions, and ecosystem carbon dynamics in tropical forests.

Recommendation: Tree plantation should consider climate of origin of species to better match right species to right place



Thank you!

D) NATURE-BASED SOLUTIONS & ECOSYSTEMS

Lepidoptera diversity within three remnant forests of Rwanda

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Introduction: from global Lepidoptera diversity to Rwanda

WORLDWIDE

~160,000

Lepidoptera is one of the major orders of insects, comprising butterflies and moths. Globally, insects are estimated to comprise about **5.5 million** species, of which roughly **one million** have been described

Stork, 2018 · Huis, 2019

AFRICA

>20,000

Lepidoptera species recorded. Butterflies account for about **a quarter of global Lepidoptera** diversity (**~18,000 species**); **moths make up the remaining three-quarters.**

Huis, 2019 · Espeland et al., 2018

RWANDA

Poorly known

Rwanda's Lepidoptera fauna remains **poorly documented**. Most surveys have focused on **protected areas**, with relatively few studies of remnant forests **in human-dominated landscapes.**

Nsengimana et al., 2025 · Uwizelimana et al., 2022, 2025

Why this group? **Sensitive indicators** of habitat condition · **Pollinators** by day and night · **Source of income** through butterfly farming

Dennis et al., 2006 · Akite et al., 2015 · Ghazanfar et al., 2016 · Macgregor et al., 2015 · Gordon & Ayiemba, 2003

Introduction: knowledge gap and objective

What remnant forests are

Residual patches of native vegetation in human-modified landscapes acting as refugia for flora and fauna.

Van Zandt et al., 2020 · Anand et al., 2010 · Horák et al., 2019

Under pressure in Rwanda

Outside protected areas and exposed to tree cutting, burning, land encroachment, and mining.

CoEB, 2024 · He et al., 2026 · Tekalign et al., 2018

The gap: little is known about the diversity and composition of butterflies and moths in remnant forests of densely populated tropical regions.

Objective: establish baseline data on Lepidoptera diversity in three geographically isolated remnant forests of Rwanda.

What we measured: species composition · richness per site · assemblage overlap · sampling completeness

Methodology: Study Area

Sampling was carried out in January 2026, at the start of the short dry season.

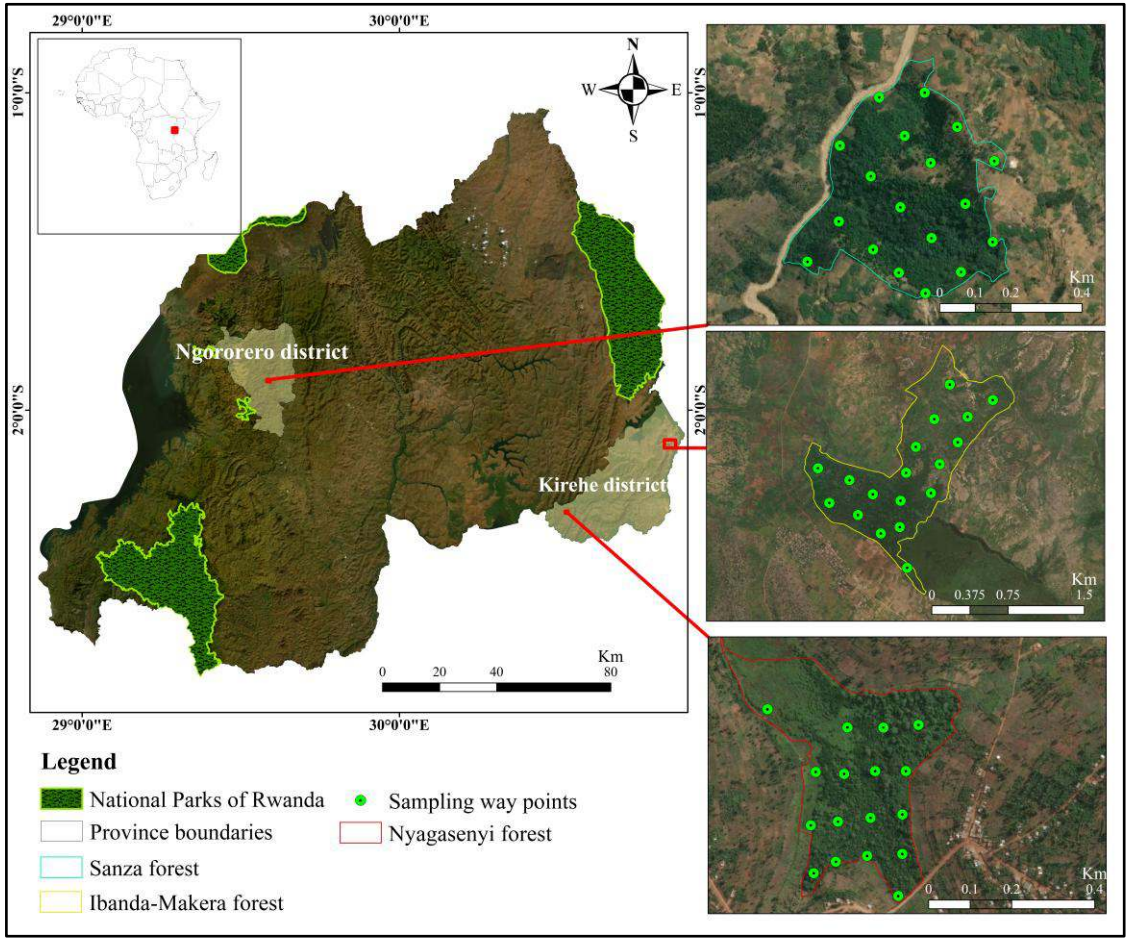


Figure 1. *The three remnant forest fragments and their sampling points.*

Sanza forest

Ngororero District, Western Province · 1.9084°S, 29.5898°E

20 ha · 1,600–1,950 m · 10–18 °C. Steep montane forest dominated by *Macaranga neomildbraediana*; two decades of mining disturbance.

Ibanda–Makera forest

Kirehe District, Eastern Province · 2.1086°S, 30.8544°E

169 ha · 1,300 m · 20–24 °C. Largest site; savanna woodland (Makera) with gallery forest (Ibanda) and papyrus swamp.

Nyagasenyi forest

Kirehe District, Eastern Province · 2.3242°S, 30.5264°E

18.6 ha · 1,329 m · 20–24 °C. Smallest site; lowland forest with *Syzygium cordatum* and rare indigenous flora.

Manishimwe et al. (2022); World Bank (2021).

Methodology: Sampling design and data collection

Field sampling

Hand net along **transects sampling** within 5 m , 09:00–15:00 ·
fruit-baited traps hung ≥1 m for 24 h · opportunistic records where transects were inaccessible.

Identification

Martins (2016); Sáfián et al. (2015); African Butterfly Database; Goff (2019) · GBIF taxonomic backbone.

Effort and mapping

Sampling in **January 2026**. **Five consecutive** days per forest · **GPS waypoint** for during sampling· maps produced in QGIS v3.44.7.

Statistical analysis

R / RStudio · vegan for rarefaction and extrapolation · ggplot2 for plots · VennDiagram for species overlap.





Setting a fruit-baited trap at the field

Vouchers deposited in the Rwanda National Zoological Collection · RNZC-INS-04746–04795

Results: Key findings

1,502
Individuals recorded

157
Species total

122
Butterfly species

35
Moth species

5
Butterfly families

6
Moth families

Family composition

Butterflies: Nymphalidae 50 · Hesperiidae 23 · Pieridae 23 · Lycaenidae 20 · Papilionidae 6

Moths: Erebidae 14 · Crambidae 8 · Geometridae 5 · Noctuidae 5 · Uraniidae 2 · Depressariidae 1

Eight butterfly species and one moth species (*Zebronia phenice*) were recorded in all three forests; the remaining 148 species occurred in only one or two fragments.

Results: Representative Lepidoptera recorded



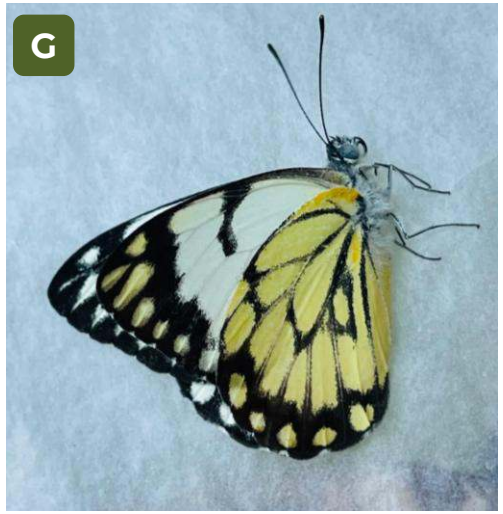














A. *Charaxes tridates* ***B.*** *Pseudacraea eurytus* ***C.*** *Charaxes numenes* ***D.*** *Neptis* serena

E. *Phalanta phalantha* ***F.*** *Salamis parhassus* ***G.*** *Belenois creona* ***H.*** *Micronia aculeata*

Representative Lepidoptera recorded across the three forest fragments. Photographs: C. Sibomana

Results: Spieces richness

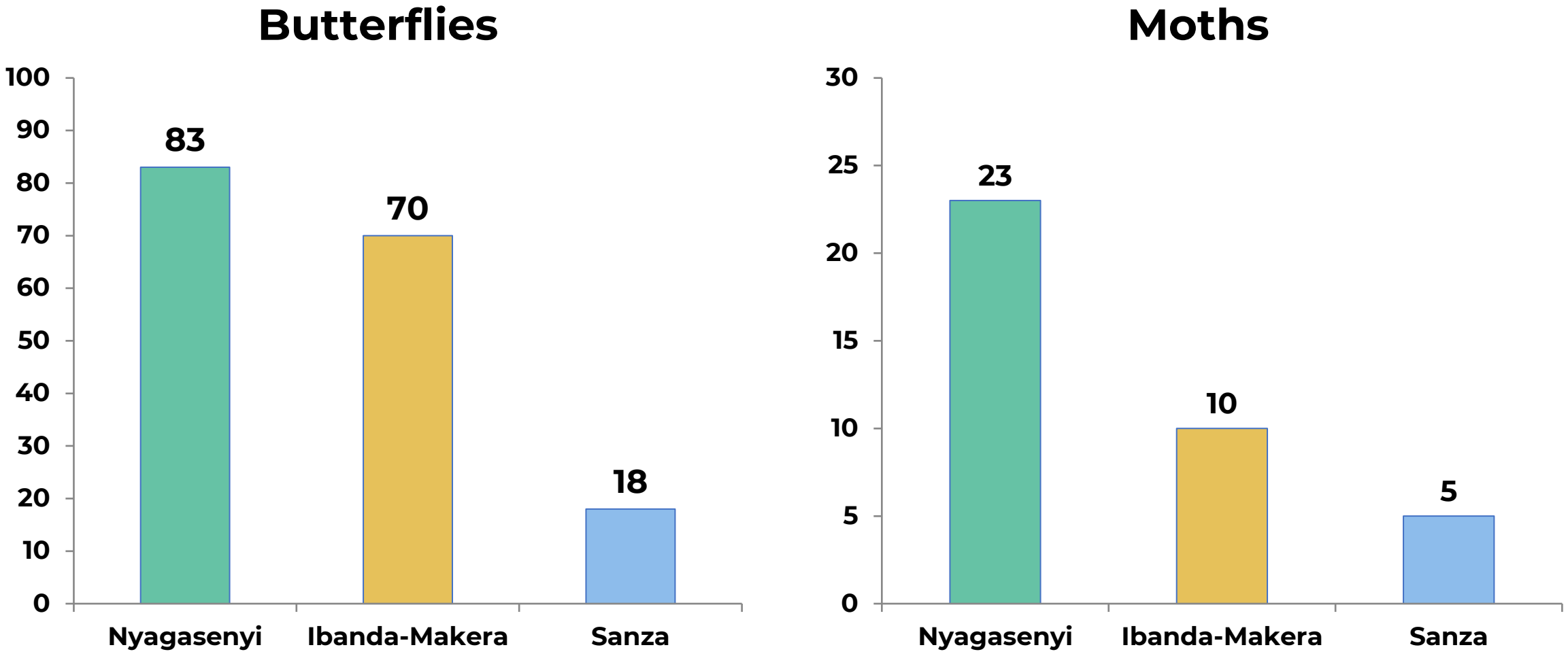


Figure 2. *Butterfly and moth species richness recorded across study sites.*

Results: Species overlap across study sites

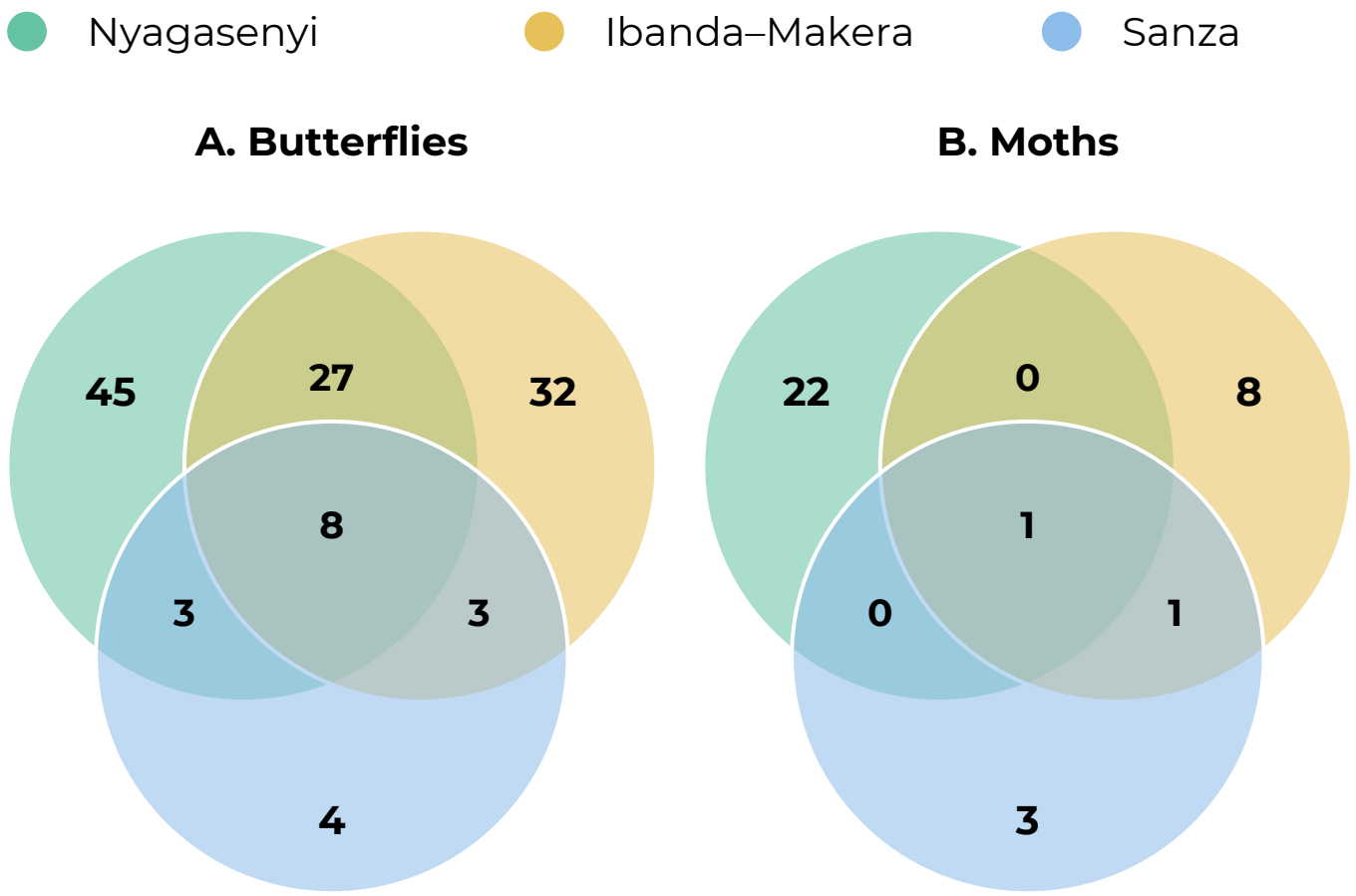


Figure 3. *Overlap of butterfly (A) and moth (B) species assemblages across sites*

Table 1. Common species recorded across sites

Family	Species
Hesperiidae	*Eretis lugens*
Nymphalidae	*Bicyclus vulgaris*
Nymphalidae	*Junonia terea*
Pieridae	*Catopsilia florella*
Pieridae	*Eronia leda*
Pieridae	*Eurema brigitta*
Pieridae	*Eurema desjardinsii*
Pieridae	*Eurema hapale*
Crambidae	*Zebronia phenice (moth)*

Results: Sampling completeness

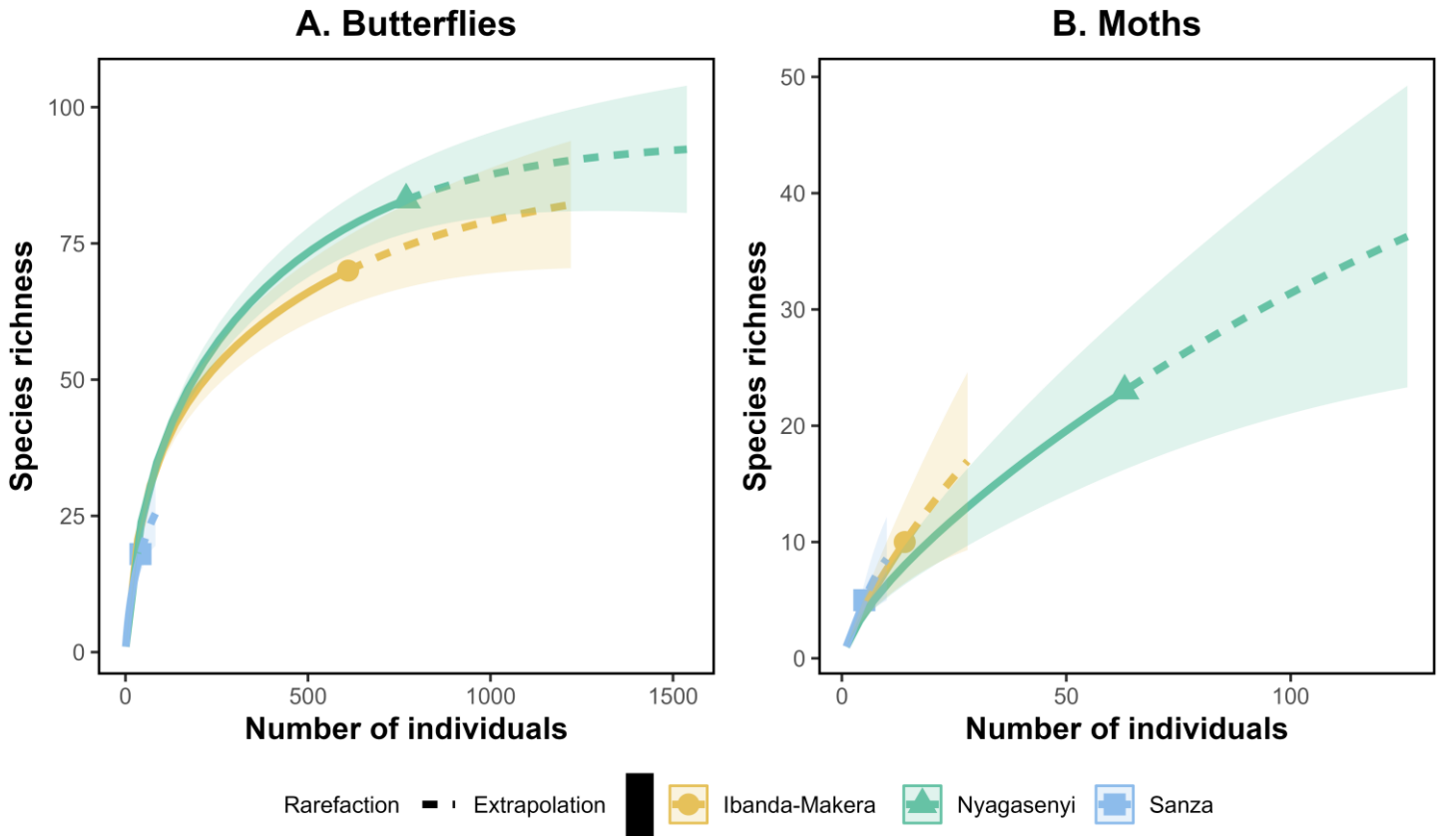


Figure 4. *Sample-size-based rarefaction and extrapolation of species richness for butterflies (A) and moths (B).*

Reading the curves

No asymptote reached

Curves did not level off at any fragment.

Extrapolation exceeds observation

Projected richness sits above recorded richness.

Moths least complete

Moth curves stay steep, with wide confidence intervals.

Sanza has fewest individuals

Both Sanza curves rest on the smallest sample.

Discussion: what the findings mean

1

Nymphalidae and Crambidae dominance matches the regional pattern

The same family **dominates butterfly assemblages** in other Rwandan forests and elsewhere in East Africa

Uwizelimana et al., 2022, 2025 · Nsengimana et al., 2026 · Rija, 2022

2

The few shared species are edge-tolerant generalists

Almost all were taken at **forest edges**. *Eurema* spp. and *Catopsilia florella* range from lowland savanna to montane zones; *Zebronia phenice* belongs to Crambidae, widely distributed in the Afrotropics.

Dongmo et al., 2025 · Taylor et al., 2012 · Schmitt et al., 2021 · Poltavsky et al., 2018

3

Sanza's low richness fits a long disturbance legacy

Montane setting plus more than two decades of **post-mining regeneration**; disturbed tropical forests can stay species-poor beyond thirty years. Sanza was low in both abundance and richness.

Whitworth et al., 2016 · Mihindukulasooriya et al., 2014

4

Method, not absence, best explains the short moth list

Hand nets and fruit-baited traps favour butterflies; **light trapping** is the most effective method for nocturnal moths, and detection also varies with altitude, season and weather.

Jonason et al., 2014 · Axmacher & Fiedler, 2008 · Neff et al., 2025

5

Two species extend the documented Ibanda–Makera butterfly community

Euxanthe crossleyi and *Axiocerses tjoane* were not in the earlier survey.

Uwizelimana et al., 2025

Conservation implications

Threats: tree cutting · burning · land encroachment · mining (Sanza)

1

Protect the network, not one site

Each fragment contributes species the others lack, so several remnant forests must be kept.

2

Use Lepidoptera to monitor

A sensitive, cheaply sampled group can flag habitat degradation early.

3

Build on this baseline

Vouchers at RNZC (**INS-04746–04795)** anchor every future comparison.

Key point: 148 of the 157 species occurred in only one or two forests — regional diversity depends on conserving the fragments together.

Conclusions and take-home messages

Take-home: three small remnant forests hold 157 Lepidoptera species with little overlap, conserving the network, not one forest, maintains regional diversity.

157

Lepidoptera species documented across the three remnant forests:**122 butterflies and 35 moths,** providing a baseline for future monitoring

9

Species shared by all three forests. The remaining 148 occurred in only one or two sites, demonstrating the complementary value of each fragment.

At sites

Sampling effort for recorded richness was still needed; therefore, it remains incomplete, **particularly for moths** sampled without light traps.

Recommendations

1. Add light trapping for moths sampling
2. Repeat surveys across seasons
3. Link species to other variables such as temperature and seasonality
4. Extend the survey to further remnant fragments
5. Embed monitoring in management planning

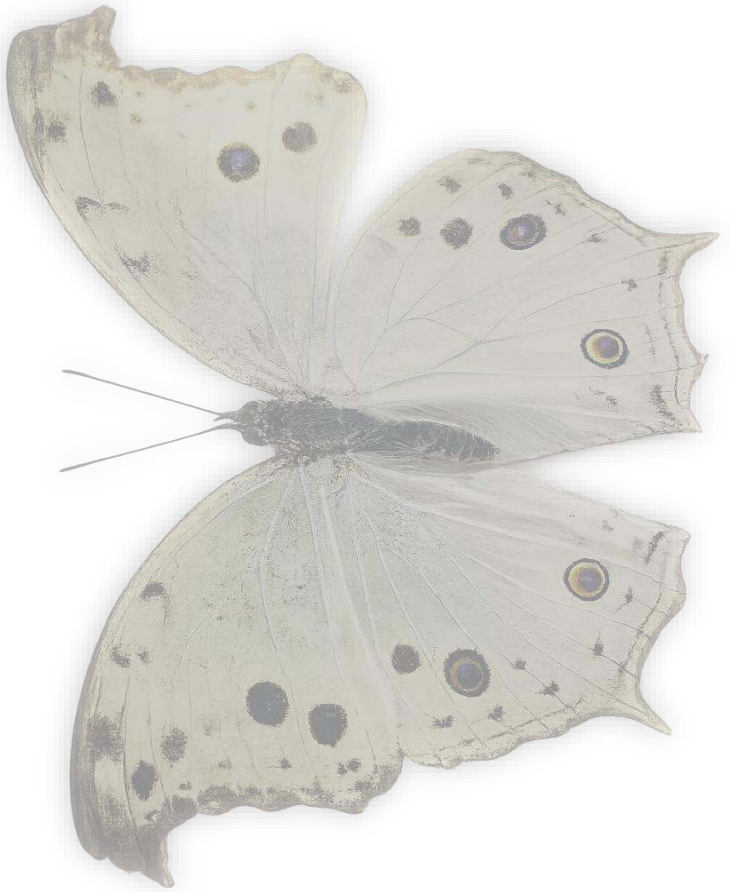
Thank you

Questions & discussion

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Full reference list in the manuscript.

D) NATURE-BASED SOLUTIONS & ECOSYSTEMS

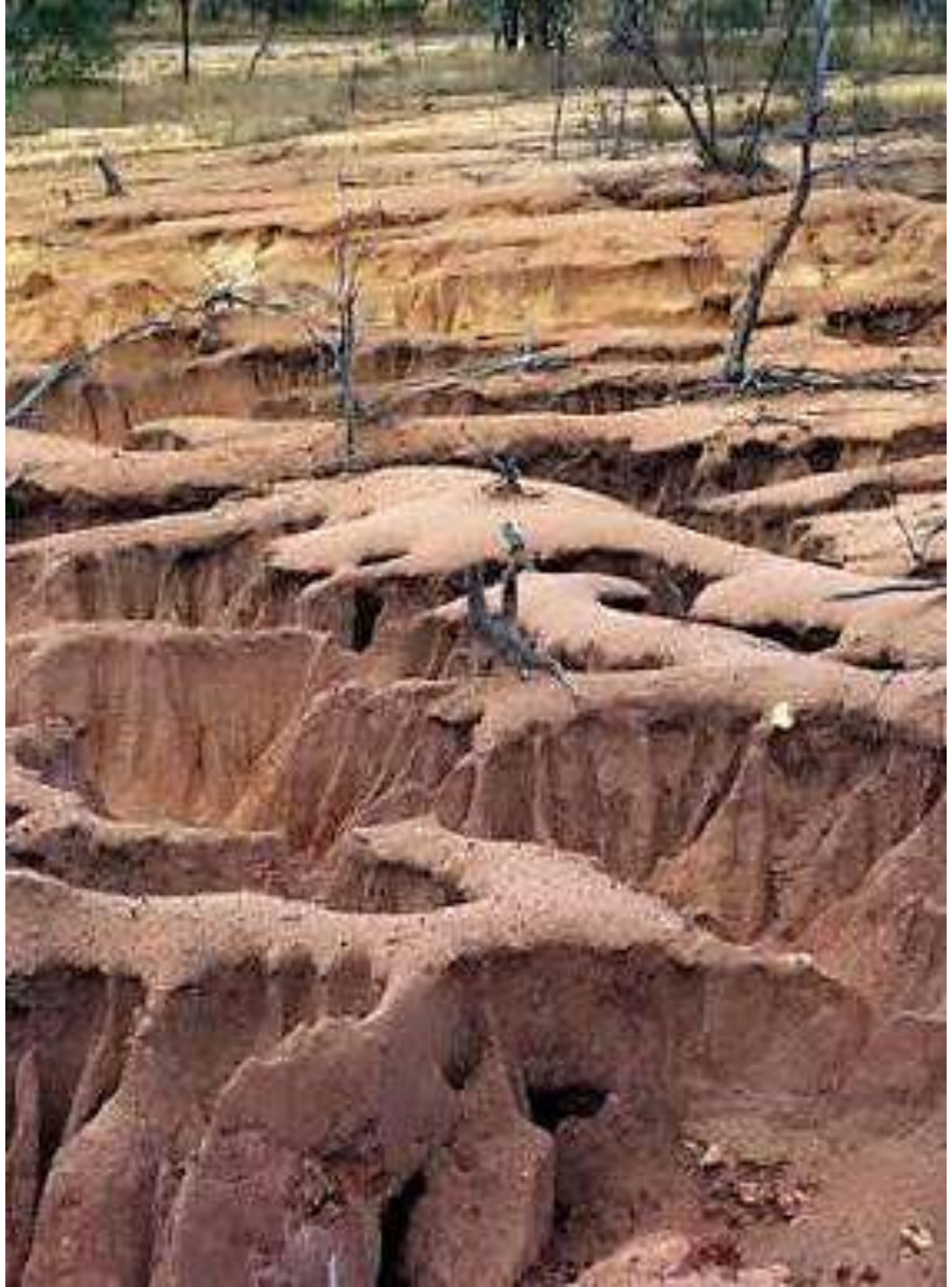
Can Africa's Bioeconomy Remain Sustainable Under Climate Change? Evidence from Emerging Bioeconomy Initiatives in East Africa

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What is the bioeconomy?

- The bioeconomy uses renewable biological resources, to produce food, materials, energy and services.
- **Its promise:** Transform biological resources through science and innovation to create economic value, jobs and sustainable development.
- **But renewable does not automatically mean sustainable.**
- The bioeconomy depends on healthy ecosystems, and climate change is altering their productivity, availability and resilience.



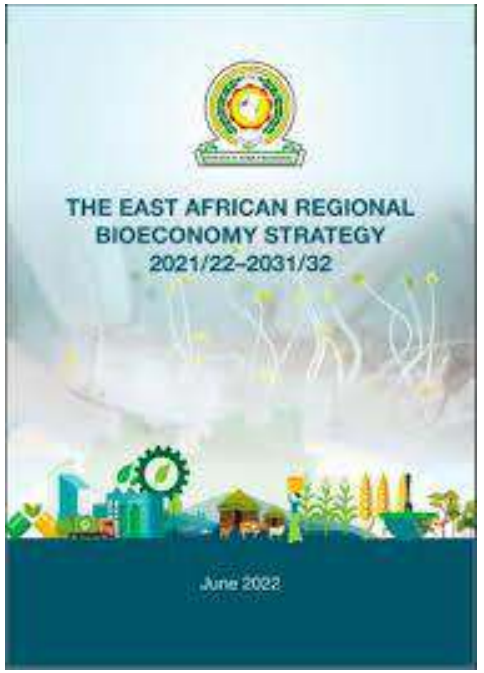


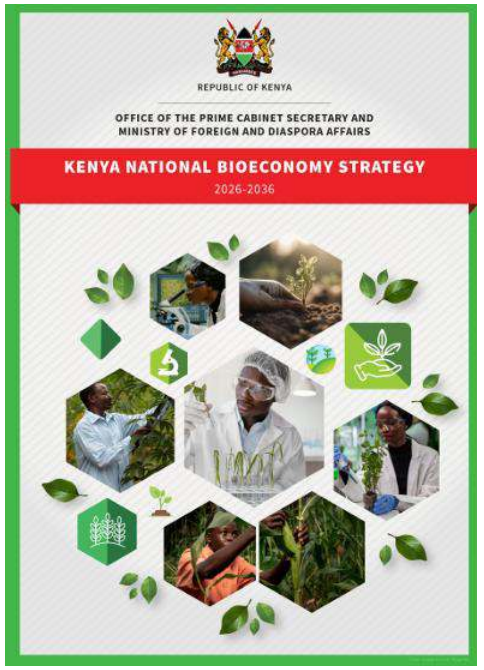
Why climate change matters for the bioeconomy

- Climate change directly affects the biological resources on which the bioeconomy depends:
  - ✓ Altered rainfall and drought reduce biomass productivity.
  - ✓ Floods disrupt production systems, infrastructure and markets.
  - ✓ Rising temperatures increase pressure from pests and diseases.
  - ✓ Biodiversity and ecosystem loss weaken nature's ability to regenerate.
  - ✓ Uncertain resource supplies destabilize bio-based value chains.
- **A bioeconomy cannot remain sustainable if its biological foundations are not climate-resilient.**

The central question

- East African countries (Kenya, Uganda and Rwanda) are increasingly investing in bioeconomy strategies, innovation and bio-based value chains.
- But are these initiatives adequately prepared for a changing climate?
- This study asks:
  - ✓ How could climate change affect emerging bioeconomy pathways?
  - ✓ How well is climate risk integrated into current planning?
  - ✓ What must change to build climate-resilient bioeconomies?
- **Sustainability is not automatic; it must be intentionally designed.**

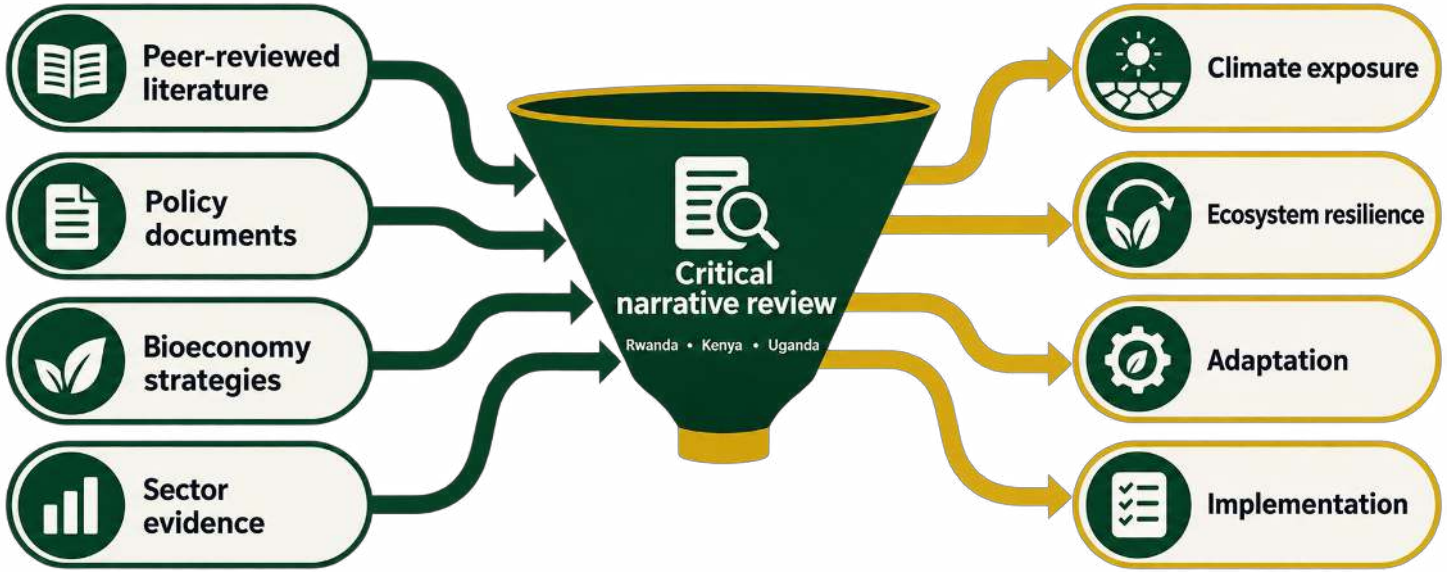




Critical Narrative Review and Policy Analysis

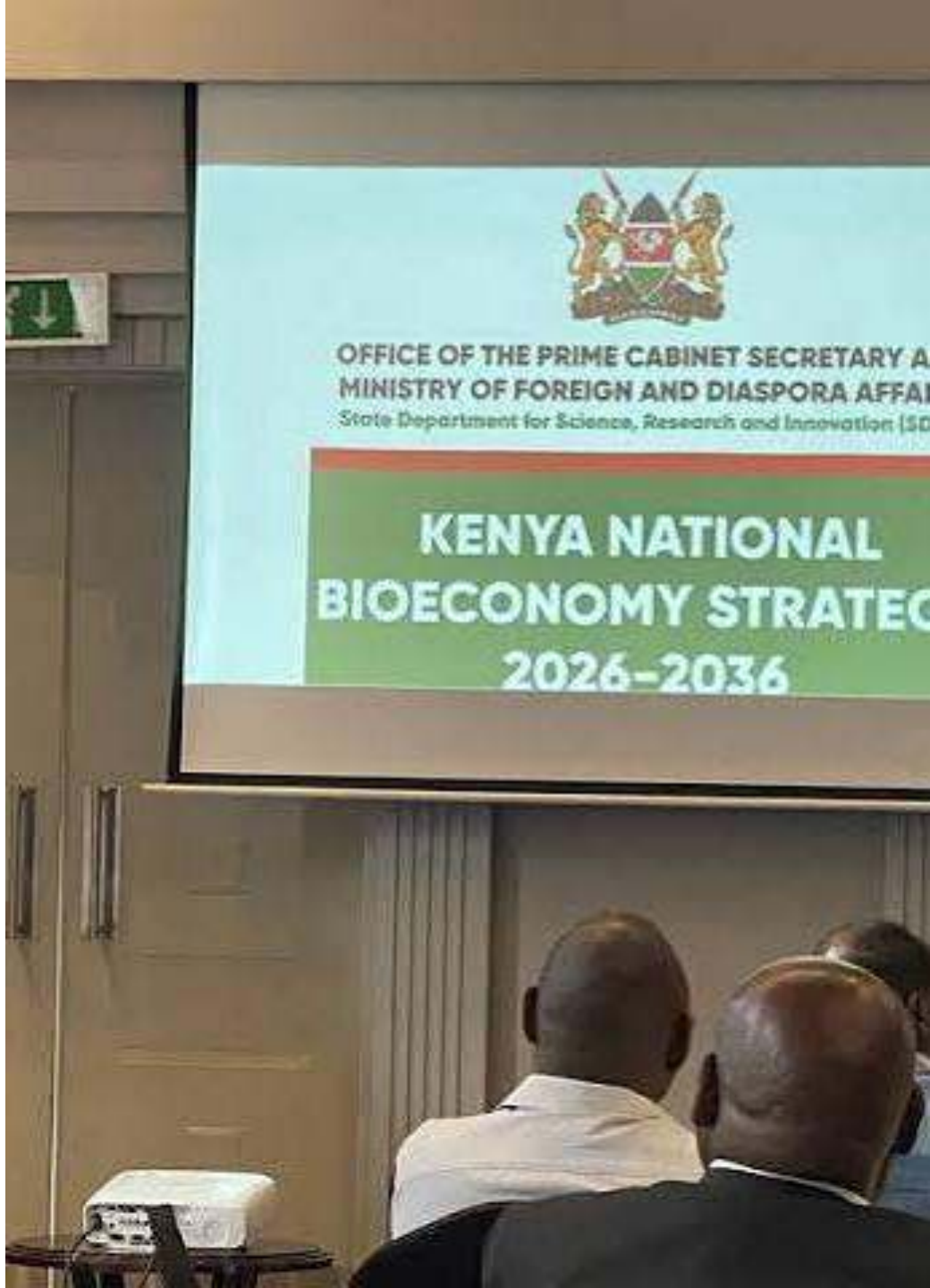
- The review synthesized scientific and policy evidence from **Rwanda, Kenya and Uganda**, focusing on four bioeconomy sectors: **Agriculture, Forestry, Fisheries, Biodiversity**

- Evidence was assessed through four dimensions: **Climate exposure, Ecosystem resilience, Adaptation, Implementation**



East Africa's bioeconomy policy landscape

- East Africa has moved from isolated bio-based initiatives towards strategic bioeconomy planning.
- Regional: The EAC Regional Bioeconomy Strategy provides a shared framework for innovation; sustainable bioresource use and inclusive growth.
- **Rwanda**: Climate resilience and green growth provide the main policy entry point.
- **Kenya**: The National Bioeconomy Strategy links biological resources, research and innovation to economic transformation.
- **Uganda**: Bioeconomy development is advancing through agriculture, biotechnology, industrialisation and STI policies.
- **The policy momentum is clear, but integration of climate risk remains uneven.**



Climate risk is already affecting East Africa's biological resources

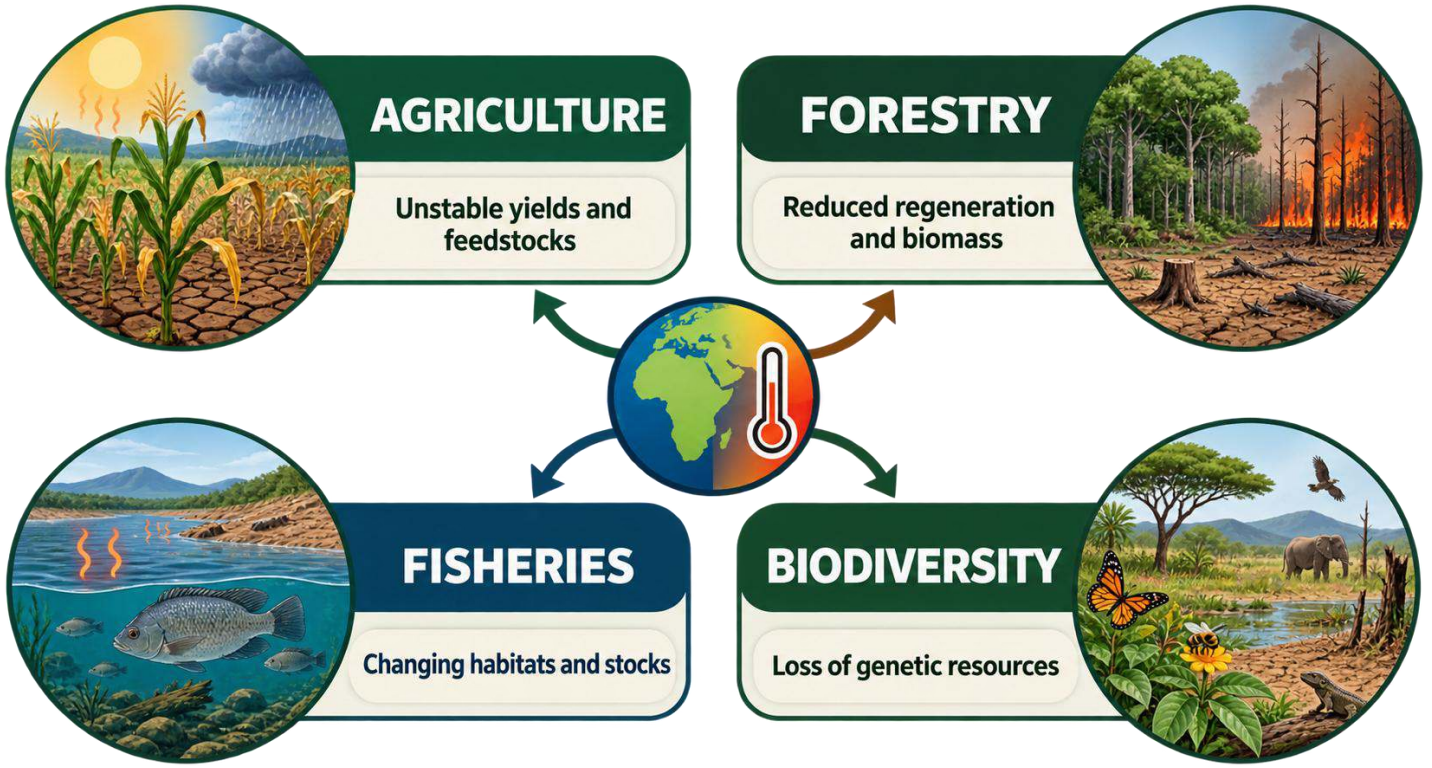
- More than **8.5 million people** in East Africa were affected by drought in 2025.
- Across the region:
  - Drought and rainfall variability are destabilizing biological production.
  - Floods are damaging ecosystems, farms, infrastructure and markets.
  - Rising temperatures are increasing water, pest and disease pressures.
  - Repeated shocks are reducing the recovery time available to producers and ecosystems.

- **Climate change is already affecting the resource base on which future bioeconomy growth depends.**



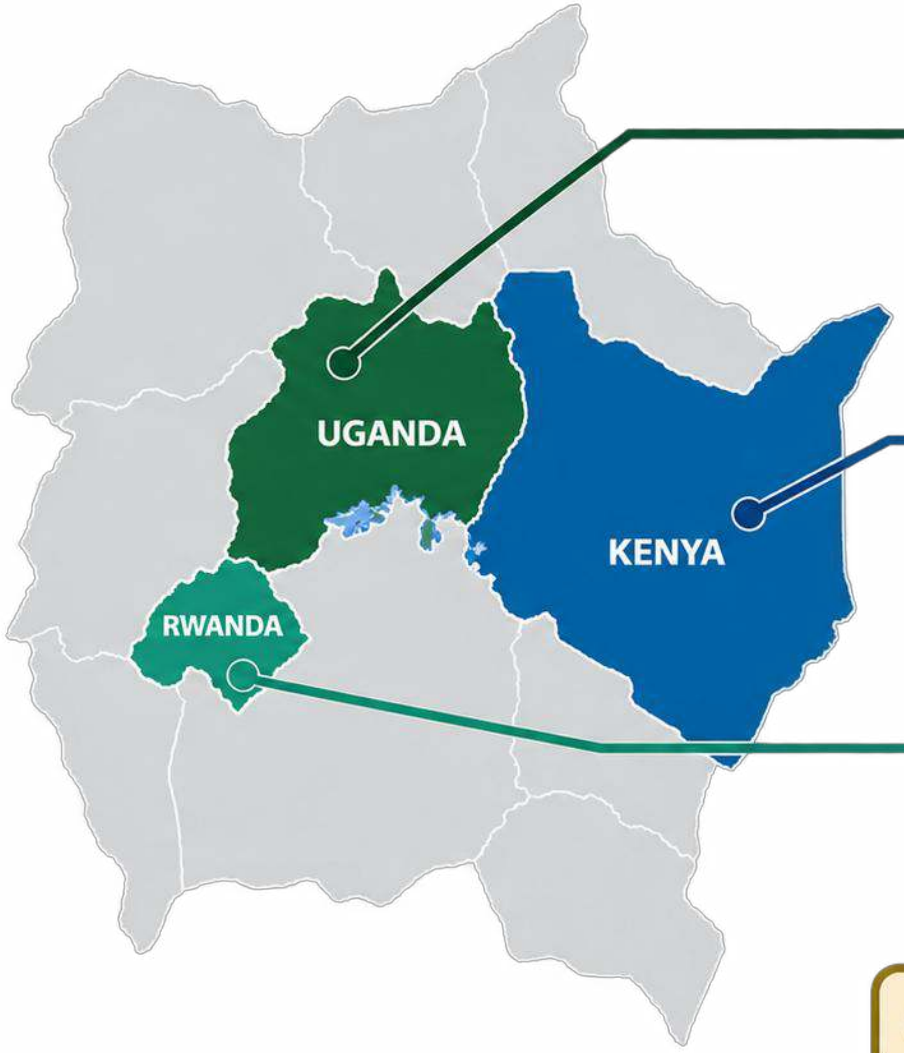
Source: WMO, State of the Climate in Africa 2025.

Climate risks extend across major bioeconomy sectors



- **Renewable does not automatically mean resilient: Biological resources must remain capable of regenerating under future climate conditions**.

Climate integration remains uneven across countries



UGANDA
Sector-led approach
Coordinate climate, STI, agriculture and industry policy

KENYA
Bioeconomy-first approach
Apply climate-risk screening and resilience indicators

RWANDA
Climate-first approach
Link resilience policy to bioeconomy value chains

SHARED GAP: Turning climate recognition into implementation



Key finding: climate change is recognised, but not yet operationalized…

- Across the three countries, policy frameworks generally acknowledge climate change as a cross-cutting challenge. However, four recurring gaps remain:

  - ✓ Risk-assessment gap: Climate exposure and sensitivity are rarely assessed before selecting or investing in bioeconomy value chains.
  - ✓ Ecosystem gap: Growth ambitions are not consistently linked to ecological limits and regeneration rates.
  - ✓ Adaptation gap: Bioeconomy implementation and climate-adaptation planning often operate separately.
  - ✓ Monitoring gap: Few indicators track climate resilience across biological resources, livelihoods and value chains.

- **Recognizing climate change is not the same as governing climate risk.**

What would make bioeconomy development climate-resilient?

1. **Climate-informed resource selection**: Select biological resources using future, not only historical or climate conditions.
2. **Protection of ecosystem resilience**: Keep production and extraction within ecological and regeneration limits.
3. **Diversified production and value chains**: Reduce dependence on a single crop, species, location or production system.
4. **Inclusive adaptation capacity**: Enable producers and communities to anticipate, absorb and respond to climate shocks.
5. **Adaptive policy and investment**: Integrate climate information, resilience financing, monitoring and learning into implementation.



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D) NATURE-BASED SOLUTIONS & ECOSYSTEMS

23 September 2025, 14:15 – 15:30 PM, Plenary

Assessing the Role of Agroforestry in Landscape Restoration for Building Climate-Resilient Livelihoods in Rwanda: Case Study of Rutsiro District, Western Province.

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Outline

- Background Information
- Problem Statement
- Objectives
- Methodology
  - Study Area Description
  - Data Collection Methods
  - Data Analysis
- Results and Discussion
- Conclusion and Recommendations



Background Information

- Climate change is among the most pressing challenges of the twenty-first century, threatening ecosystems, food security, and the livelihoods of millions of people worldwide (Ahmed & Augustine, 2018).

- Heavy reliance on natural resources and rain-fed agriculture makes Africa highly exposed to deforestation, soil erosion, drought, and desertification, with severe socio-economic impacts (Tofu & Wolka, 2023).

- Rwanda aligns with global frameworks (SDGs, Bonn Challenge, AFR100) and implements national strategies and projects (Green Gicumbi, A4L, Green-Amayaga, MuLaKiLa, TREPA, Combio and CND) (Tuyizere et al., 2025).

- Integrating trees into farming systems enhances soil fertility, reduces erosion, conserves biodiversity, and strengthens livelihoods. Evidence gaps remain in Mushubati and Mukura sectors, requiring GIS and household-level assessments.

Problem Statement

- Rwanda faces acute soil erosion, declining fertility, and reduced productivity due to high population density, intensive land use, and climate variability (Hossain et al., 2020).
- Despite strong national strategies and global commitments, restoration outcomes remain uneven, revealing gaps between policy intentions and actual results (World Bank, 2018).
- Limited technical knowledge, poor follow-up, restricted access to quality seedlings, and competing land-use priorities hinder widespread adoption (Tofu & Wolka, 2023).
- Steep slopes, high rainfall, and erosion make Rutsiro highly vulnerable. Restoration efforts show promise but lack localized research on sustainability and livelihood resilience (Tuyizere et al., 2025)
- This study therefore assessed the role of agroforestry in restoring landscapes and enhancing climate-resilient livelihoods to inform sustainable land management strategies in Rutsiro District

Objectives

General Objective

- The primary objective of this study is to assess the role of agroforestry in landscape restoration towards climate-resilient livelihoods in Rutsiro District of the Western Province of Rwanda.

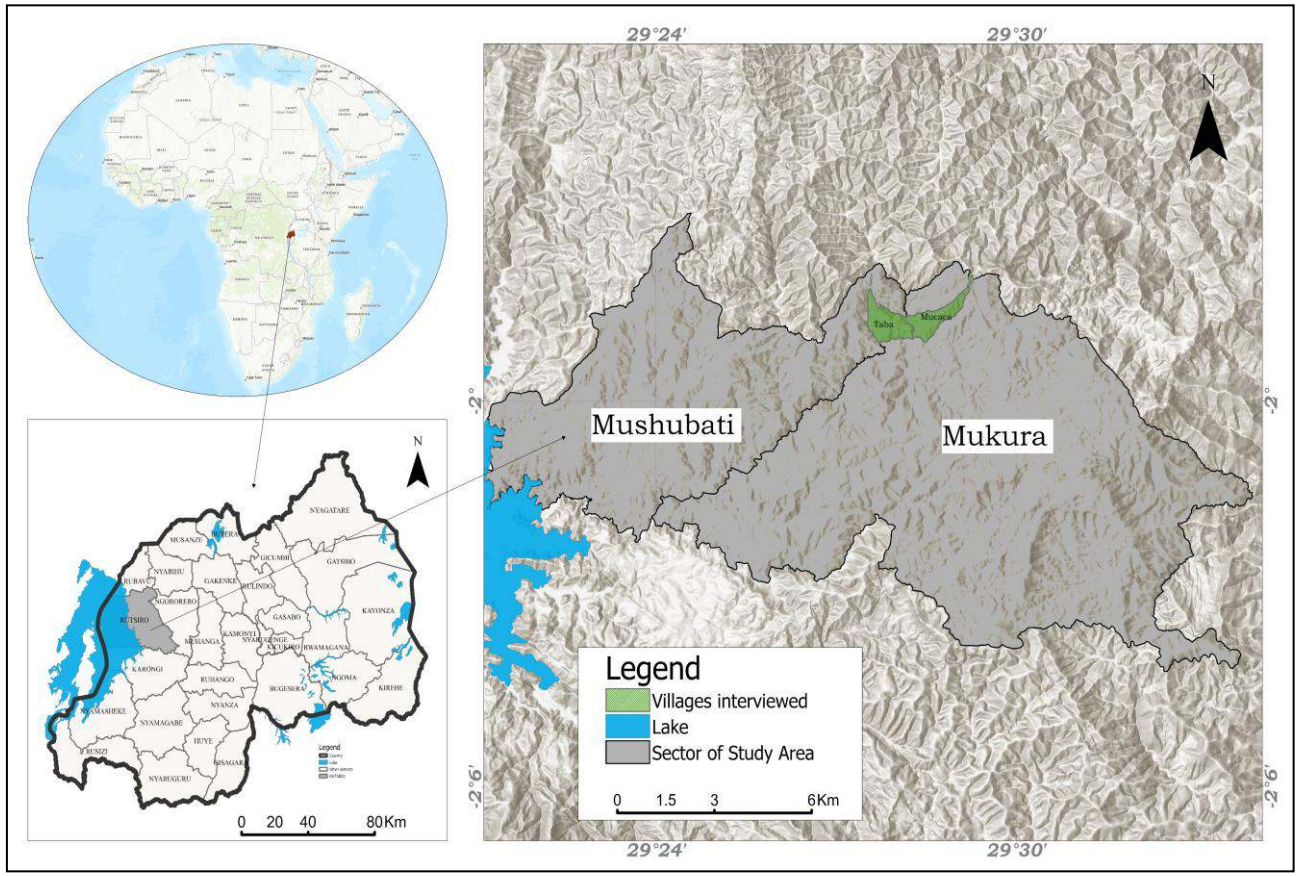
Specific Objectives

- To describe the extent of land degradation and the vulnerability of local communities in Mushubati and Mukura sectors prior to agroforestry interventions.
- To assess the contribution of agroforestry practices to landscape restoration and identify associated environmental and socio-economic benefits.
- To analyze the challenges faced by local communities in adopting agroforestry and achieving improved livelihood options.
- To propose sustainable solutions that strengthen agroforestry adoption, enhance climate resilience, and improve household livelihoods in the study area.

Methodology

❖ Study Area Description

- This study was conducted in Mukura and Mushubati sectors of Rutsiro district, both are highlands with Mushubati sector extending into some lowland areas around Lake Kivu.



Map of the Study Area

Methodology (cont.)

- **Secondary Data Collection**
  - Secondary data were collected from reliable national and international sources.
  - Demographic and socioeconomic information was mainly obtained from the 2022 Rwanda Population and Housing Census.
  - Geospatial datasets, including satellite images, elevation, CROM database, and administrative boundaries, were obtained from Esri and NLA.

- **Primary Data Collection**
  - **Field Observation**
    - ✓ Ground-truth assessment of existing land degradation, SALM practices and restoration impacts.
  - **Household Survey**
    - ✓ **Target Population**: **302 households** in Mucaca and Taba villages.
    - ✓ **Sample Size**: **172 households** determined using Yamane (1967) formula.
  - **Interviews:**
    - ✓ A total of 12 key informants were interviewed
- **Data Analysis**
  - Demographic and socioeconomic data were analyzed using R and Excel.
  - Geospatial technology (ArcGIS, Google Earth Engine) was used to produce land use map, erosion map and Crom recommendations.

Results and Discussion

- **Demographic and Socioeconomic of Respondents**
  - 91.9% of respondents were between 18-45years, indicating an economically active population.
  - Gender participation was well balanced (52.9% male; 47.1% female).
  - 51.2% of respondents were married, providing family labour for agricultural activities.
  - 89.0% of households had 1-5 family members.
  - 57.0% had completed primary education, while 15.7% had no formal education.





Key Findings on Objective No. 1: *Extent of Vulnerability & Degradation*

- Rutsiro District is highly vulnerable to land degradation.
- 41.9% households reported reduced fertility, soil color change, and crop yield loss.
- 55.2% observed erosion and organic matter depletion, weakening productivity.
- 54.1% noted wetlands, riverbanks, and forest exploitation.
- Droughts led to poor or dried seedlings and erratic rainfall affected 55.2% households, raising stress.
- 66.3% cited low education, poor disaster information, weak engagement.



Deepened Gully in Mukura Sector

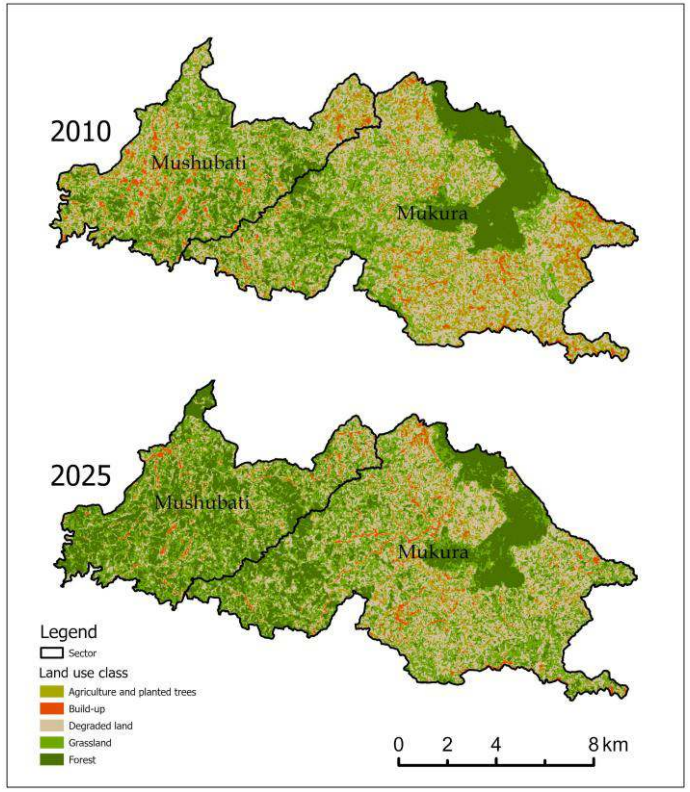


Dried Seedling (low Survival Rate) in Mushubati Sector.

Key Findings on Objective No. 1: *Extent of Vulnerability & Degradation (cont.)*

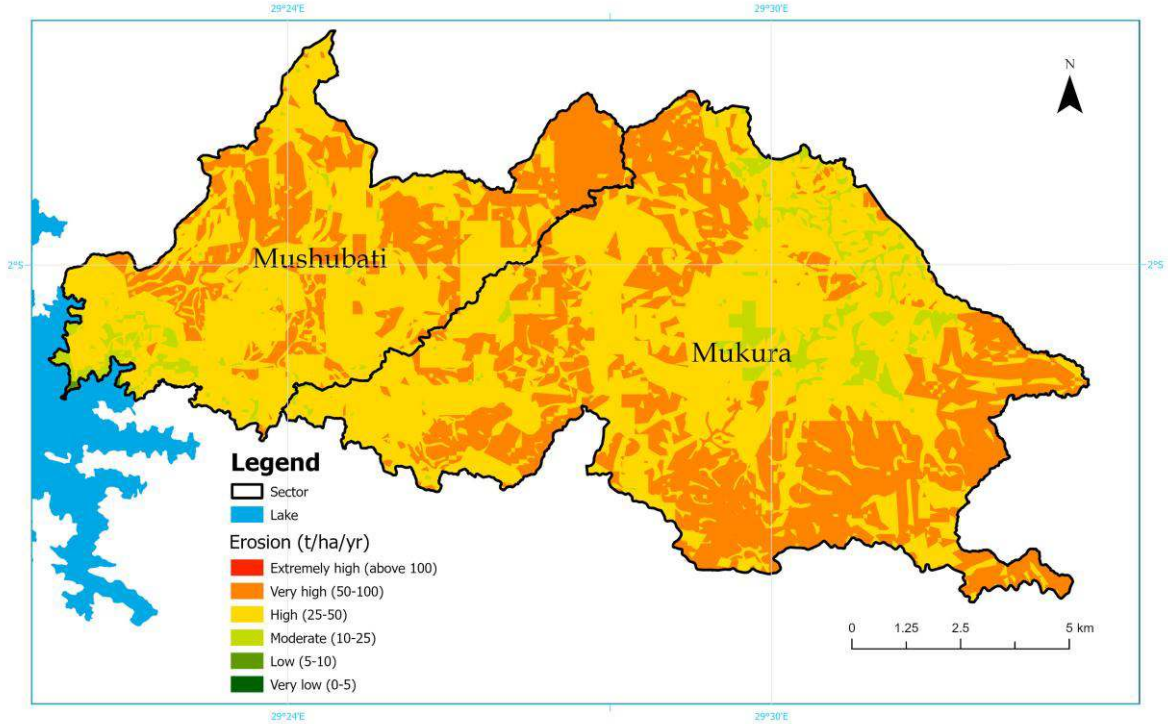
❖ Land Use and Land Cover 2010-2025

- Forest Cover: +49.6% (+1,383.58 ha), Agriculture/Planted Trees: +36.4% (+630.21 ha), Built-up Areas: +22.9%, Degraded Land: -32.9% (-1,904.93 ha), and Grassland: -5.1%



❖ Soil Erosion Status

- Combined high (25–50 t/ha/yr) and very high (50–100 t/ha/yr) erosion risk zones cover 95.47% of the across the study area.



Key Findings on Objective 2: *Contributions of Agroforestry in Restoring Degraded Areas*

- **Environmental benefits** – Erosion control **(Mean = 2.24; 51.7%)**, biodiversity **(2.19; 52.9%)**, climate resilience **(2.05; 57.6%)**, water retention **(1.90; 64.5%)**, and soil fertility **(1.65; 75% not experienced)**.

- **Income improvement** – Sale of tree products increased household income **(Mean = 2.02; 58.7%)**.

- **Food & livelihood security** – Fruit and fodder trees improved food supply **(2.01; 58.7%)**, while beekeeping and tree products diversified livelihoods **(1.98; 60.5%)**.

- **Household support & coping** – Timber and fuelwood supported households **(1.93; 59.9%)**, while agroforestry products provided a coping mechanism during droughts, poor harvests, and financial hardship.



Landscape with agroforestry



Terraces with trees reduces food insecurity

Key Findings on Objective 3: *Challenges in Agroforestry Adoption*

- **Environmental:** Droughts, floods, tree damage, and crop competition reduce adoption.
- **Socio-economic:** Small land size, limited finance, and weak markets constrain farmers.
- **Political:** Weak institutional support and land-tenure insecurity discourage investment.
- **Operational:** Labor shortages, limited technical knowledge, cultural resistance, and low awareness are major barriers.



Poor seedlings



Trees planted without nurture



Low Survival Rate

Key Findings on Objective 4: *Sustainable Solutions*

- **Political & Governance Solutions –** Policy integration (Mean = 1.99; 40.7%), regulation enforcement (1.84; 34.9%), youth & women (1.74; 27.3%).
- **Technical Solutions –** Awareness campaigns (2.14; 45.9%), training (2.05; 41.3%), seedling access (1.65; 26.7%).
- **Environmental Solutions –** Alternative energy (2.08; 43.6%), disaster preparedness (1.92; 39.5%).
- **Socio-Economic Solutions –** Cooperatives (2.24; 47.7%), financial incentives (2.08; 42.4%), market access (1.95; 40.7%), diversified livelihoods (1.94; 40.1%).



Good seedlings Like this Markhamia



Nurturing the planted trees

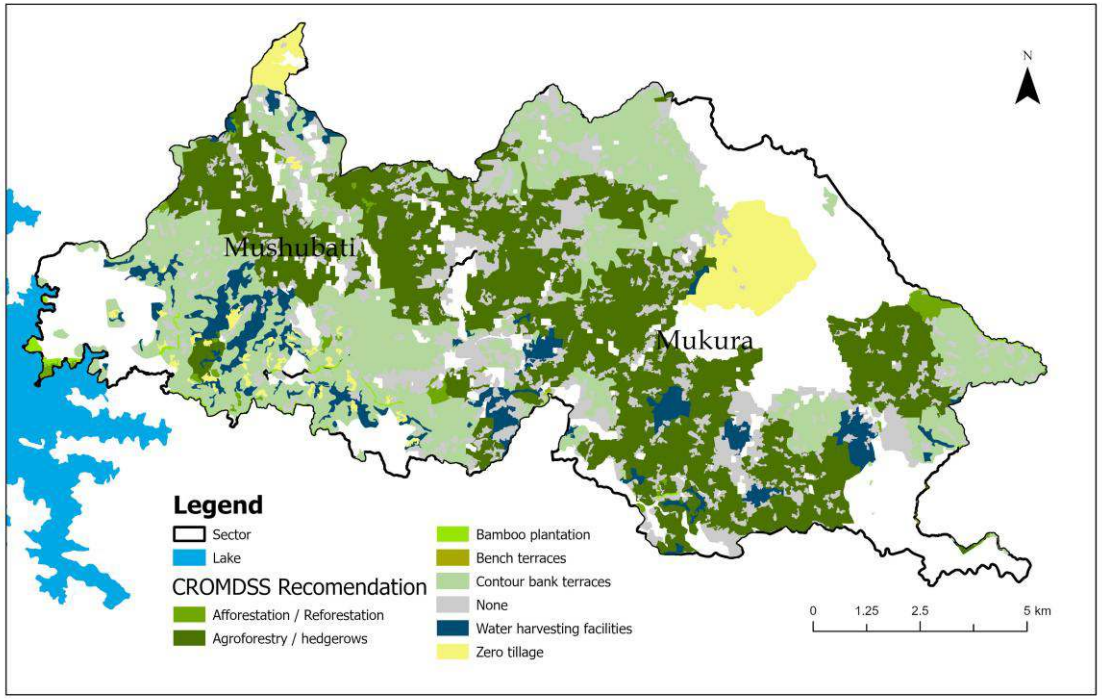


Terraces establishment

Results and Discussion: *CROM–DSS Recommendations.*

Summary statistics of the CROM-DSS recommendations

CROM-DSS Recommendations	Area (ha)	Occupancy (%)
Afforestation / Reforestation	127.17	0.82
Agroforestry	4,517.18	29.18
Bamboo Plantation	54.06	0.35
Bench terraces	1.85	0.01
Contour Bank Terraces	3,495.35	22.58
Unspecified Interventions	5,870.02	37.92
Water Harvesting Facilities	737.05	4.76
Zero Tillage	675.43	4.36
Total	**15,478.11**	**100.00**



Spatial Distribution of CROM-DSS Recommendations in the Study Area

Conclusion

- **Persistent Degradation** – Soil fertility decline, topsoil loss, drought, and erratic rainfall continue to threaten livelihoods.
- **Agroforestry Contributions** – Improves soil conservation, biodiversity, income diversification, and food security.
- **Spatial Evidence** – Forest cover ↑ 49.6%, degraded land ↓ 32.9% (2010–2025).
- **Erosion Challenge** – 95% of study area remains high/very high erosion risk.
- **CROM-DSS Insights** – Agroforestry most suitable (29.18%), followed by terraces, water harvesting, and zero tillage.

Recommendations

- **Scale up Agroforestry** – Target priority areas identified by CROM-DSS.
- **Integrate Soil & Water Conservation** – Combine agroforestry with terraces and watershed practices.
- **Financial Support** – Credit schemes, subsidies, and community financing.
- **Land Tenure Security** – Accelerate registration and promote secure rights.
- **Extension & Training** – Practical guidance on agroforestry and climate-resilient farming.
- **Community Participation** – Involve locals in planning, implementation, monitoring for ownership and sustainability.



Thank you for Listening!!!



HEALTH–CLIMATE NEXUS

2nd RWANDA CLIMATE SCIENCE SYMPOSIUM 2026
Where Rwanda's climate research meets policy

E) HEALTH–CLIMATE NEXUS



Greening Last-Mile Vaccine Delivery in Resource-Limited Settings: Acceptance of Drone-Based Vaccine Delivery and Associated Factors Among Healthcare Workers in Rwanda

Etienne NUMVIYUMUKIZA[123], Olivier NIYONKURU[2], INEZA Gislaine[2]
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Last-mile reliability links climate resilience to immunization







Climate & terrain stress road access → **Transport disruption** delays replenishment → **Last-mile supply** becomes less predictable → **Immunization** continuity is threatened

Climate-resilient health systems need logistics that maintain essential vaccine services when surface transport is constrained.

Drone capability matters only when frontline workers adopt it

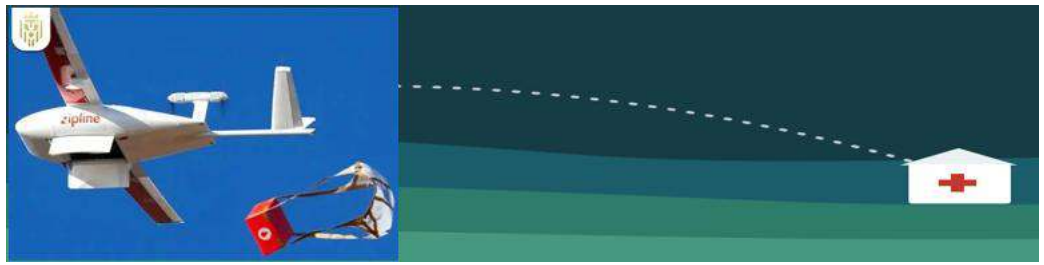
TECHNICAL CAPABILITY

- Rapid, on-demand transport
- Bypasses some road constraints
- Reaches decentralized health posts

FRONTLINE ADOPTION

- Fits ordering and receipt workflows
- Trusted to protect vaccine integrity
- Supported by clear safety procedures

Routine integration requires both.



We asked one practical implementation question

How acceptable is drone-based vaccine delivery to vaccination focal persons & what shapes that acceptance?

1. **Measure acceptance**

   among frontline vaccination focal persons

2. **Identify associated factors**

   across benefits, usability, leadership and risks

3. **Describe concern patterns**

   with emphasis on operational and privacy risks

A census captured frontline experience across 24 districts

124
programme-listed health posts

→

20
ineligible after verification

→

104
eligible and completed

DESIGN & SETTING

Analytical cross-sectional census
24 districts · 4 provinces
15 Jan–15 Feb 2026

MEASUREMENT

Bilingual 46-item questionnaire
8-item acceptance outcome
7 theory-informed predictors

ANALYSIS

Spearman correlations
7-predictor OLS model
Inference + sensitivity checks

UR-CMHS IRB approval: CMHS/IRB/714/2025 · 100% completion among eligible participants

Participants were experienced vaccination focal persons

91.3%
had prior drone-delivery experience
(n=103 valid responses)

81.7%
were nursing professionals

41.3%
had ≥16 years in their current role

ROLE AT THE HEALTH POST



The findings reflect workers with direct responsibility for receiving and managing vaccine supplies.

Acceptance was exceptionally high

4.64 / 5

mean acceptance score
95% CI: 4.56–4.72

71.2%

scored ≥4.5 on the descriptive
'high acceptance' threshold

100%

wise idea

100%

desirable

99.0%

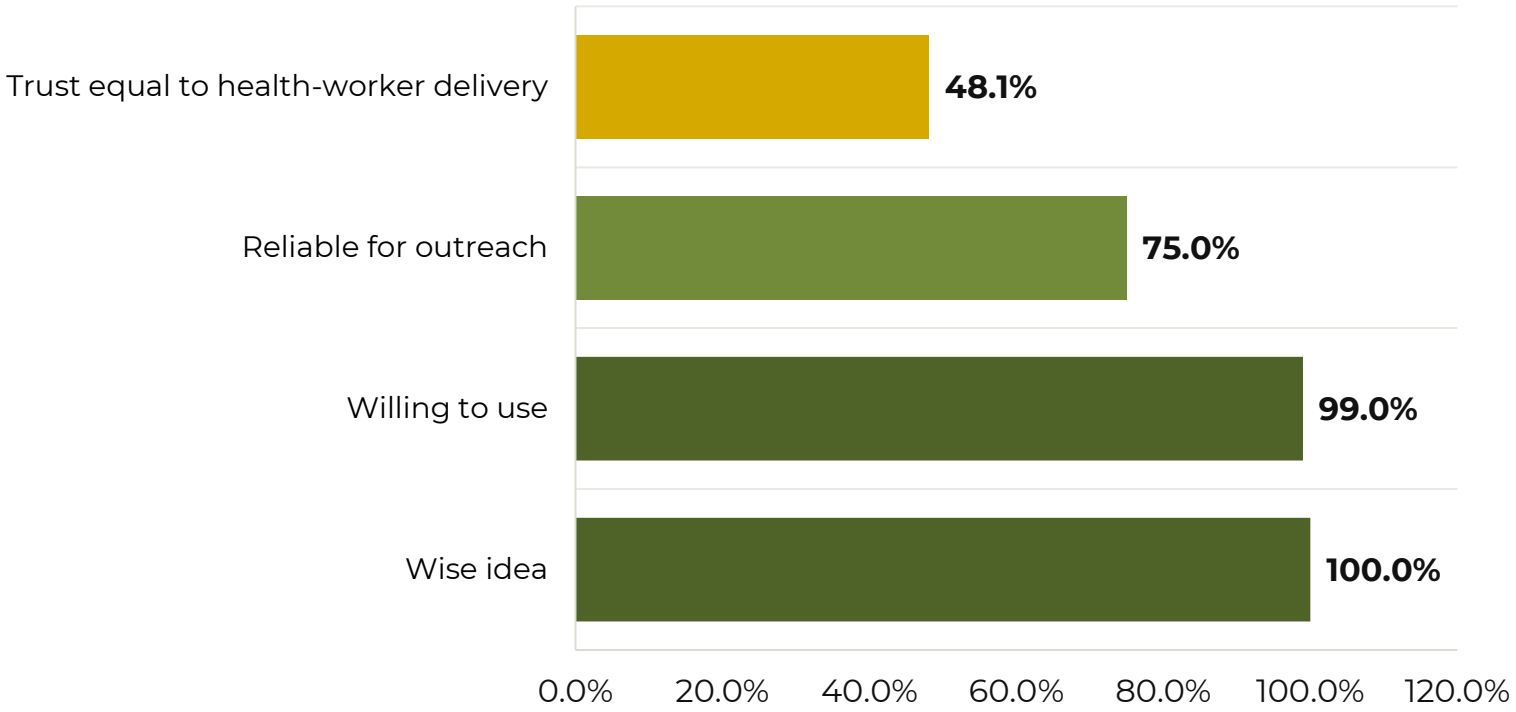
willing to use

99.0%

would continue

The ≥4.5 threshold is descriptive and non-validated; all inferential analysis used the continuous score.

High willingness coexisted with a clear trust gap

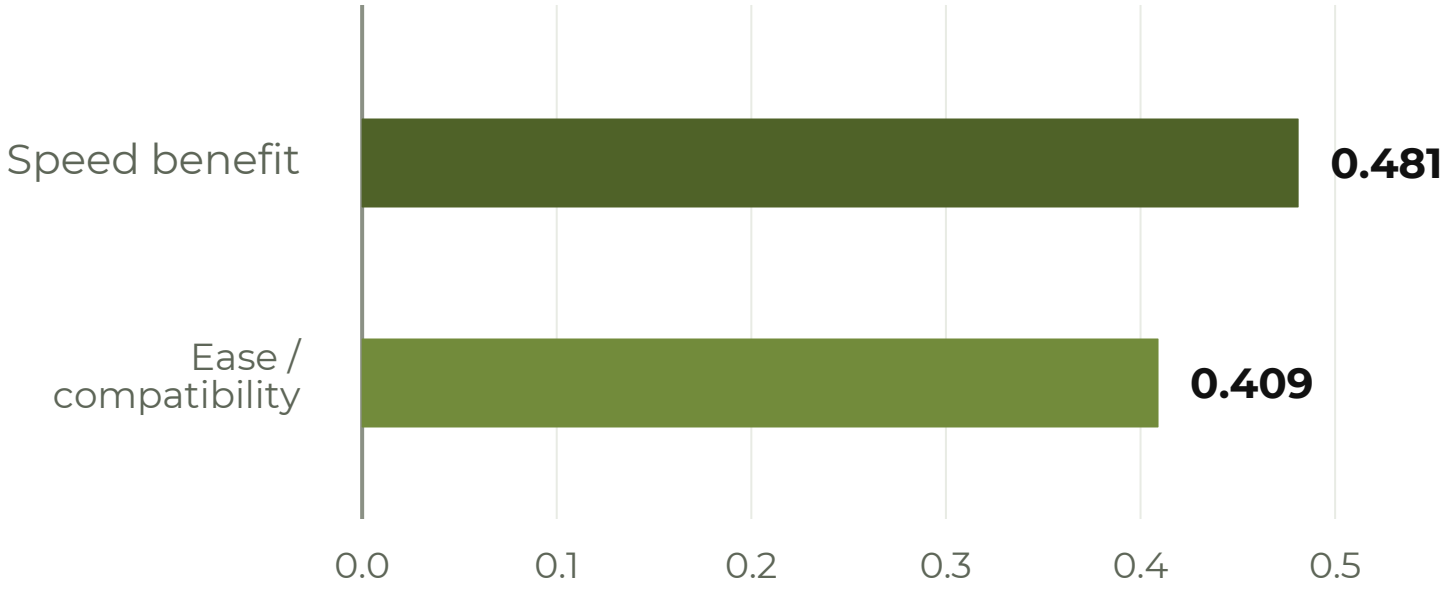


48.1%

trusted drone-delivered vaccines as much as vaccines delivered by health workers

Implementation momentum is strong, but vaccine-quality confidence needs visible reinforcement.

Speed and usability were the stable drivers of acceptance



R^2 = 0.679

variance explained

Privacy risk: β = −0.165 p=0.062 — not significant

Speed: p<0.001
Ease/compatibility: p=0.004

All other domains: p>0.05

Standardized coefficients; seven-predictor OLS model with HC3 robust inference (N=104).

Perceived environmental benefit is not measured climate impact

4.50 / 5

mean perceived environmental benefit

ρ = 0.598

bivariate correlation with acceptance, $p < 0.001$

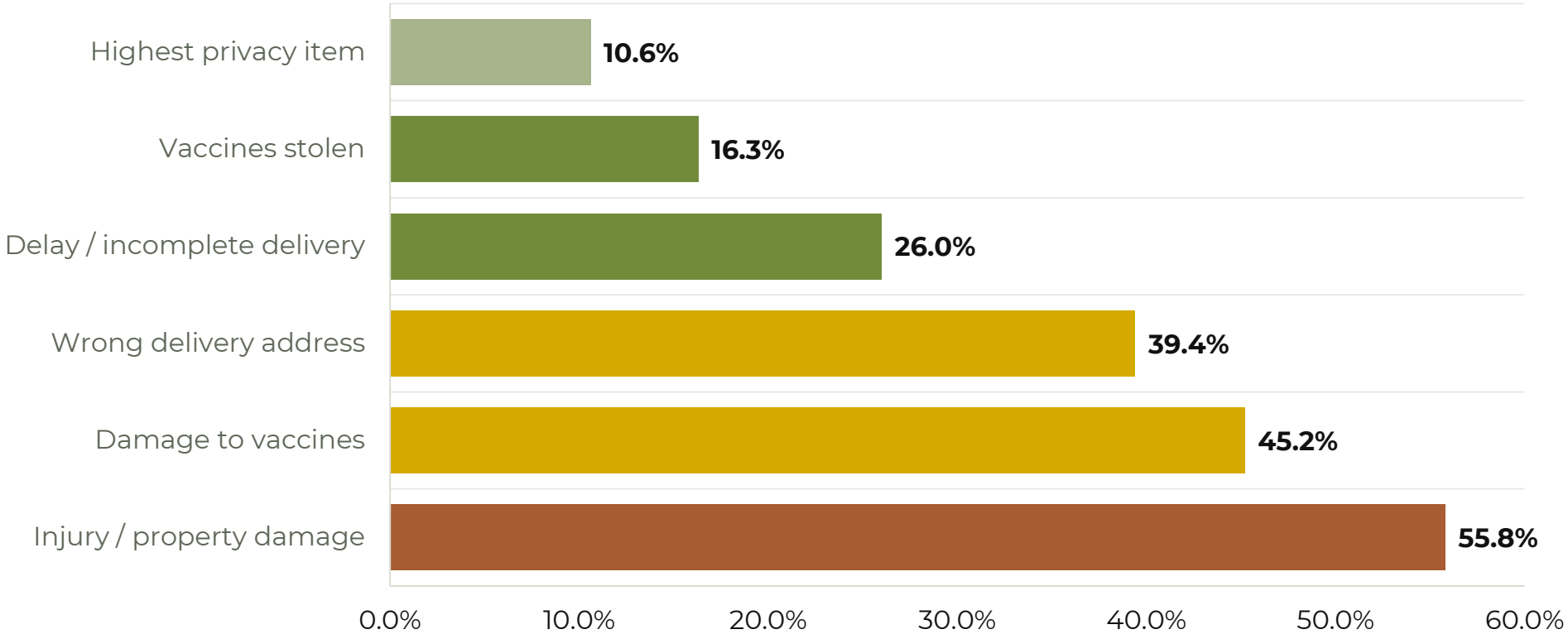
β = 0.004

adjusted association $p = 0.965$

This study measured perceptions, not fuel use, life-cycle emissions, avoided road kilometers, or carbon intensity.

Next step: compare routes prospectively using logistics outcomes and context-specific life-cycle emissions.

Operational safety concerns outweighed privacy concerns



2.77

performance risk mean

1.99

privacy risk mean

Acceptance supports readiness, not proof of system performance

THE EVIDENCE SUPPORTS

✓ Very high attitudinal acceptance among eligible focal persons

✓ Speed and ease/compatibility as stable correlates

✓ A need to address trust, safety, and workflow design

THE EVIDENCE DOES NOT ESTABLISH

× Causal effects of drone delivery

× Verified time, cold-chain, stock-out, cost or coverage gains

× Carbon reduction or overall environmental impact

Cross-sectional · self-reported outcomes · one focal person per eligible health post · strong ceiling effects

Climate-smart scale-up needs four implementation safeguards

1	**Protect the workflow advantage**	Keep ordering, receipt and replenishment rapid, predictable and uncomplicated.
2	**Make vaccine integrity visible**	Audit temperature control, handling, chain of custody, quarantine and contingency procedures.
3	**Institutionalize safety & data governance**	Standardize incident reporting, safe delivery points, community protection and data-access rules.
4	**Measure climate and health outcomes**	Track time, cold chain, stock-outs, cost, coverage and route-specific life-cycle emissions prospectively.

Design for speed, simplicity, safety, and measurement

1. Acceptance provides strong implementation momentum.
2. Trust and operational safety must accompany scale-up.
3. Climate claims require direct comparative measurement.

Questions & discussion • Etienne NUMVIYUMUKIZA • numviyumukizaetienne@gmail.com

D) NATURE-BASED SOLUTIONS & ECOSYSTEMS

Estimating the subnational burden of temperature-attributable under-five malaria cases in Rwanda using standards for official climate-health statistics

Authors: Etse Yawo Dzakpa, Mouhamadou Bamba Sylla, Lema Logamou Seknewna, Marta Blangiardo, Monica Pirani, Vijendra Ingole
Affiliations: African Institute for Mathematical Sciences Research and Innovation Centre (AIMS RIC), Kigali, Rwanda; MRC Centre for Environment and Health, Imperial College London, UK; Office for National Statistics (ONS), UK
Contact: edzakpa@aimsric.org

Background & Motivation

Global health challenge

- **282 million** malaria cases in 2024, up from 263 million in 2023)
- **64 cases** per 1,000 people at risk**,** up from 60 cases in 2023
- **610,000 deaths** in 2024, up from 263M cases in 2023 (WHO, 2025). Africa bears 94% of cases.
- **Africa's share** is **94% of cases and 95% of deaths** in 2024 (essentially unchanged from 2023's 94%/95%)

Rising climate risk

- **Disproportionately** affects child health outcomes in low- and middle-income countries
- Higher mortality from floods, droughts, and storms in highly climate-vulnerable regions (IPCC AR6, 2023).
- Malaria, a climate-sensitive disease, is expected to increase over the next 80 years if there are no effective adaptation and strengthened control strategies (IPCC, 2023)

Most at risk

Children under five, pregnant women, and the elderly face the greatest malaria risk (Leal et al., 2023).

The gap

Official health statistics lack subnational estimates of climate-attributable malaria burden.

Objectives

- **Quantify the subnational** (district- and region-level) burden of under-five malaria cases attributable to maximum temperature in Rwanda, 2016–2023.

- **Apply the SOSCHI framework** (Standards for Official Statistics on Climate–Health Interactions, Indicator 44) to generate an official, policy-ready climate-health indicator for Rwanda.

SOSCHI Framework-Global Set

Indicator 44: Incidence of cases of climate-related diseases

- Incidence of diarrheal disease cases attributable to (a) heat and (b) rainfall
- Incidence of malaria cases attributable to (a) heat and (b) rainfall
- Incidence of other vector-borne diseases of national importance attributable to (a) heat and (b) rainfall

Indicator 45: Incidence of heat- and cold-related illnesses or excess mortality

- Mortality from all causes attributable to (a) heat and (b) cold
- Mortality from suicide attributable to excess heat (proxy for mental health)
- Hospital admissions from all causes attributable to (a) heat and (b) cold
- Incidence of occupationally-related health outcomes of excess heat

Indicator 46: Climate-induced air pollution

- Mortality attributable to short-term effects of outdoor air quality (PM2.5)
- Mortality attributable to effects of wildfire smoke (PM2.5)
- Mortality attributable to long-term effects of outdoor air quality

Pathway between climate and malaria

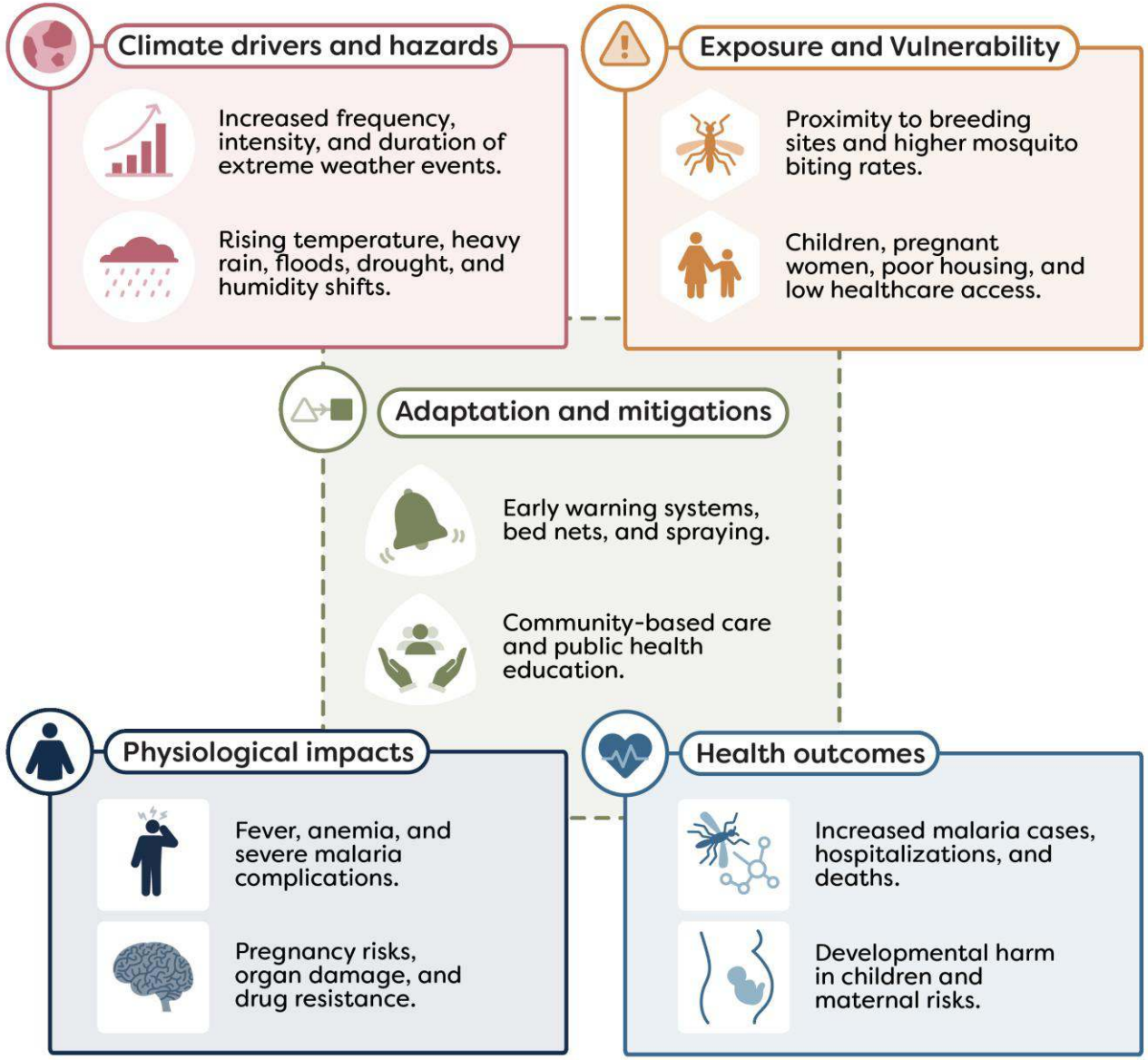
How does climate affect malaria?

❖ Temperature effect on malaria

- Ambient temperatures enhance mosquito life cycles, increase parasite development rates, and affect mosquito-human interactions, leading to higher malaria prevalence.
- 20- 30 °C is the optimal range for mosquito larval development, but it differs according to the species

❖ Rainfall effect on malaria

- Rainfall creates breeding sites for mosquitoes, facilitating their development
- The impact varies with the amount and timing of rainfall
- While increased rainfall generally promotes mosquito breeding, heavy rainfall may reduce malaria transmission by washing away mosquito breeding sites



Key statistics on malaria and climate

Malaria burden attributable to extreme temperature

- **Relative risk** of malaria cases attributable to extreme temperature (**RR**)
- **Number of malaria cases** attributable to extreme temperature (**AN**)
- **Fraction of malaria cases** attributable to extreme temperature (**AF**)
- Malaria cases per 100,000 population attributable to extreme temperature (**Attributable rate, AR**)

Data

Monthly reported malaria cases at the district level are required

Key Variables

- **Health data:** monthly under-five malaria case counts, 30 districts, 2016–2023 (Rwanda HMIS / DHIS2).
- **Climate data:** ERA5 reanalysis (0.25° resolution) — maximum temperature, rainfall, relative humidity, surface runoff.
- **Denominator:** district-level under-five population, used as model offset and attributable-rate denominator.

Data Sources Recommended

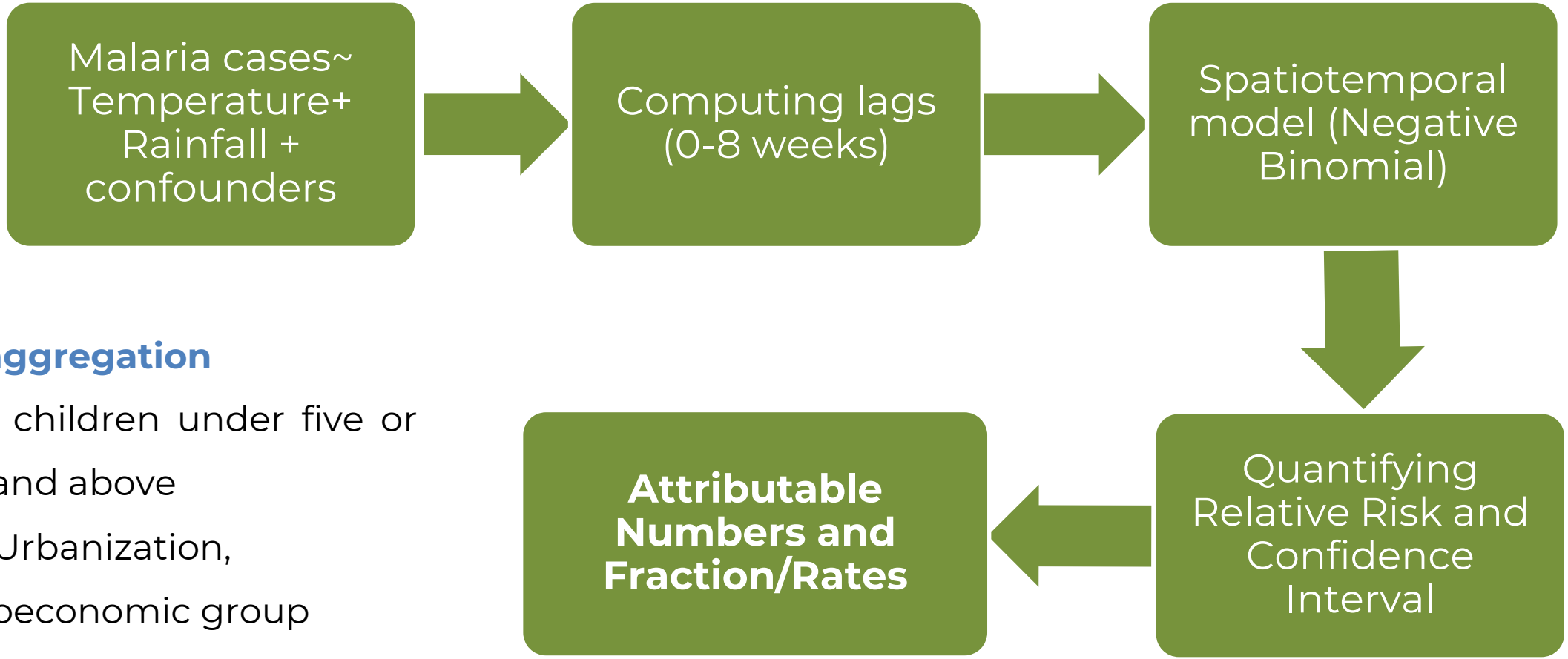
✓ Health Data:

National Health Management Information System (HMIS), District Health Information System (DHIS2)

✓ Climate Data:

National Meteorological Agency, ERA5 reanalysis data, NOAA, CORDEX-CMIP6

Methods



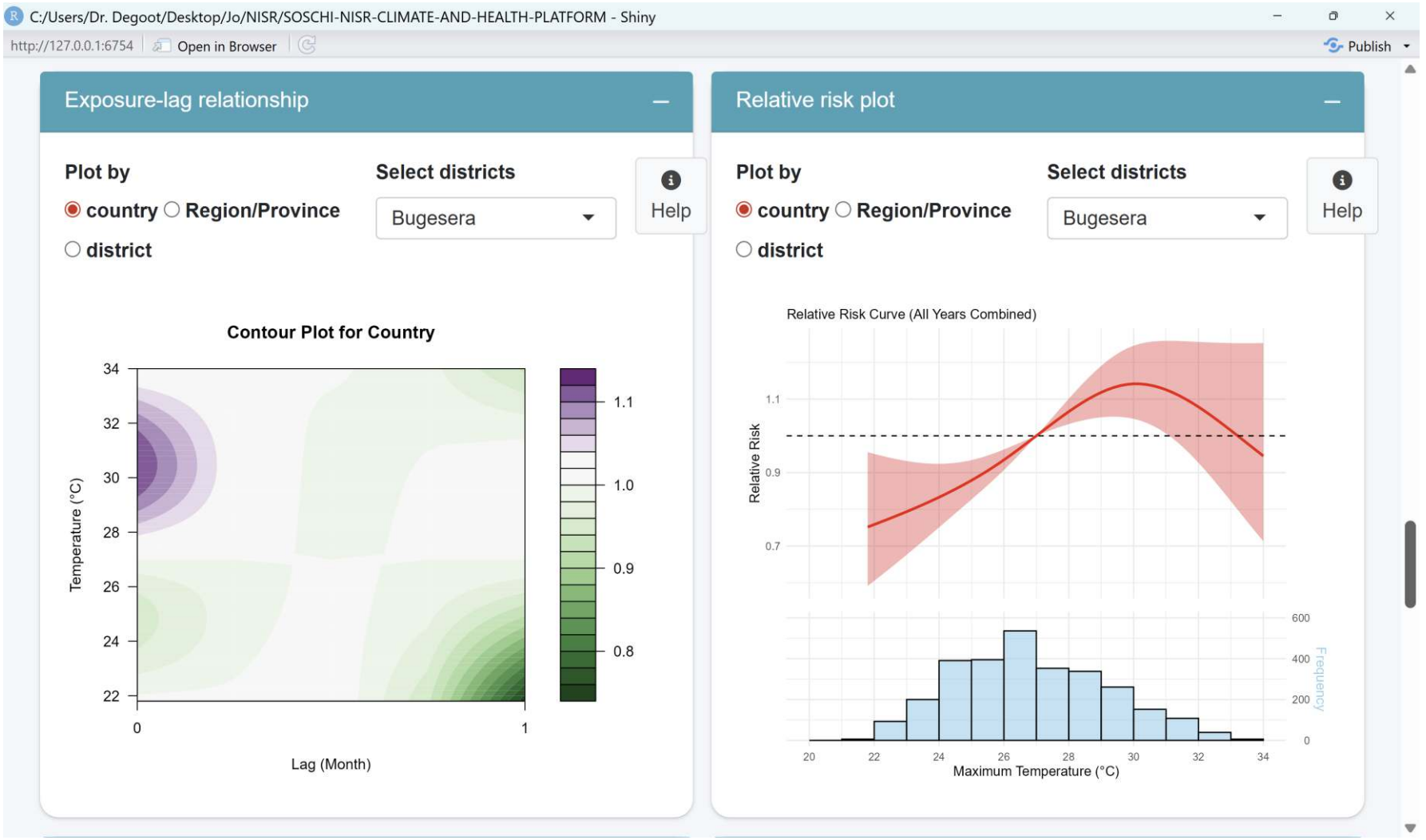
Key disaggregation

- ✓ Age: children under five or five and above
- ✓ sex, Urbanization,
- ✓ Socioeconomic group

The proposed model is based on [Lowe et al., (2021)]

Results: Temperature–Malaria Risk Relationship

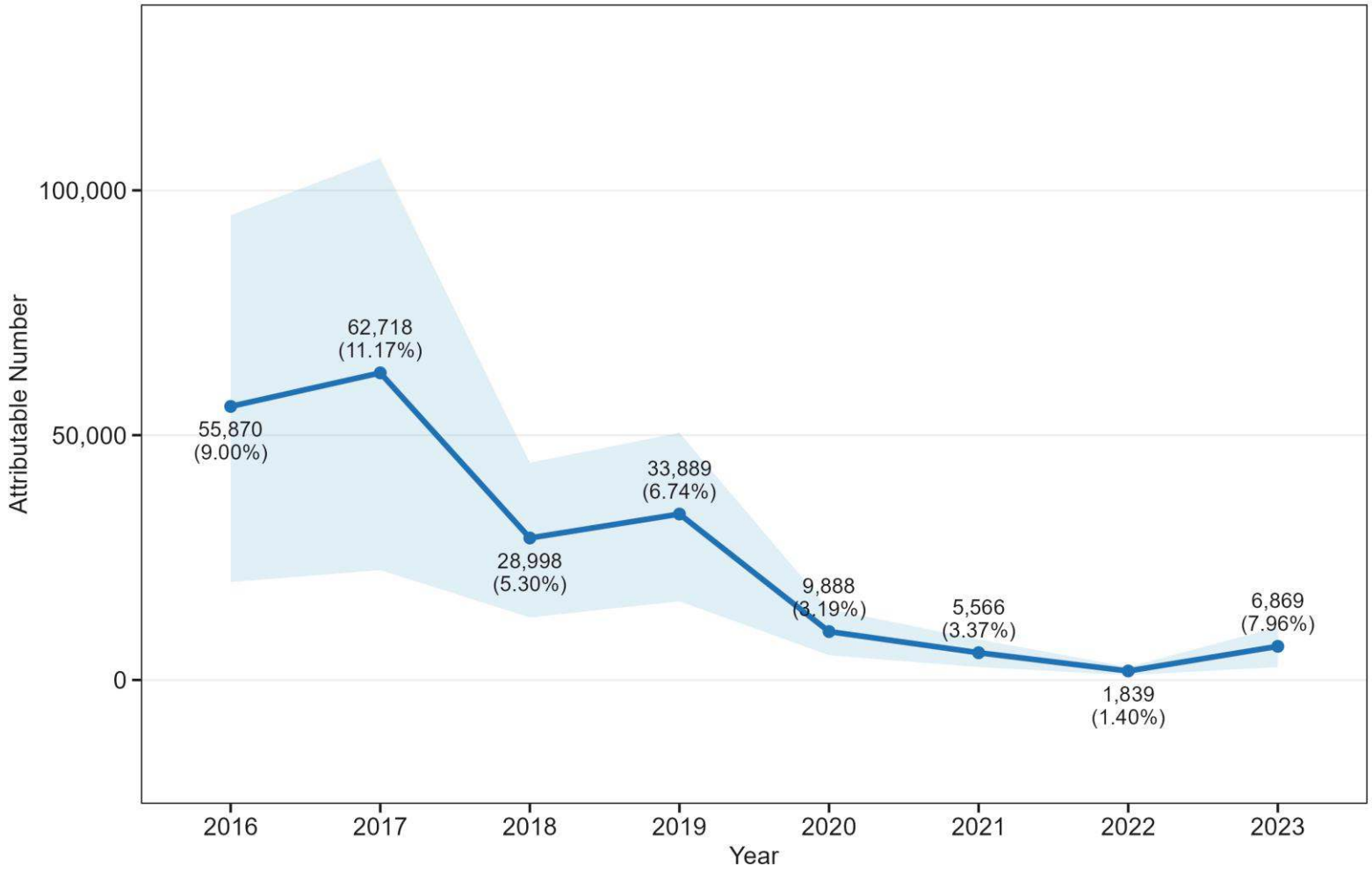
- Malaria risk rises with maximum temperature above approximately 27°C.
- **Peak relative risk:** 1.14 (95% CrI: 1.05–1.25) at 30°C.
- Risk is significantly elevated between 27°C and 31°C and declines at higher temperatures.



Results: National Attributable Burden (2016–2023)

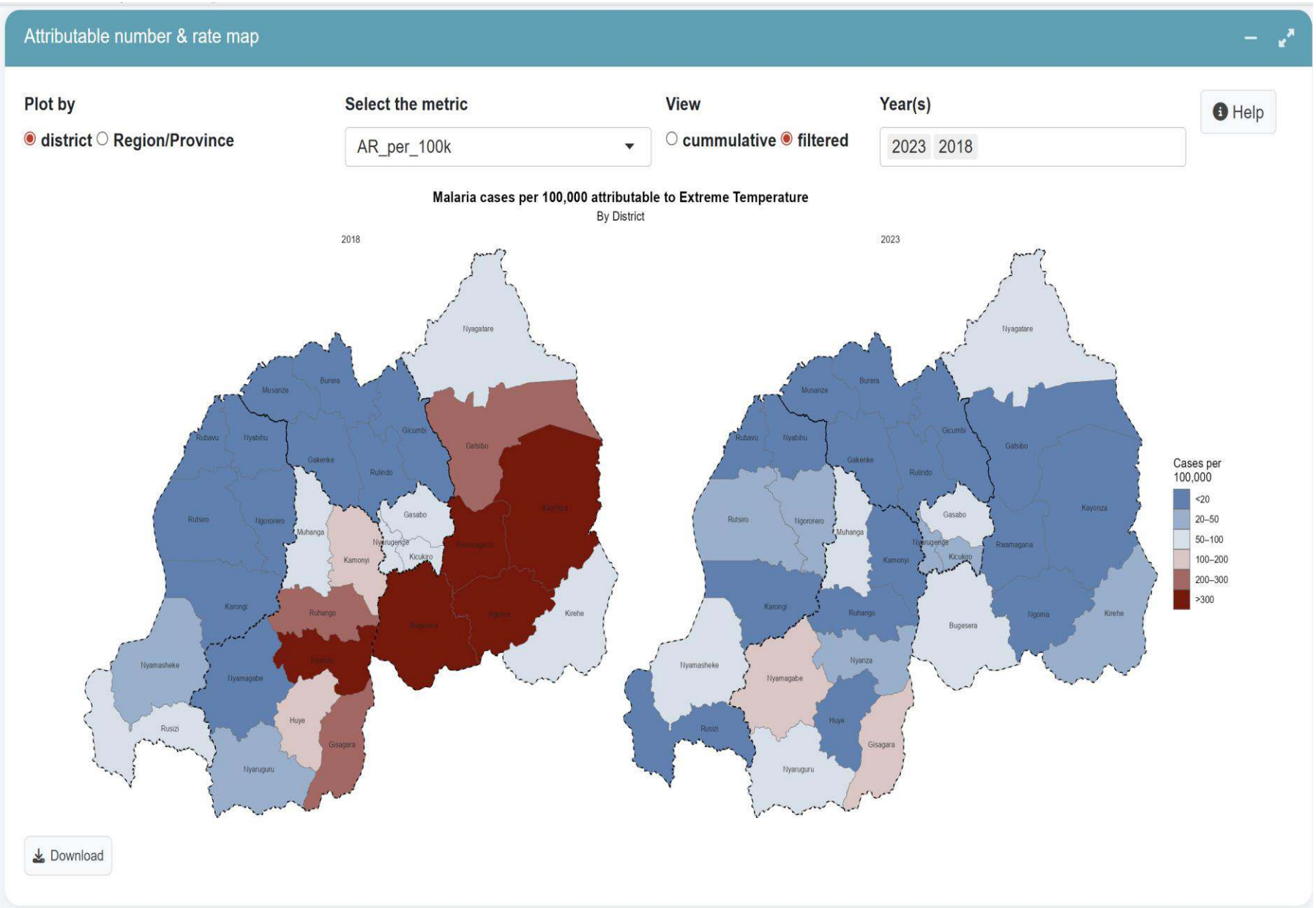
- **Declining trend:** the annual AR fell sharply from **285 per 100,000 in 2016** to **31 per 100,000 in 2023**, likely reflecting national gains in malaria control alongside climate exposure.

- An estimated **205,637** under-five malaria cases attributable to nonoptimal temperature over 2016–2023 (95% CrI: 82,581–332,548), representing **AF= 6%** of all under-five malaria cases during that period. And AR of **132 per 100,000** population



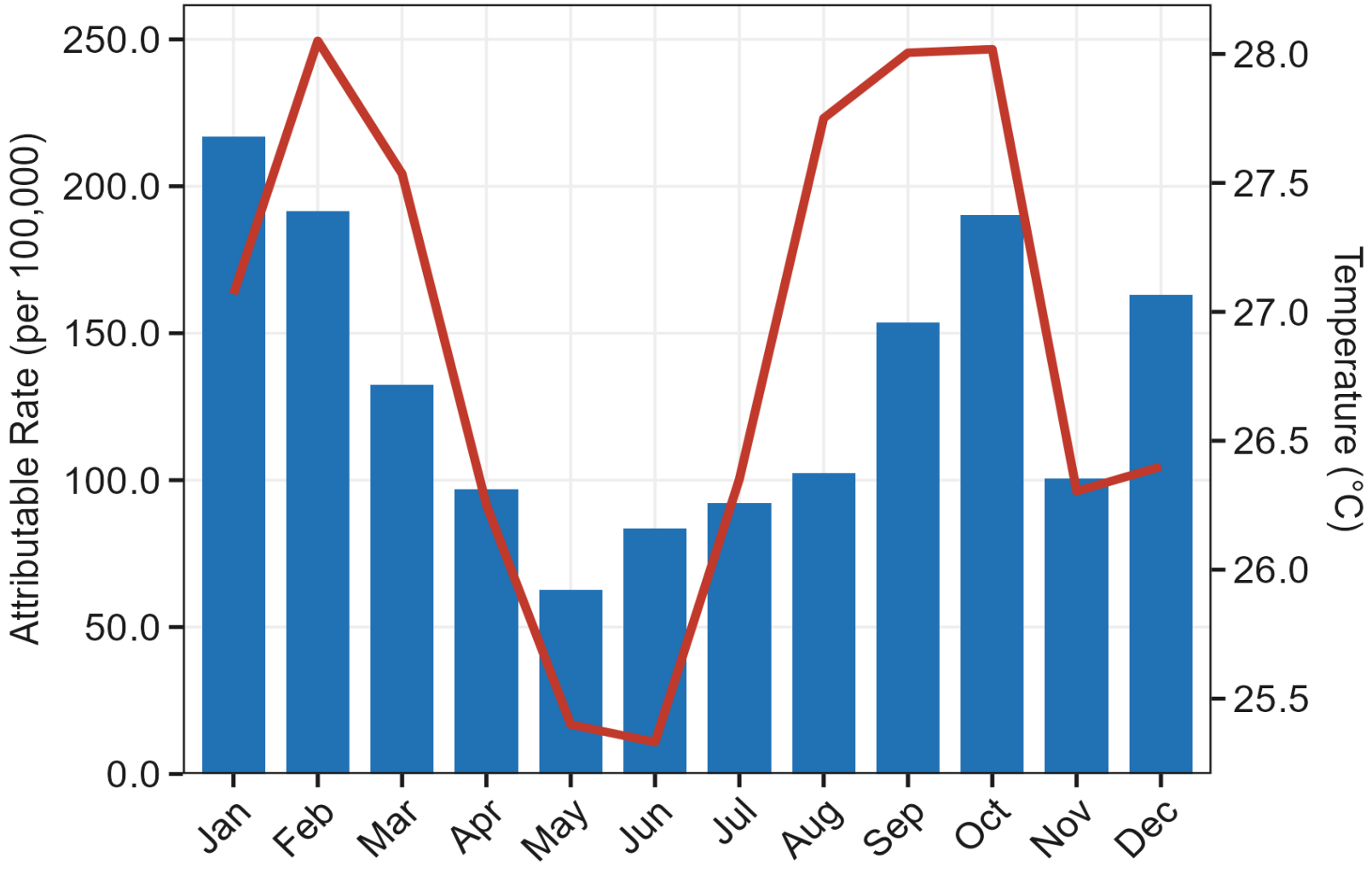
Results: Subnational Heterogeneity

- **Attributable rate dropped in** East from (384 per 100,000) in 2018 to (30 per 100,000) in 2023, and in South from (165 per 100,000) in 2018 to (57 per 100,000) in 2023.
- **Musanze, Nyabihu, Rubavu (North/West):** near-zero attributable burden throughout the period.
- **Climate sensitivity (relative risk) and attributable rate** diverge geographically — high-burden districts combine elevated baseline incidence with climate exposure, so both dimensions matter for planning.



Results: Seasonal Pattern of Attributable Burden

- **Bimodal pattern:** attributable burden peaks January-March and again September-December, with the lowest burden in the April-August window.
- These windows align with Rwanda's two rainy seasons and their lagged effect on malaria transmission.
- Defines two concrete windows for pre-emptive intervention timing.



Conclusion & Policy Relevance

- **First district-level**, temperature-attributable under-five malaria burden estimates for Rwanda, applying the SOSCHI framework (Global Set Indicator 44).
- **Two policy tracks:** climate-resilient health systems where climate sensitivity is highest; sustained vector-control investment in high-burden districts, where the attributable rate is greatest.
- **Timing:** the January–March and September–December burden peaks define concrete windows for pre-emptive chemoprevention and vector-control deployment.
- **Trend:** the marked decline in attributable rate since 2016 suggests continued malaria control efforts should be sustained even as climate risk persists.
- **Embedding these indicators** into official statistics can shift climate-health adaptation planning from reactive to anticipatory.

Thanks to the team, partners, and funders

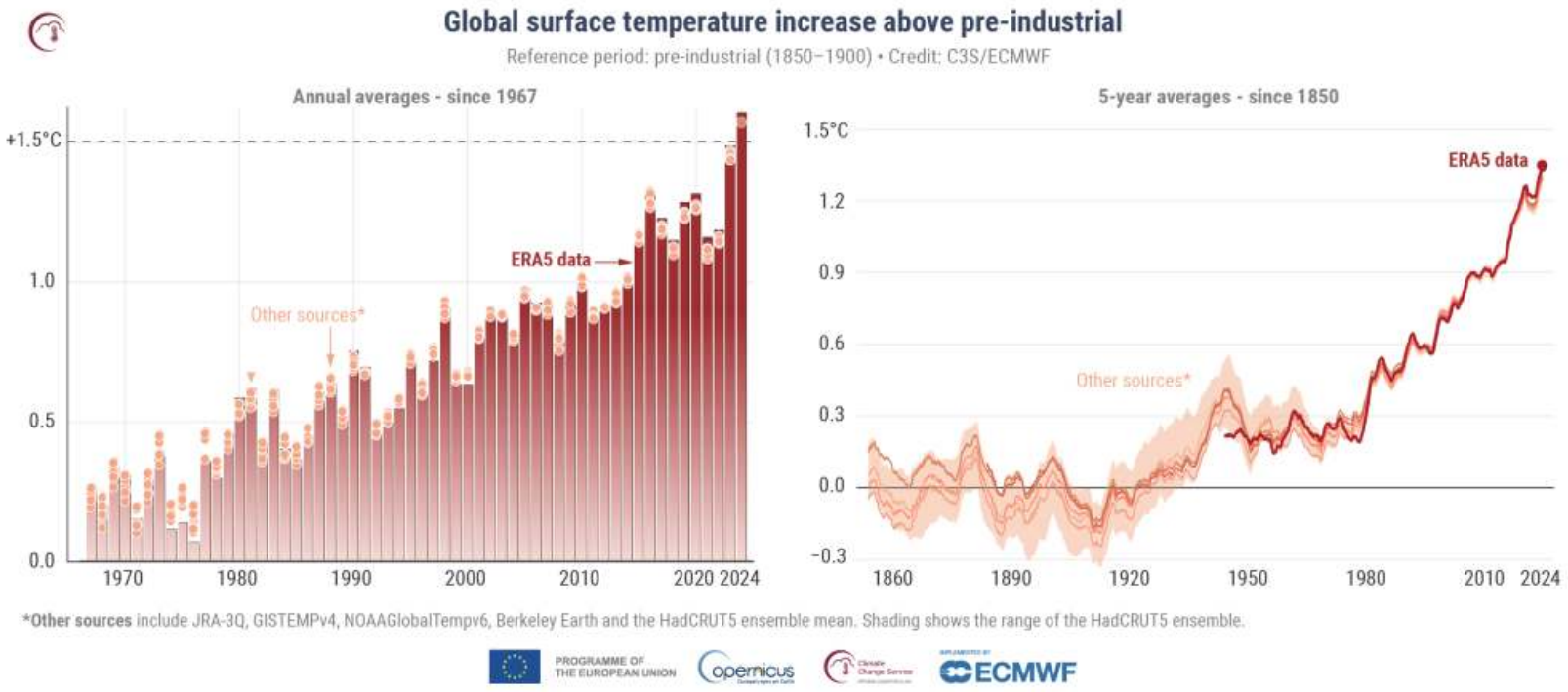
- African Institute for Mathematical Sciences (AIMS) Rwanda
- Cochrane Planetary Health Thematic Group (University of Alberta)
- UK Office for National Statistics (Climate and Health Team)
- UK Health Security Agency
- UN Global Platform
- Regional Institute for Population Studies (RIPS) at the University of Ghana
- Wellcome (grant no. 224682/Z/21/Z)

D) NATURE-BASED SOLUTIONS & ECOSYSTEMS

Modelling Heat Stress Impacts on Construction Workers' Health and Productivity in Kigali, Rwanda

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A warming climate threatens health and work



- **2024: first year above +1.5 °C**

  The warmest year on record globally (C3S, 2025).

- **Health and work at risk**

  Heat affects living and working environments and threatens the health and work capacity of millions of people (Kjellstrom et al., 2009).

- **Impacts are local**

  They vary with geography and local weather conditions (Kjellstrom et al., 2009).

Chart: Copernicus Climate Change Service (C3S)/ECMWF, ERA5, Global Climate Highlights 2024 (January 2025).

Outdoor workers are the most exposed to heat





Who

People working long hours outdoors in the sun, e.g. in agriculture and construction

Why

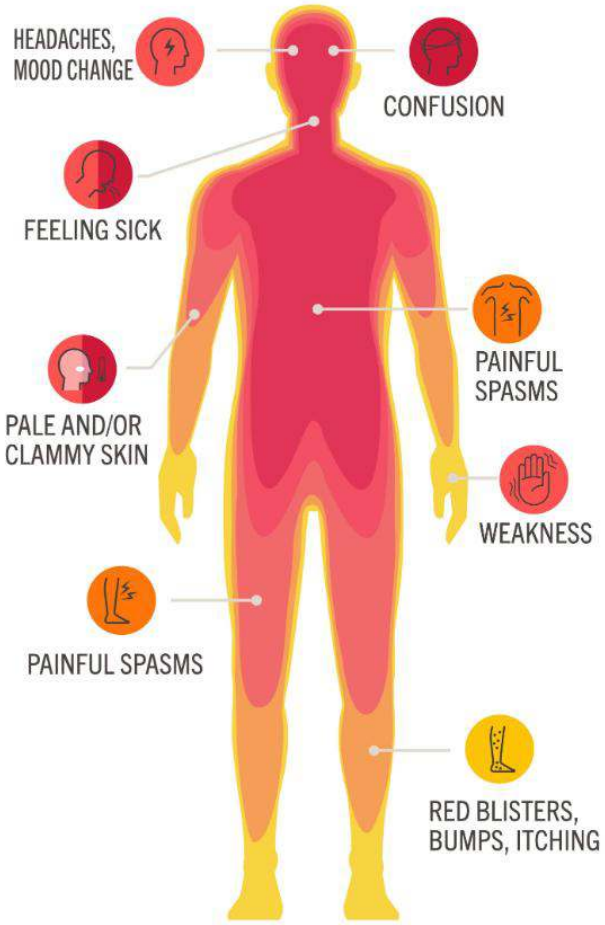
Physical work produces heat in the body, which must be lost mainly by sweat evaporation

Limit

Core body temperature should stay below 38 °C (WHO, 1969)

Photos: left, World Vision (wvi.org/stories/global-hunger-crisis) · right, Marcopolis, construction sector in Côte d'Ivoire (marcopolis.net).

When the body cannot cool down, heat illnesses follow



HEAT RASH

HOW IT HAPPENS: Sweat ducts become clogged & sweat can't get to the surface of the skin

HOW TO TREAT IT: Keep the skin dry & rest in a cool place

HEAT CRAMPS

HOW IT HAPPENS: Salt & moisture levels are depleted through excessive perspiration

HOW TO TREAT IT: Move to a cool, shaded area, apply something cool, drink plenty of fluids

HEAT EXHAUSTION

HOW IT HAPPENS: Prolonged exposure to high temps & poor hydration

HOW TO TREAT IT: Move to a cool, shaded area, apply something cool, drink fluids & monitor

HEAT STROKE

HOW IT HAPPENS: When the body becomes unable to controls its core body temp

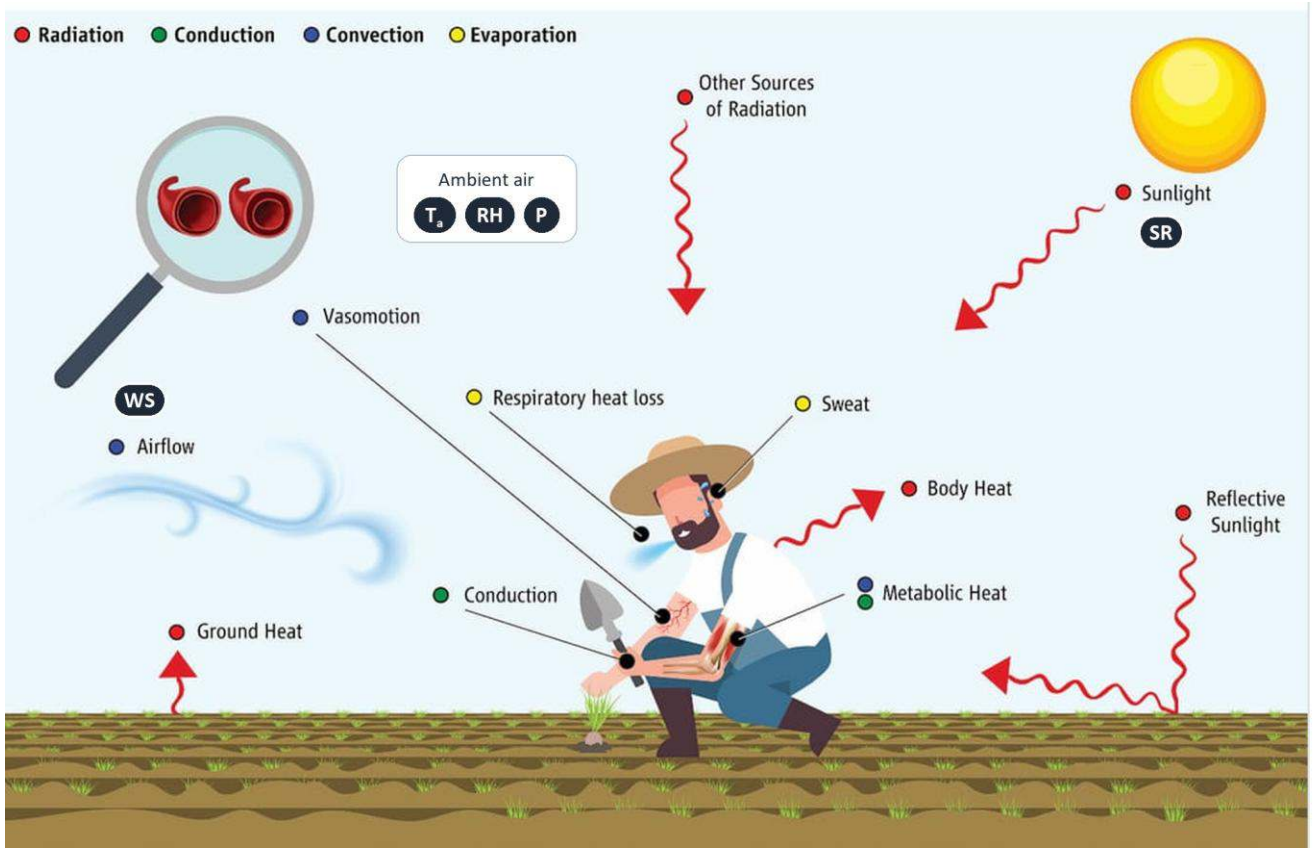
HOW TO TREAT IT: Seek medical attention immediately

- **Heat must leave the body**
  During physical work, heat is lost mainly by sweat evaporation.
- **When cooling fails**
  Heat rash and cramps can progress to heat exhaustion and heat stroke, a medical emergency.
- **Above 38 °C core temperature**
  Work capacity and mental performance drop, and accident risk rises (Kjellstrom et al., 2009).

Infographic: Ergodyne, 'Who is most at risk for heat stress' (ergodyne.com/blog). Physiology: Kjellstrom et al. (2009).

UTCI and WBGT: two heat-stress indices

UTCI (Universal Thermal Climate Index) describes outdoor thermal stress for the general public; **WBGT** (Wet Bulb Globe Temperature) is the international reference for workplaces (ISO 7243:2017).



Variables used by WBGT

Liljegren et al. (2008) outdoor model

$$WBGT = 0.7\,T_{nwb} + 0.2\,T_g + 0.1\,T_a$$

70 % T_{nwb} Natural wet-bulb temperature
evaporation · convection · radiation

20 % T_g Black-globe temperature
radiation · convection

10 % T_a Air temperature (shaded)
convection

Meteorological inputs

T_a	Air temperature (2 m)	°C
RH	Relative humidity (2 m)	%
WS	Wind speed (10 m)	$m\ s^{-1}$
SR	Global solar radiation	$W\ m^{-2}$
P	Surface pressure	hPa

SR is split into direct and diffuse parts using the solar zenith angle; T_{nwb} and T_g are then solved from the heat balance of each sensor.

Illustration: Ioannou et al. (2022), Figure 1, Temperature 9(1):67–102, 'Occupational heat strain in outdoor workers: a comprehensive review and meta-analysis'. WBGT model: Liljegren et al. (2008).

WBGT limits set how much rest workers need each hour

Recommended maximum WBGT (°C) by work intensity and rest time per hour

Rest time per hour	Light	Medium	Heavy	Very heavy
0% (continuous work)	31.0	28.0	27.0	25.5
25%	31.5	29.0	**27.5**	26.5
50%	32.0	30.5	29.5	28.0
75%	32.5	32.0	31.5	31.0
100% (no work at all)	39.0	37.0	36.0	34.0

How to read it: for heavy work, WBGT above 27 °C already requires rest breaks, and above 27.5 °C at least half of each hour must be rest. That rest time is lost work time.

Source: Kjellstrom, Holmer & Lemke (2009), Table 2 (average acclimatised worker, light clothing); values approximated from ISO 7243; 'no work' row from NIOSH.

Rest breaks protect health but reduce productivity

Hourly WBGT → Work intensity (light to very heavy) → Required rest time per hour → **Lost work time = productivity loss**

Four published approaches to be compared in this study

Dunne et al.

Labour capacity as a function of WBGT (Dunne et al., 2013)

Hothaps

Work-capacity loss functions by work intensity (Kjellstrom et al., 2018)

ISO 7243

Work–rest limits converted to work capacity (Bröde et al., 2018)

NIOSH

Work–rest limits converted to work capacity (Bröde et al., 2018)

Estimated work ability depends on the heat-stress metric chosen (Bröde et al., 2018).

Sources: Kjellstrom et al. (2009); Dunne et al. (2013); Kjellstrom et al. (2018); Bröde et al. (2018).

Aim: link heat stress to workers' health and productivity

Main objective: link climate-driven heat stress to the occupational health and labour productivity of construction workers in Kigali.

1 Health and productivity

Assess heat impacts by physical-activity intensity: unsafe days, productivity loss and its economic cost

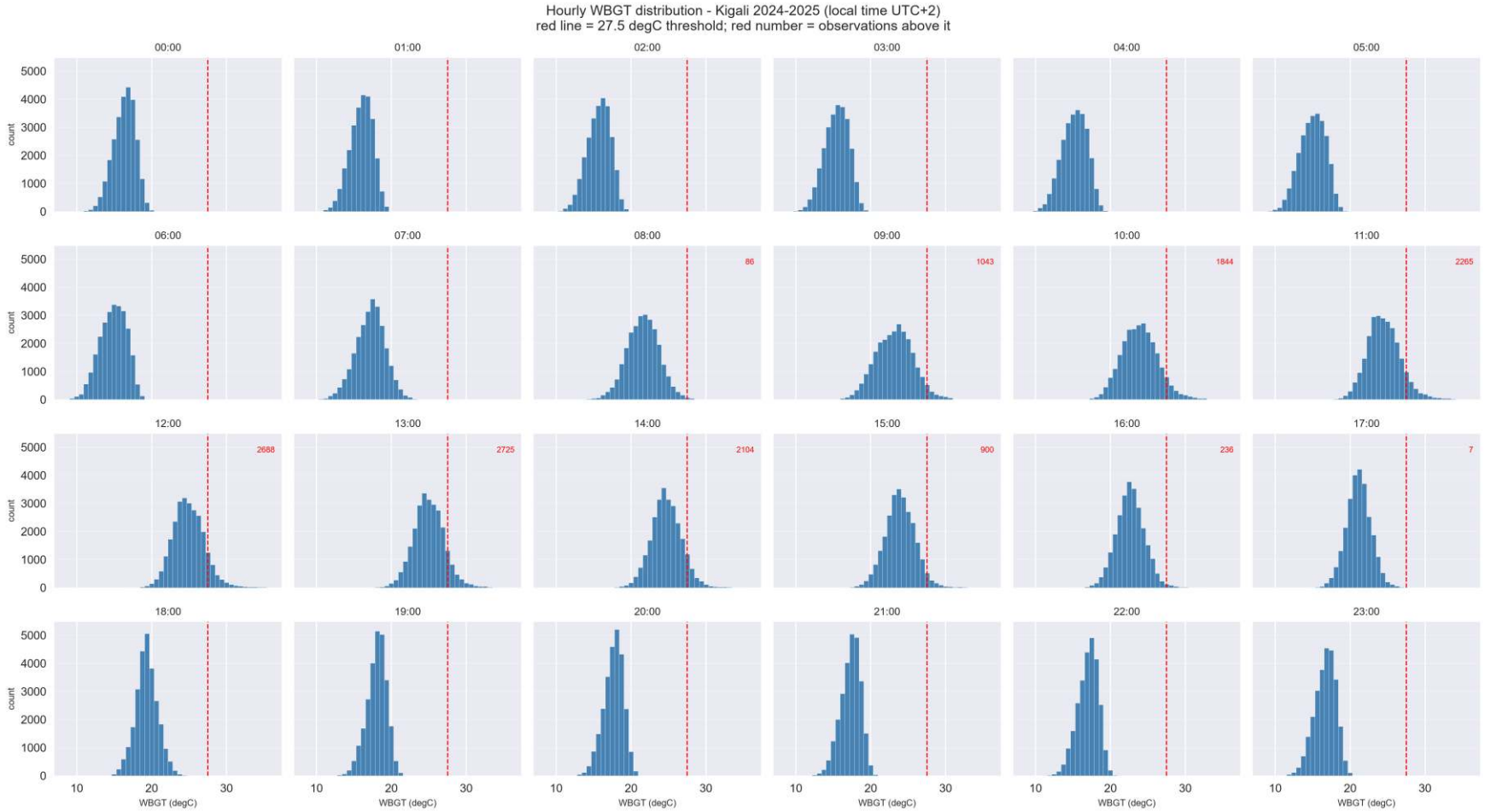
2 Heat-stress climatology

WBGT climatology of Kigali and projections to 2050 under three climate scenarios (High, Medium, High-to-Low), downscaled with deep learning

3 Adaptation

Recommendations for the construction sector: working hours by task type and WBGT thresholds (e.g. 08-17 h, 07-16 h or 06-15 h)

Exploratory analysis: hourly WBGT in Kigali, 2024–2025



How to read it

Each panel: one hour of the day.

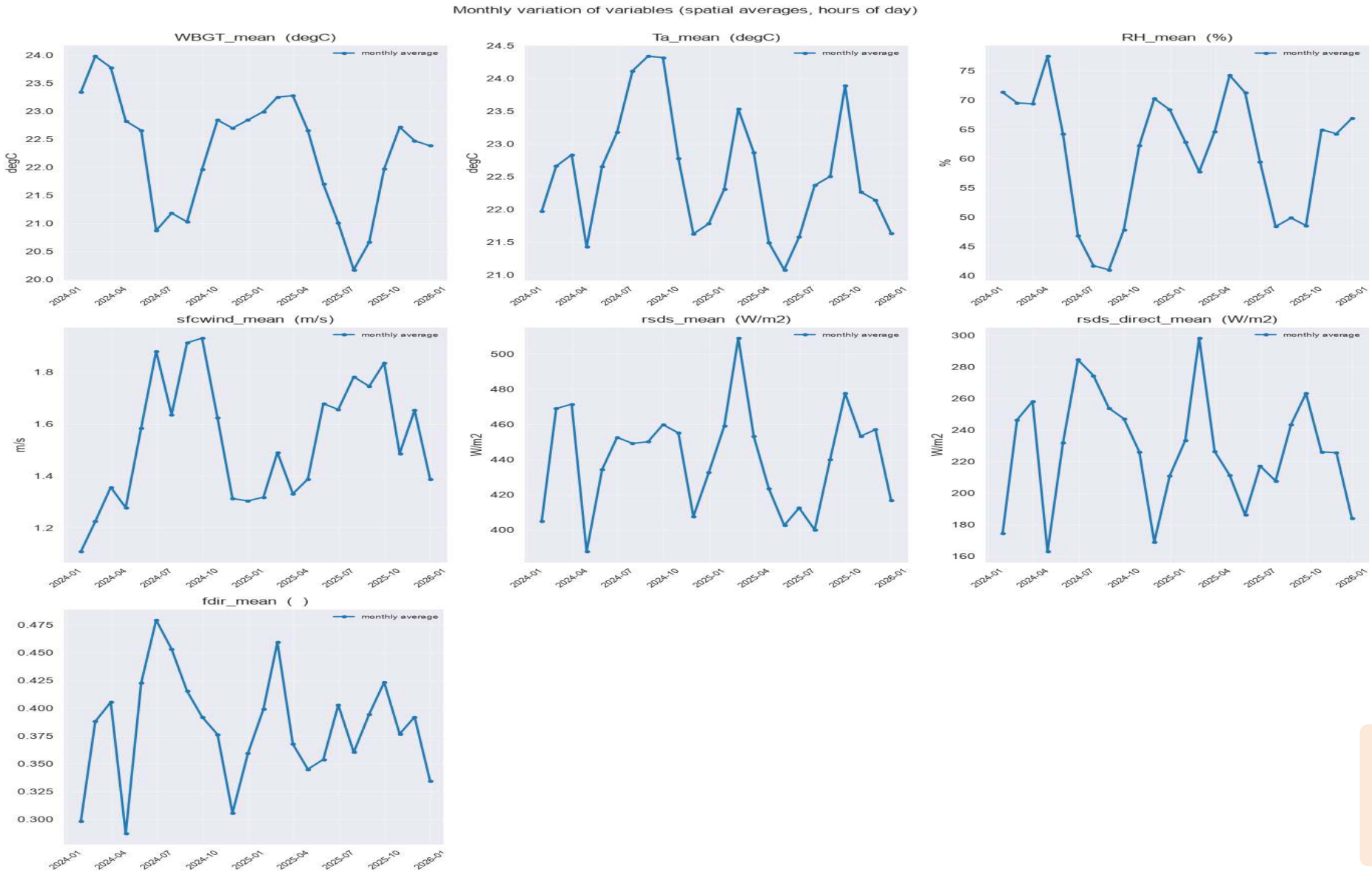
Red line: WBGT 27.5 °C (heavy work, 25% rest limit)

Red number: grid-cell hours above the line

Exploratory output, not yet validated

Data: ERA5-Land hourly, 2024–2025, 36 grid cells (Muñoz-Sabater et al., 2021). WBGT: Liljegren et al. (2008), PyWBGT (Kong & Huber, 2022). Figure: author.

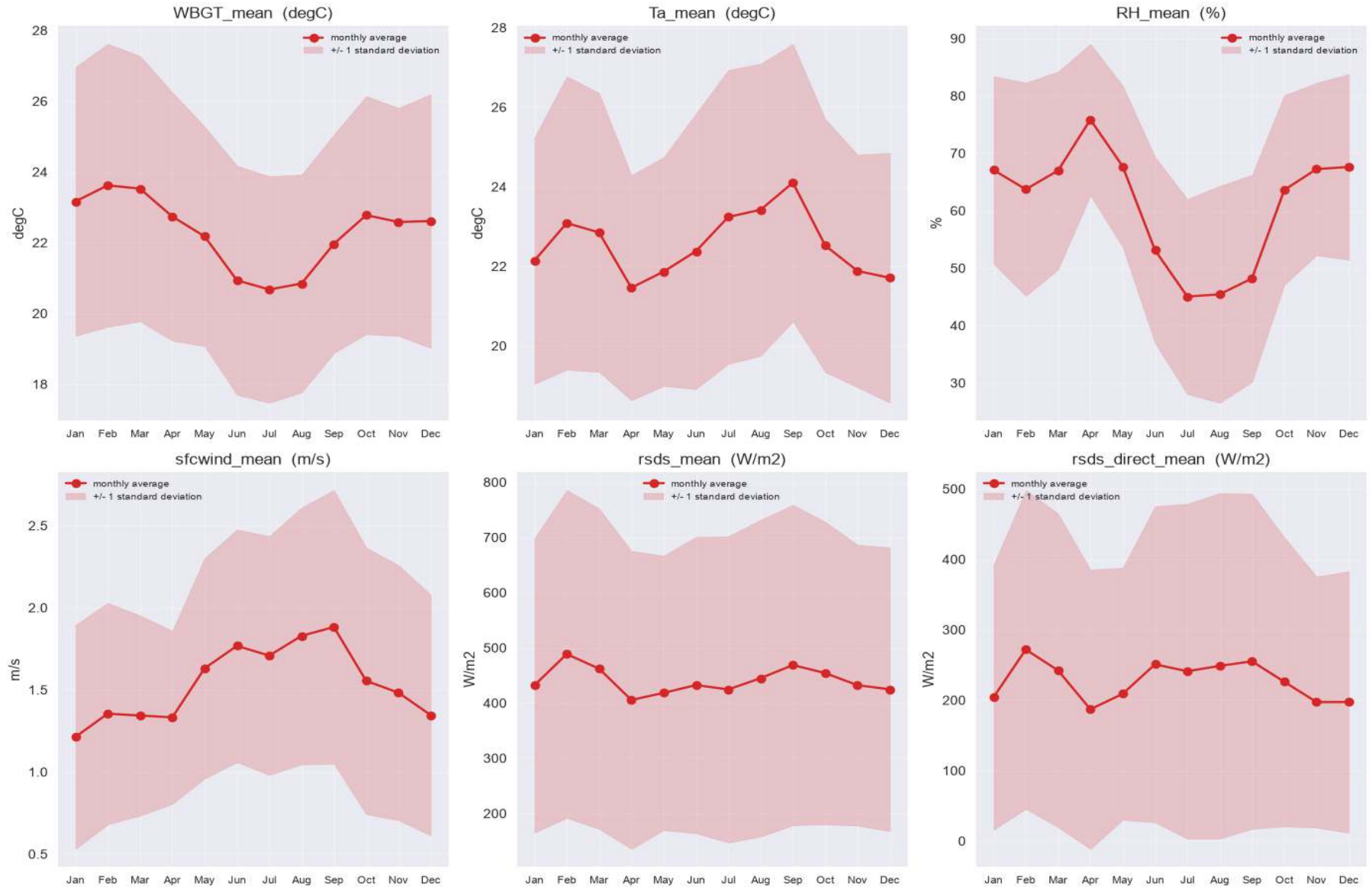
Monthly variation of WBGT and its drivers , 2024–2025



Exploratory output, not yet validated

Data: ERA5-Land hourly, 2024–2025, 36 grid cells. Figure: author. Exploratory output, not yet validated.

Seasonal cycle of WBGT and its drivers in Kigali



Monthly means over 2024–2025, spatial average

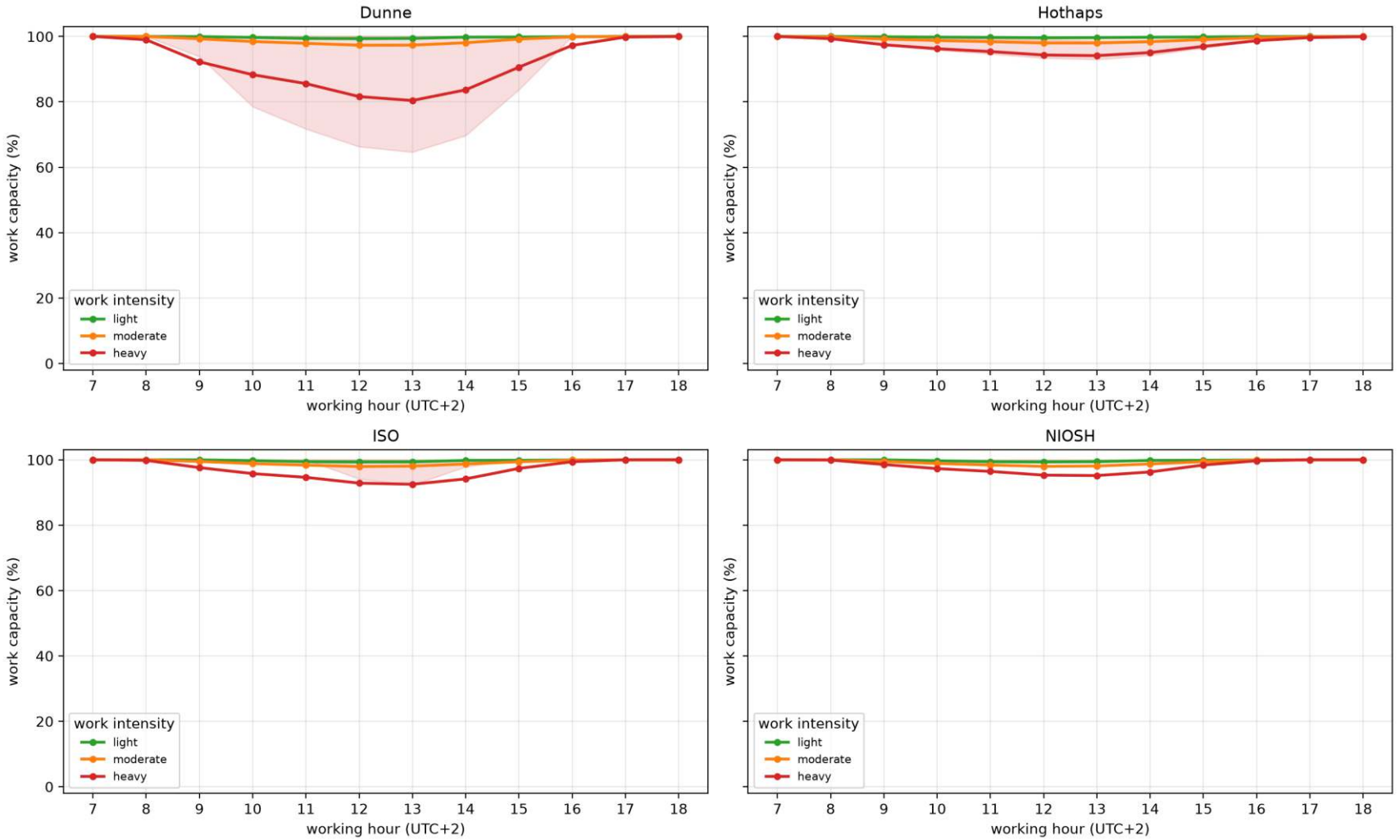
Shaded band: ±1 standard deviation

WBGT, air temperature, humidity, wind and solar radiation

Exploratory output, not yet validated

Data: ERA5-Land hourly, 2024–2025, 36 grid cells (Muñoz-Sabater et al., 2021). WBGT: Liljegren et al. (2008), PyWBGT (Kong & Huber, 2022). Figure: author.

Work capacity over the working day, by method



One panel per method; colours are work intensity

Band: interquartile range over all days

Lower capacity means more rest is needed

Exploratory output, not yet validated

Methods: Dunne et al. (2013); Hothaps (Kjellstrom et al., 2018); ISO 7243 and NIOSH after Bröde et al. (2018), computed with pythermalcomfort. Figure: author.

Take-home message

Heat is a growing risk for construction workers in Kigali. WBGT and work–rest standards can turn weather data into safe working hours, and this study will build that evidence for Kigali.

Why it matters

Heavy outdoor work in a warming climate threatens workers' health and productivity

How

WBGT (ISO 7243) linked to work–rest limits and productivity-loss functions

What it will deliver

Unsafe days, productivity loss and cost by task intensity, and working-hour options to 2050

Next steps: validate WBGT against Meteo Rwanda station data · quantify unsafe days and productivity loss by task · co-design working-hour recommendations with the construction sector

Thank you for your attention!

mkone@aimsric.org

E) HEALTH-CLIMATE NEXUS

Reforestation and Ecosystem Restoration by Native Tree Species for Climate Resilience and Water Resource Improvement in Rwanda

Olivier IRADUKUNDA
Rwanda Young Water Professionals (R-YWP)
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Introduction

Rwanda's landscapes provide essential ecosystem services that support agriculture, biodiversity, livelihoods and water security.

However, increasing climate variability, land degradation, deforestation, flooding and drought are placing growing pressure on these systems.

Nature-based solutions provide an opportunity to address these interconnected challenges by restoring degraded ecosystems while simultaneously improving environmental resilience.

Can restoration using native tree species improve ecosystem health, biodiversity, soil-water retention and water-resource resilience under changing climatic conditions?

Problem Statement

Rwanda is increasingly exposed to climate-related pressures, including intense rainfall events, flooding, prolonged dry periods and drought conditions.



AllAfrica.com



On 8 September 2020, IIED

1. Flooding
2. Drought and Water Stress
3. Biodiversity Loss
4. Soil Degradation



AL Jazeera



Top African news

Study Objectives & Questions

Specific Objectives

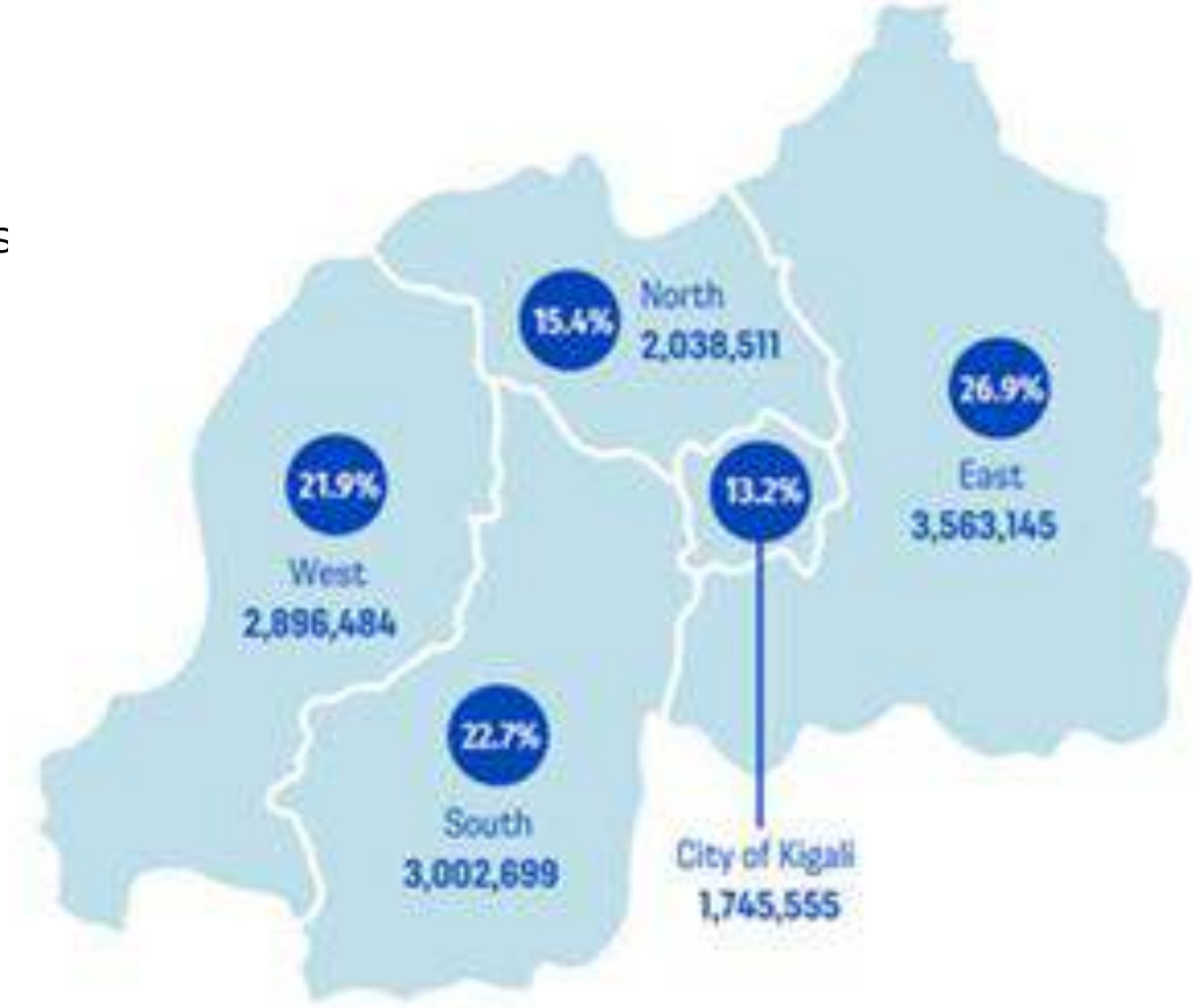
1. Objective 1: Ecosystem Restoration
2. Objective 2: Biodiversity
3. Objective 3: Soil Conservation
4. Objective 4: Water Resources
5. Objective 5: Climate Resilience

Research Questions

1. Do native tree species improve ecosystem recovery compared with degraded sites?
2. How does native-tree restoration influence soil moisture retention?
3. What relationship exists between canopy development and water-resource improvement?
4. Does native-tree restoration support greater biodiversity?
5. How can restoration outcomes inform Rwanda's climate-adaptation policies?

Study Area

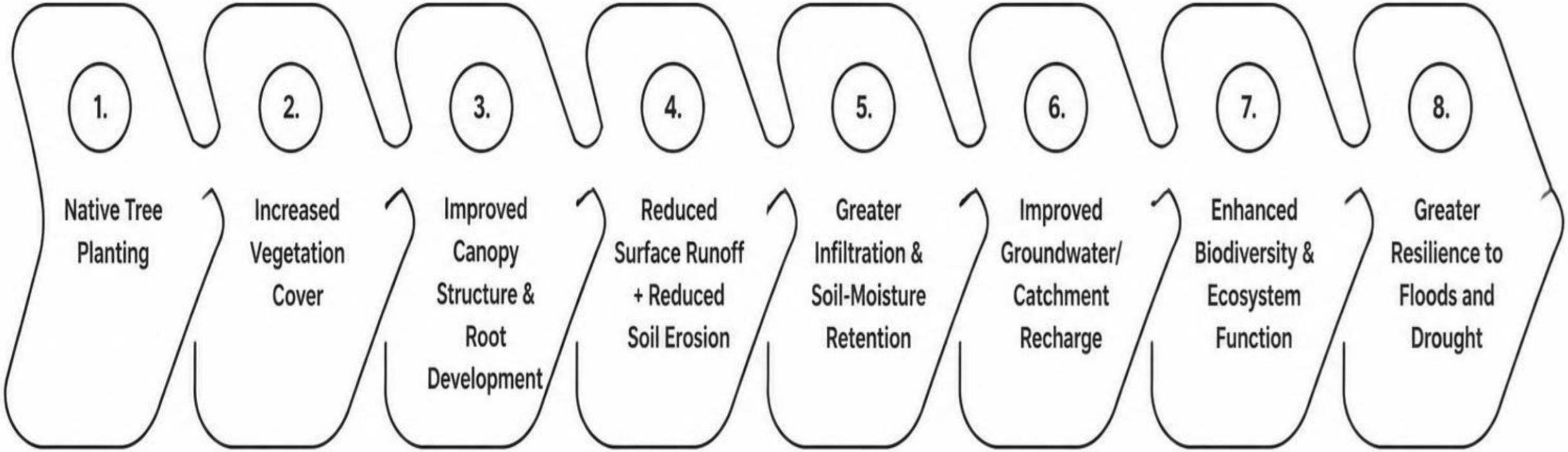
- Field sites located across Rwanda's Eastern and Western Provinces.
- Sites include both restored (native afforestation) and degraded reference locations.
- Selected to capture varied catchment conditions relevant to flood and drought exposure.



Upscale

Methods & Approach

A mixed-methods approach is used to evaluate ecosystem restoration across selected sites in the Eastern and Western Provinces of Rwanda.



Methods & Approach (Con't Down)

A mixed-methods approach is used to evaluate ecosystem restoration across selected sites in the Eastern and Western Provinces of Rwanda.

- Field Ecological Surveys
- Soil Assessment
- Remote Sensing
- Hydrological Modelling
- Data Integration







Data Collected

- Tree survival rates across restored sites.
- Canopy cover, from remote sensing imagery.
- Soil moisture retention measurements.
- Biodiversity indices, from restored and degraded sites in the Eastern and Western Provinces.

Indicator	What it Measures
Tree survival rate	Restoration establishment
Canopy cover	Vegetation recovery
Soil moisture	Water retention
Biodiversity index	Ecological recovery
Surface runoff	Catchment regulation
Soil erosion	Soil conservation
Infiltration	Water entry into soil
Groundwater recharge	Water-resource support

NDWI (Normal different water index)

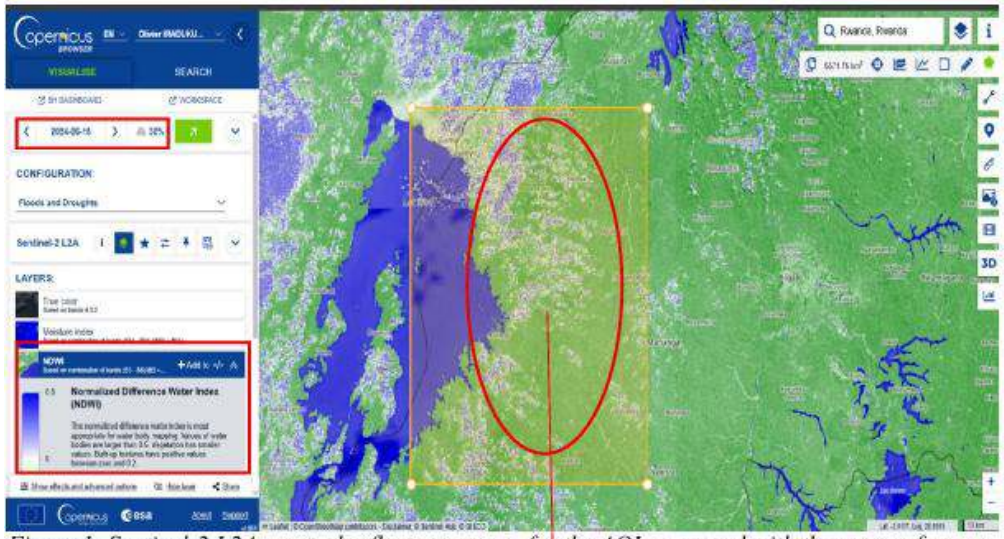


Figure 1: Sentinel-2 L2A spectral reflectance curve for the AOI compared with the same reference land-cover types - 2024 acquisition.

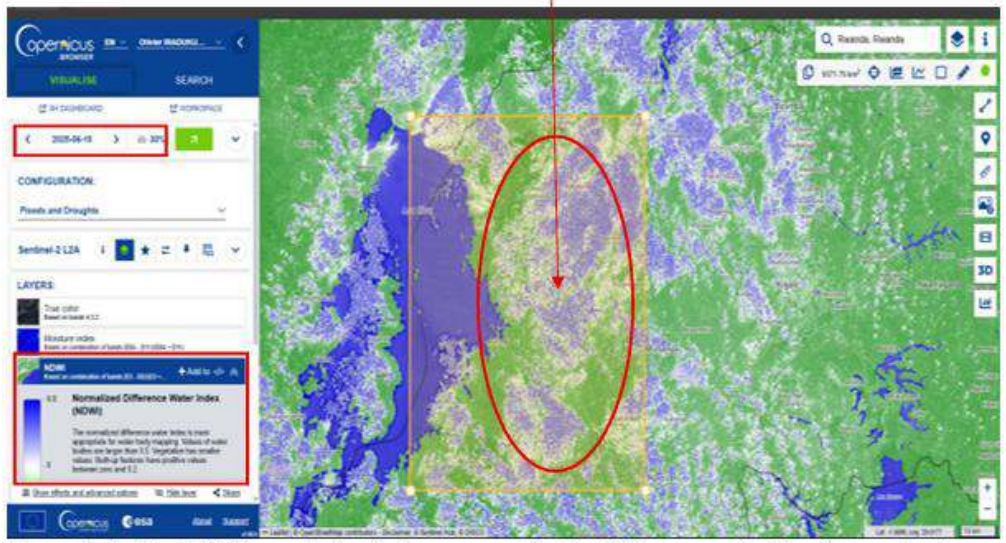
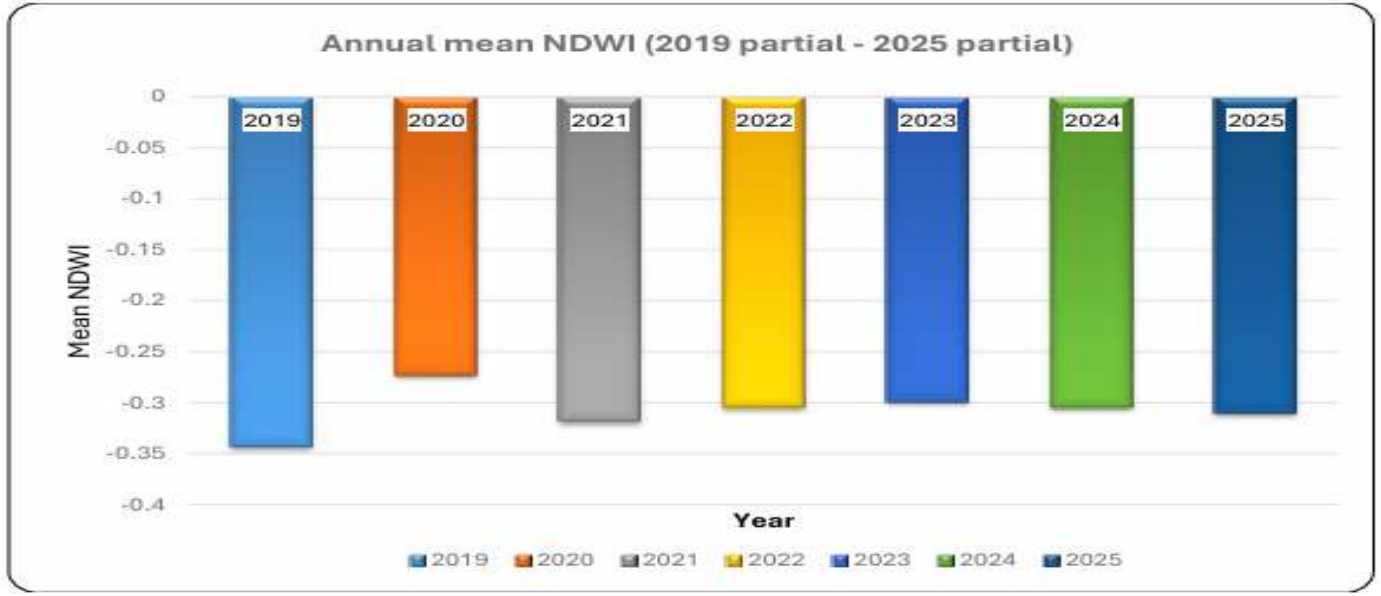


Figure 2: Sentinel-2 L2A spectral reflectance curve for the AOI compared with reference land-cover types (open water, grass, soil, concrete) - 2025 acquisition.

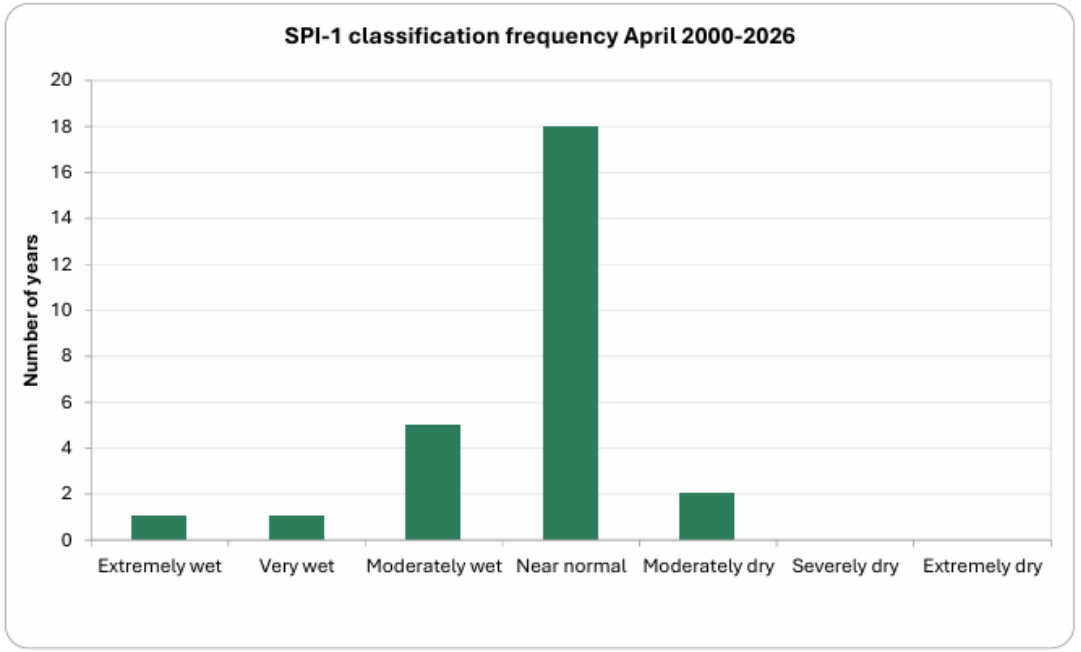


Statistic	Value
Mean NDWI (overall)	-0.3066
Minimum (scene mean)	-0.4273
Maximum (scene mean)	-0.1913
Std. deviation (scene-to-scene)	0.0572
Linear trend (NDWI/year)	0.00375
Trend R^2	0.0133
Trend p-value	0.3211
Trend significant? (p<0.05)	No
Mean cloud coverage (%)	15.8
Scenes with cloud cover > 20%	28 of 76 (37%)
Scenes with positive mean NDWI	0 of 76 (0%)

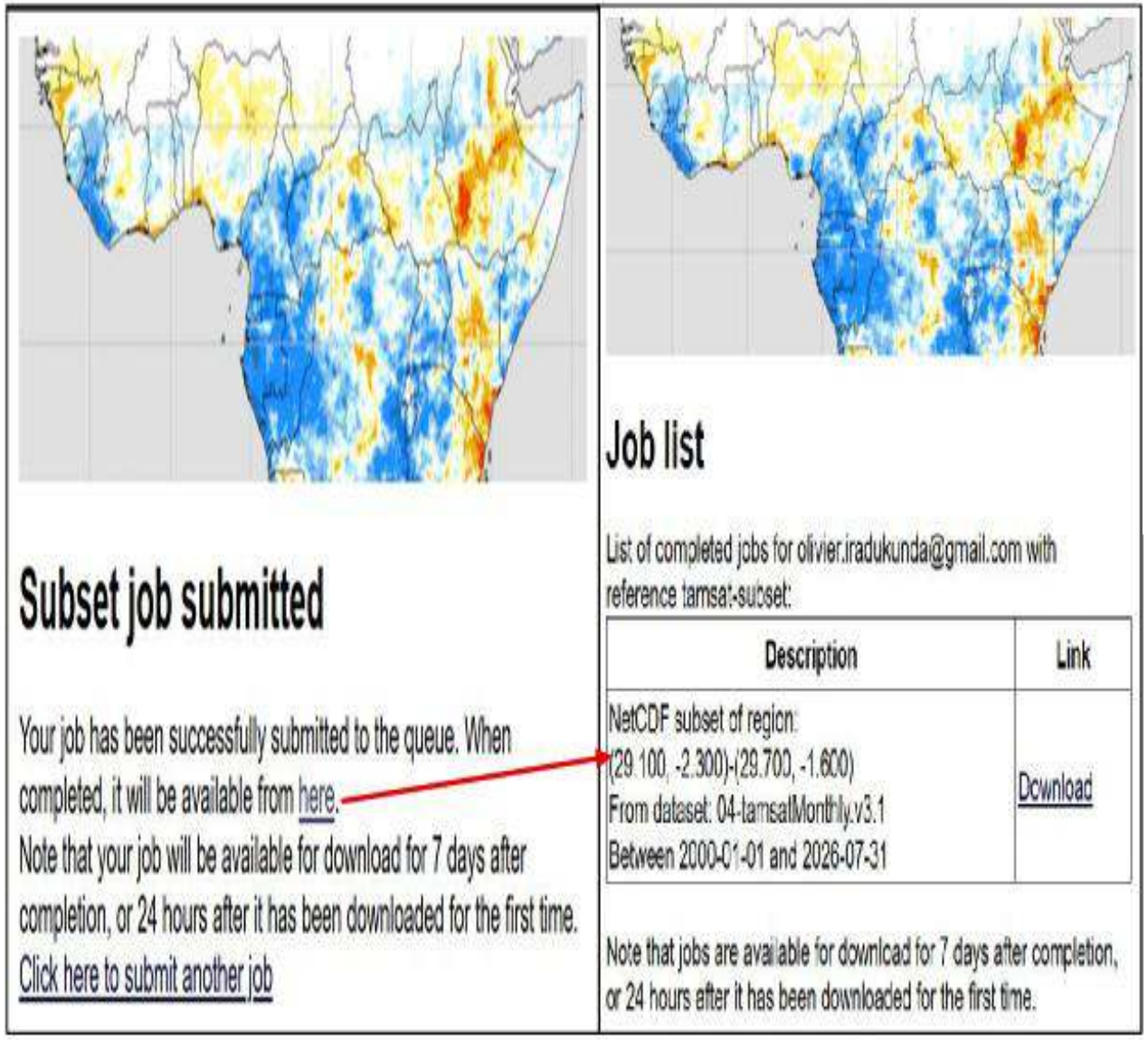
Drought assessment



Classification	SPI range	Years (Counts)	% of years
Extremely wet	>= 2.0	1	4%
Very wet	1.5 to 1.99	1	4%
Moderately wet	1.0 to 1.49	5	19%
Near normal	-0.99 to 0.99	18	67%
Moderately dry	-1.49 to -1.0	2	7%
Severely dry	-1.99 to -1.5	0	0%
Extremely dry	<= -2.0	0	0%



Seasonal Rainfall Pattern Analysis



Subset job submitted

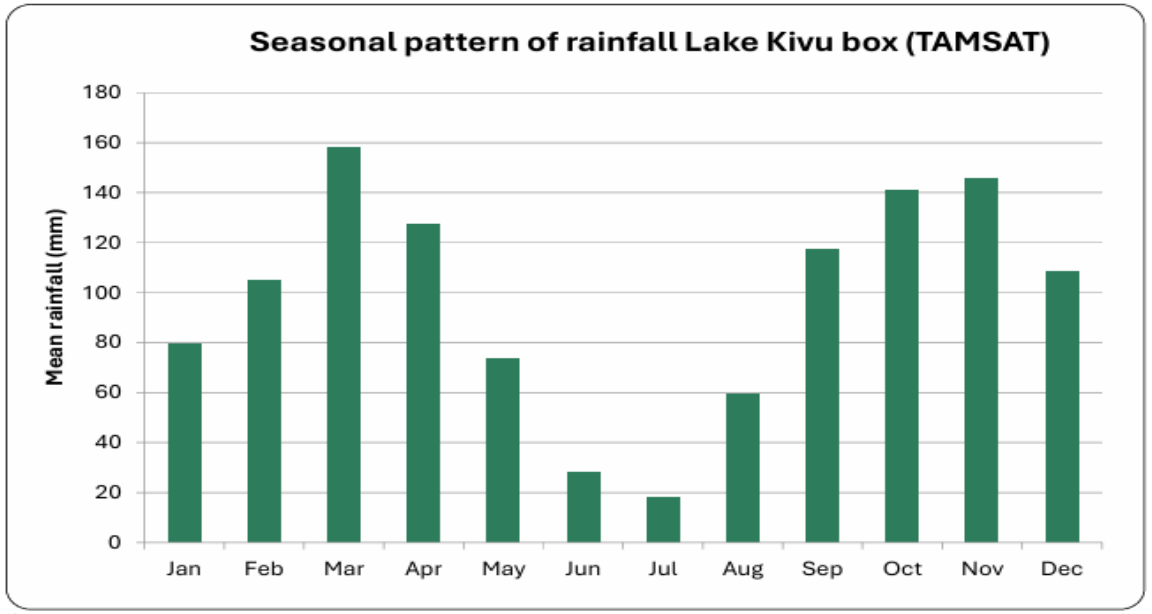
Your job has been successfully submitted to the queue. When completed, it will be available from here.
Note that your job will be available for download for 7 days after completion, or 24 hours after it has been downloaded for the first time.
Click here to submit another job

Job list

List of completed jobs for olivier.iradukunda@gmail.com with reference tamsat-subset:

Description	Link
NetCDF subset of region: (29.100, -2.300)-(29.700, -1.600) From dataset: 04-tamsatMonthly.v3.1 Between 2000-01-01 and 2026-07-31	Download

Note that jobs are available for download for 7 days after completion, or 24 hours after it has been downloaded for the first time.



Descriptive statistics (full record)	
➢ **Months (n)**	320
➢ **Mean monthly rainfall**	96.574 mm
➢ **Standard deviation**	56.019 mm
➢ **Coefficient of variation (CV%)**	58.0%
➢ **Minimum**	0.0 mm (2005-07)
➢ **Maximum**	245.173 mm (2012-03)
Linear trend (monthly series vs. time)	
➢ **Slope**	+0.06948 mm/month (+0.834 mm/year)
➢ **R-squared**	0.0132
➢ **p-value**	0.0402: statistically significant ($p < 0.05$)
➢ **Slope**	+11.42 mm/year
➢ **R-squared**	0.238
➢ **p-value**	0.0115: statistically significant ($p < 0.05$)

Preliminary / Expected Findings

Initial observations and the study hypothesis indicate that native-tree restoration may provide significant improvements in ecosystem function.

Anticipated Ecological Benefits

- Improved habitat conditions
- Increased biodiversity support
- Greater soil stability
- Reduced erosion

Anticipated Hydrological Benefits

- Increased soil-water retention
- Improved infiltration
- Reduced rapid surface runoff
- Enhanced catchment water regulation

Climate-Resilience Benefit

Restored vegetation can act as a natural buffer against climate extremes by increasing the landscape's capacity to retain water during wet periods and maintain soil moisture during dry periods.

Conclusion & Policy Relevance

Native-tree ecosystem restoration represents a promising nature-based approach for simultaneously addressing biodiversity loss, soil degradation, water insecurity and climate vulnerability in Rwanda.

The integration of field ecological surveys, remote sensing and hydrological modelling provides a framework for understanding restoration outcomes from individual sites to broader catchments.

Policy & Practice Recommendations

1. Prioritize native species
2. Restore strategically
3. Integrate restoration with water management
4. Strengthen monitoring
5. Scale successful restoration models

Thank You

Keywords: Ecosystem restoration, Native tree species, Water resource management, Climate resilience, Nature-based solutions.

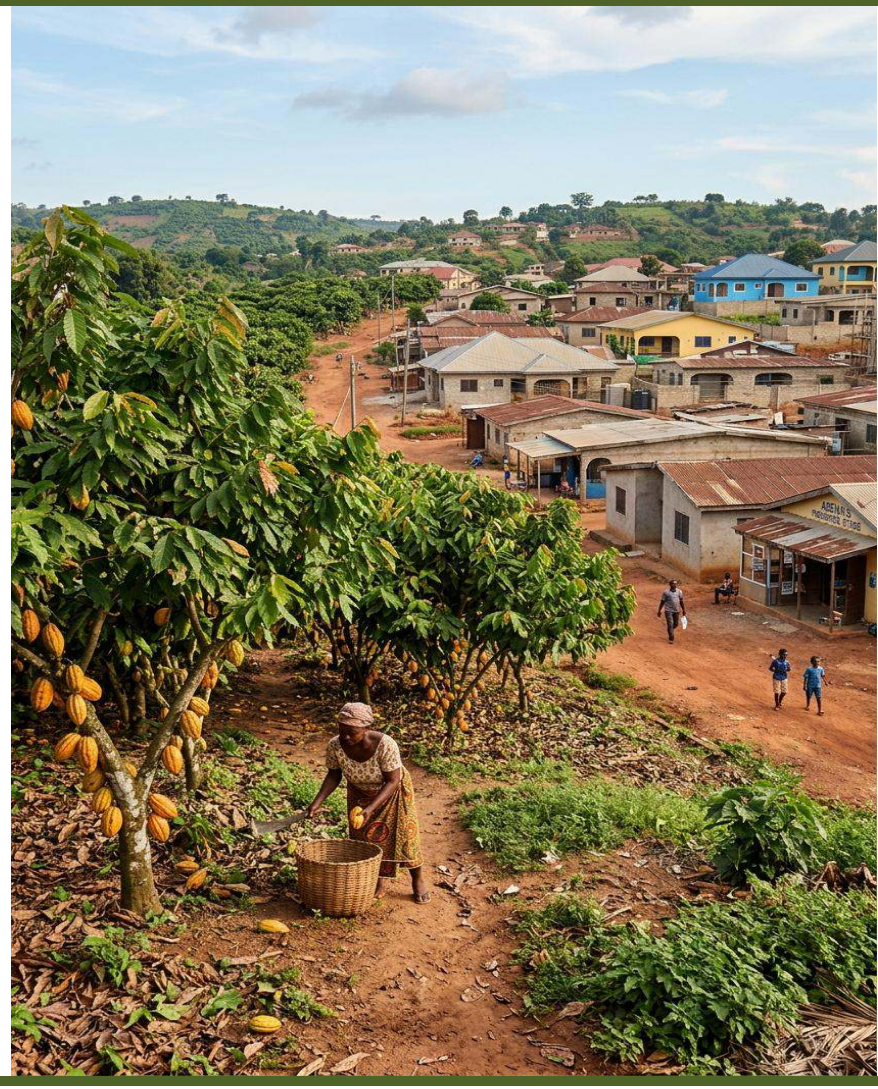
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2ND RWANDA CLIMATE SCIENCE SYMPOSIUM 2026
Where Rwanda's climate research meets policy

Molecular Characterization and Environmental Drivers of the Anopheles gambiae Complex Across Agricultural and Residential Landscapes in Ghana

(VIRTUAL)



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THE CLIMATE–HEALTH CONNECTION

Environmental change can reshape malaria transmission

- Land-use change modifies mosquito habitats
- Agricultural activity alters aquatic environments
- Residential development changes human-vector contact
- Microclimate influences mosquito biology
- Transmission risk is therefore spatially heterogeneous



PROBLEM & KNOWLEDGE GAP

The problem

Broad land-use categories may mask important local ecological differences.

Knowledge gaps

- Which *Anopheles* sibling species dominate these landscapes?
- Does land use correspond to vector composition?
- Where is *Plasmodium falciparum* infection concentrated?
- Which environmental variables predict abundance and infection?
- Can spatial information identify higher-risk locations?

AIM & OBJECTIVES

Aim

To investigate the influence of agricultural and residential land-use environments on the composition, distribution and *P. falciparum* infection status of the *Anopheles gambiae* complex.

Objectives

1. Molecularly characterize *Anopheles gambiae* complex mosquitoes.

2. Compare vector composition across land-use environments and determine *P. falciparum* infection status.

3. Assess spatial variation in vector abundance and infection.

4. Identify environmental predictors of abundance and infection.

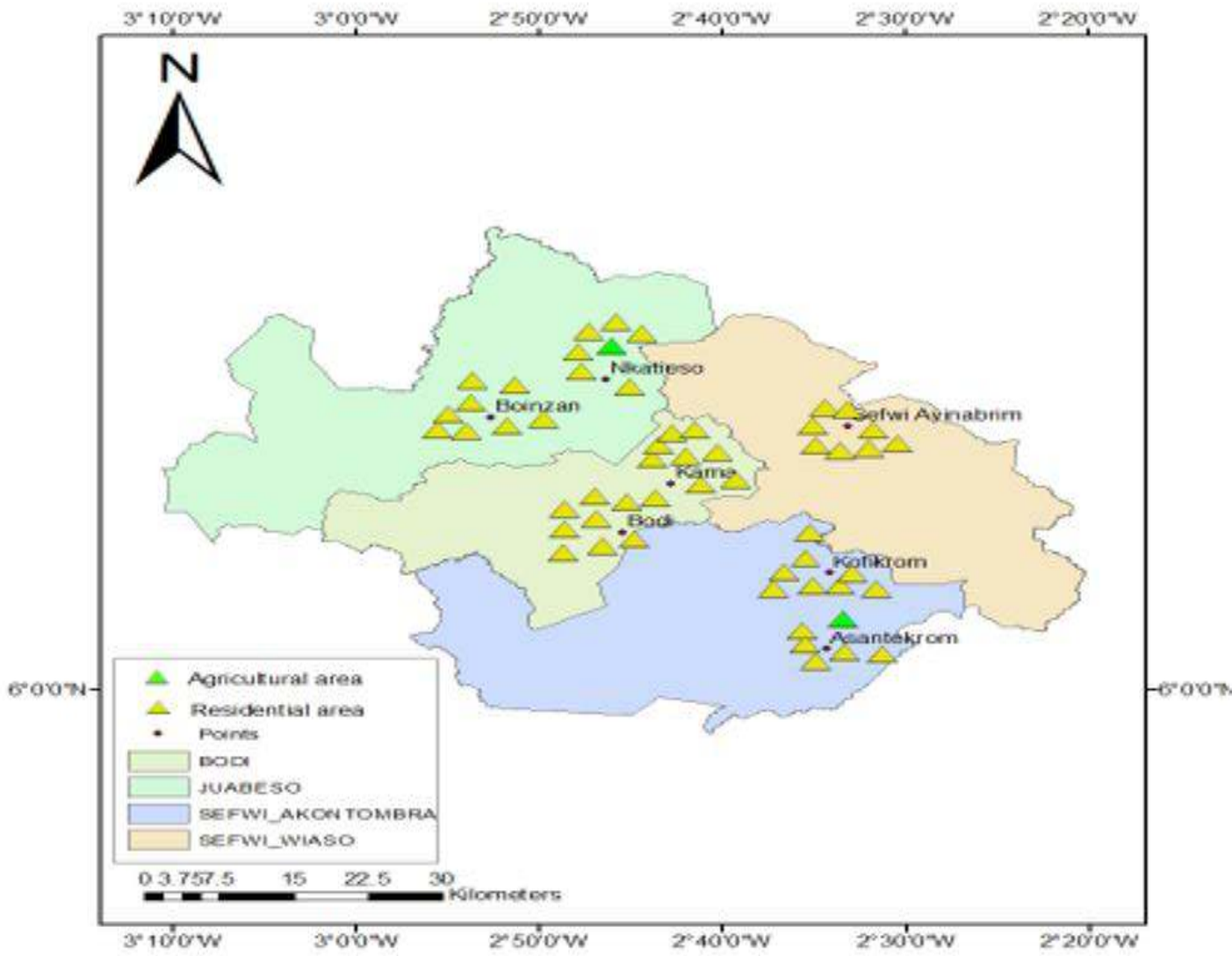
STUDY LANDSCAPE

Western North Region, Ghana

4 districts
Sefwi Wiawso
Sefwi Juaboso
Sefwi Akontombra
Bodi

7 communities
Bodi
Kama
Asantekrom
Nkatieso
Boizan
Kofikrom
Anyinabrim

Agricultural + residential landscapes



INTEGRATED METHODOLOGICAL APPROACH

Field Sampling

- 569 adult female mosquitoes collected from the field.



Molecular Characterization

- Morphological identification
- Species-specific PCR

Infection Status

- Nested PCR
- *Plasmodium falciparum* detection

Environmental & Spatial Analysis

- Integration with environmental and GIS spatial data
- Statistical modelling to determine predictors and distribution.



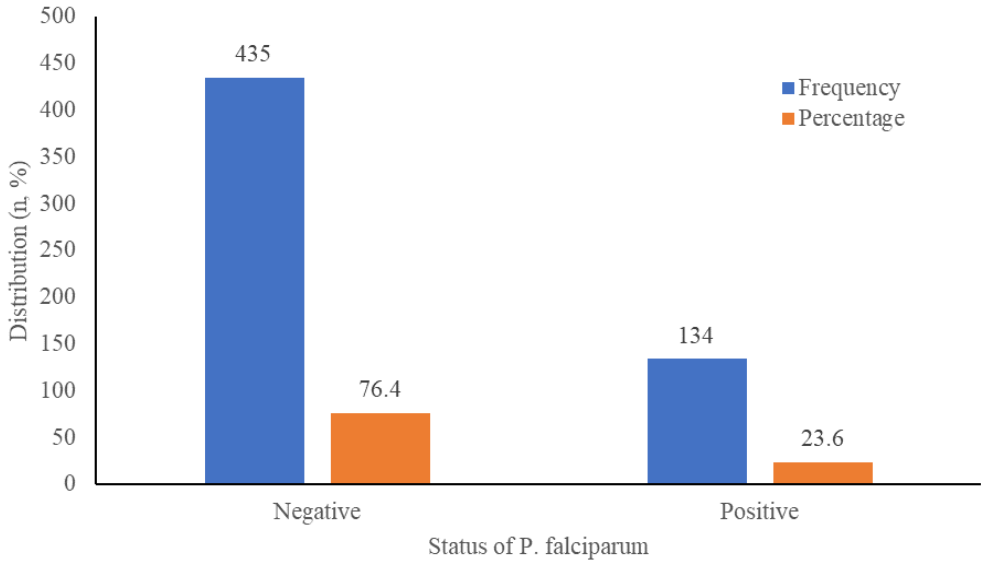


WHO WAS IN THE LANDSCAPE?

Distribution of *Anopheles* Species Across Different Landscapes

Land Use	Species of *Anopheles*		Total	Chi-square value	P-value
	An. coluzzii	*An. Gambiae*			
Residential	556 (97.7%)	7 (1.2%)	563 (98.9%)	0.0755	0.783
Agricultural	6 (1.1%)	0 (0%)	6 (1.1%)		
Total	562 (98.8%)	7 (1.2%)	569 (100%)		

PARASITE INFECTION WAS NOT UNIFORM



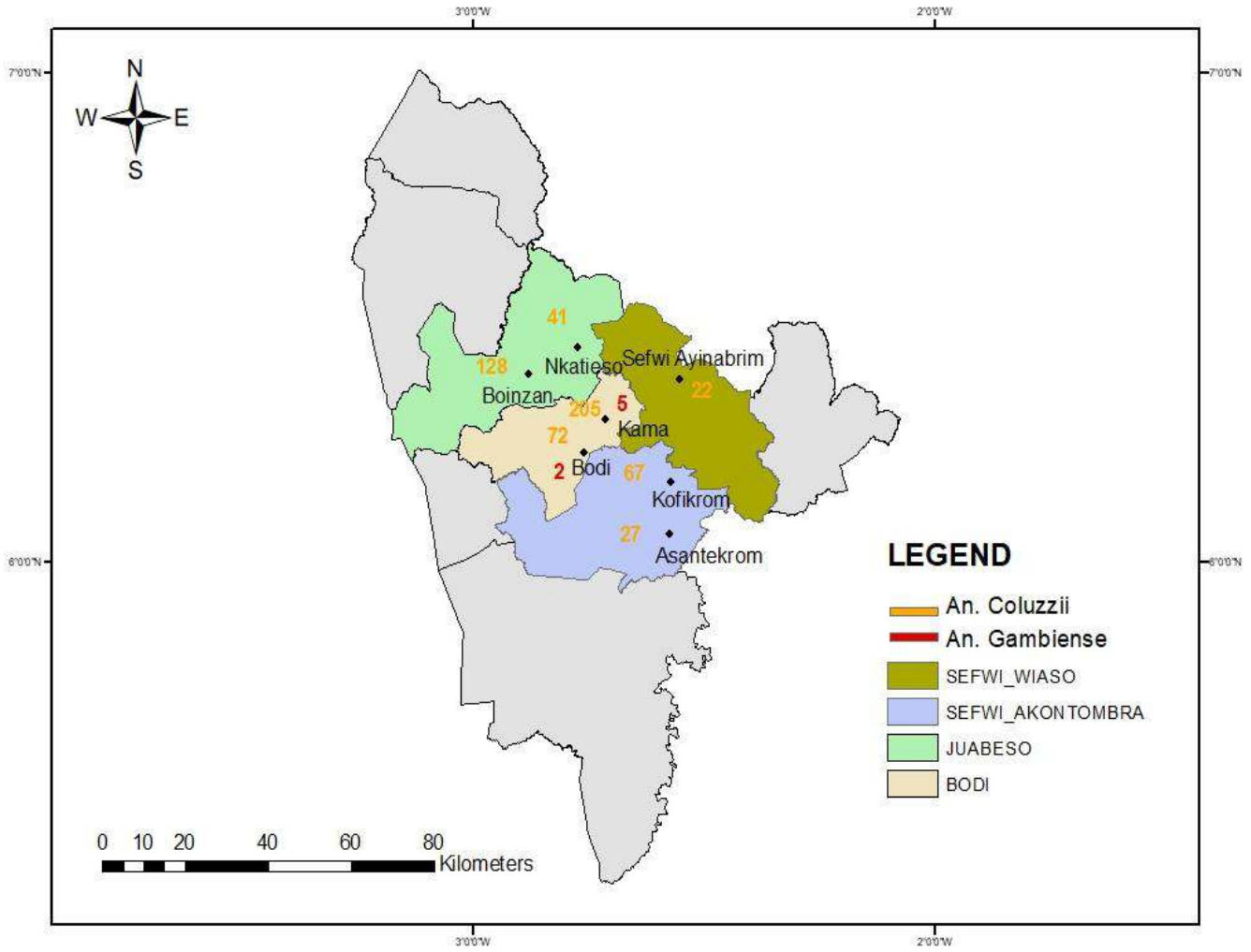
Plasmodium falciparum detection

- 134 / 569 mosquitoes positive
- 23.6% overall positivity

But:

- Land-use category → not significant
- Community → significant heterogeneity ($\chi^2 = 32.314$, $p < 0.001$)

Broad land-use categories did not adequately explain infection patterns.



SPATIAL HETEROGENEITY IN TRANSMISSION

Transmission intensity varied substantially between communities

HBR

- 9.5 → 106 bites/person/night

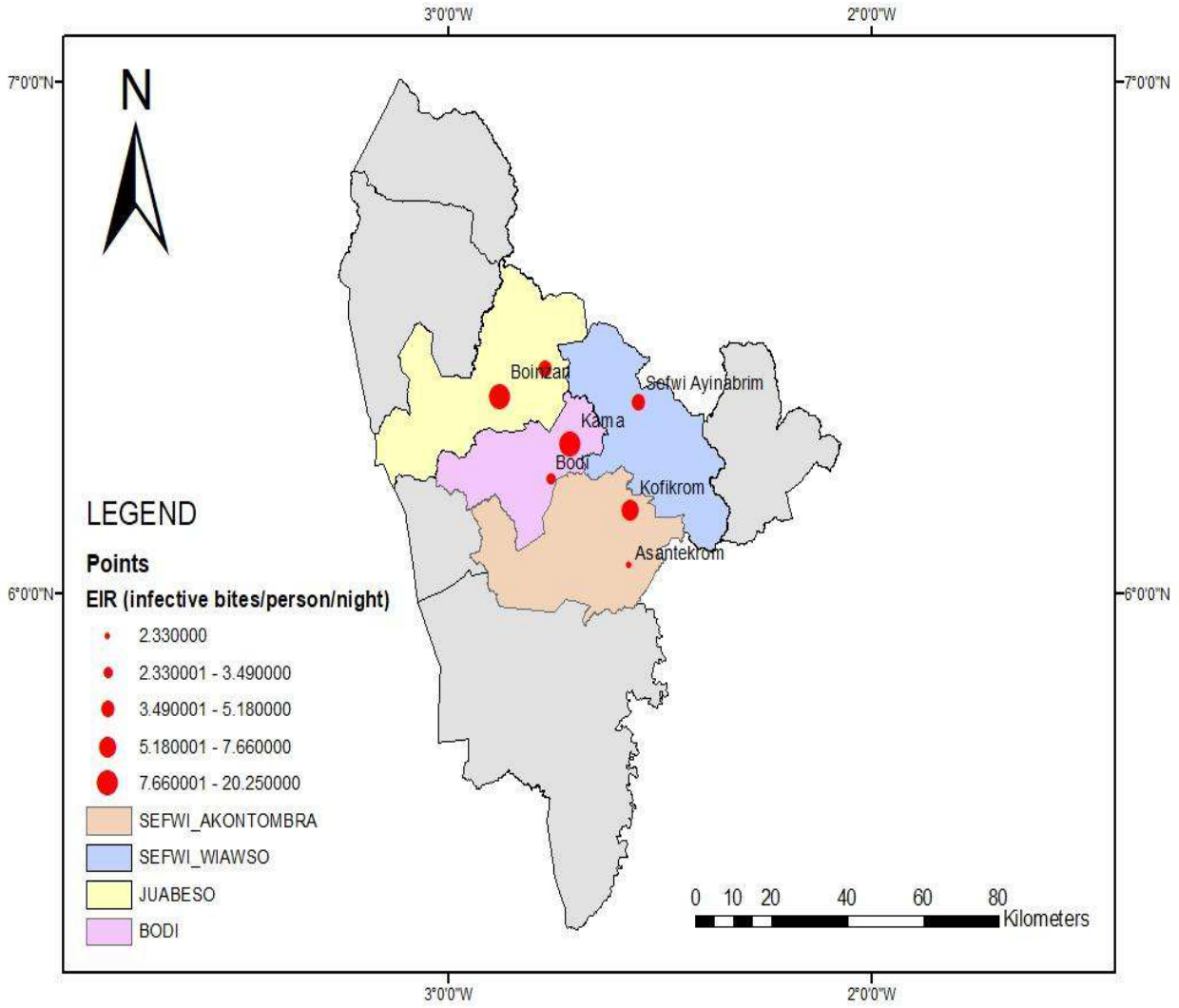
EIR

- 2.33 → 20.25 infective bites/person/night

Highest EIR

- Kama - 20.25 infective bites/person/night

The same dominant vector species can support very different local transmission intensities.



ENVIRONMENTAL DRIVERS

Different processes predicted abundance and infection

Mosquito abundance

Residential land use

- $\beta = 3.505$, $p < 0.001$

P. falciparum infection

Relative humidity

- $\beta = 0.2562$, $p < 0.001$

Interpretation

- Vector abundance ≠ infection risk

CLIMATE & ECOSYSTEM MANAGEMENT IMPLICATIONS

Environmental factor	Ecological effect	Potential risk
Landscape structure	→ Mosquito habitat	→ Vector persistence
Residential modification	→ Vector abundance	→ Increased exposure
Microclimate	→ Infection conditions	→ Transmission potential
Spatial heterogeneity	→ Localized transmission	→ Uneven risk

CONCLUSION

KEY FINDINGS

- 98.8% *Anopheles coluzzii* = Dominant vector
- 23.6% *P. falciparum* positivity
- 2.33–20.25 EIR range *marked variation in transmission*

ENVIRONMENTAL DRIVERS

Residential land use

- Vector abundance

Relative humidity

- Infection

TAKE-HOME MESSAGE

- Malaria risk is spatially and environmentally heterogeneous even within a landscape dominated by a single vector species.
- Local environmental conditions matter for identifying and targeting malaria transmission risk.