

Hybrid Mathematical Modelling and Physics-Informed AI for Climate Resilience and Digital Twin Early Warning Systems

South Eastern Kenya University (SEKU), Kenya | Proposed collaborative research and doctoral training concept



Project at a glance

We propose a research and training collaboration to develop locally useful early warning systems for floods, droughts and agricultural climate risks. The project will combine mechanistic mathematical models with physics-informed AI and continuously updated environmental observations in a digital twin. Forecasts will be accompanied by uncertainty estimates and translated into actionable risk information for local users.

The challenge

In data-scarce settings, warning systems must work with incomplete sensor records, uneven satellite coverage and changing climate conditions. Purely statistical forecasts can be difficult to extrapolate beyond observed events, while detailed physical simulations may be too slow or costly for frequent updates. This project will investigate hybrid methods that preserve relevant physical constraints while learning from available observations.

Overall aim

To design, test and demonstrate a transferable digital twin framework that improves the timeliness, reliability and interpretability of climate-risk forecasts and supports decisions before hazards cause harm.

Research objectives

- Integrate ground observations, satellite products and relevant historical records into a quality-controlled, updateable data pipeline.
- Develop hybrid forecast models linking hydrological or agroclimatic processes with physics-informed neural networks, statistical time-series models and data assimilation.
- Build digital twin components for scenario simulation, risk mapping and early warning under uncertain inputs and changing conditions.
- Evaluate forecast skill, calibration, robustness, lead time, computational cost and decision usefulness against transparent baselines.
- Co-design outputs with prospective users so warnings express expected impacts, uncertainty and practical response options.

Proposed technical approach

1. Observe	Weather, rainfall, river level/discharge, soil and crop indicators, satellite observations and local exposure data, subject to access and site selection.
2. Model	Coupled process models and physics-informed AI; conservation laws, boundary conditions and known dynamics guide learning.
3. Update	Data assimilation and probabilistic forecasting refresh the digital twin as new measurements arrive.
4. Warn	Risk thresholds and impact scenarios feed maps, alerts and a decision dashboard designed with end users.

Validation and responsible deployment

Candidate models will be evaluated through time-aware and event-based testing, with comparisons against conventional physical and statistical forecasts. Assessment will include extreme-event performance, false alarms, missed events, probability calibration and warning lead time. Pilot sites, hazard priorities and data-sharing arrangements will be agreed with partners before implementation; no operational warning service is claimed at this concept stage.

Illustrative doctoral research projects

- Physics-informed learning and data assimilation for flood forecasting in sparse-gauge catchments.
- Probabilistic digital twins for drought and agricultural risk under incomplete observations.
- Explainable hybrid models for compound climate hazards and impact-based warning thresholds.
- Decision-centred evaluation of forecast uncertainty, warning lead time and community response.

SEKU contribution and collaboration offer

SEKU proposes to contribute expertise in statistics, mathematical modelling, time-series forecasting and AI, alongside Kenyan research context and links to potential local stakeholders. Subject to consortium agreement and institutional arrangements, SEKU is ready to recruit and host a doctoral candidate as a beneficiary, take part in joint supervision, and host visiting doctoral researchers in mathematics and AI for 3–6 months. Specific facilities, field sites, data access and employment arrangements will be confirmed during consortium development.

Partners sought

We seek academic and non-academic partners in hydrology, climate science, numerical modelling, remote sensing, AI, digital twin engineering, disaster risk management, agriculture and early warning practice.

Partners can contribute complementary methods, datasets, doctoral training, pilot sites, user engagement and pathways to uptake.

Expected outputs

- Open and reproducible modelling methods, subject to data rights and partner agreements.
- Validated prototype digital twin workflows and decision-facing warning demonstrations.
- Joint doctoral training, exchanges, publications and policy or practitioner engagement.
- A consortium-ready research plan with agreed pilot sites, work packages, supervision and impact measures.

Next step for interested partners

Discuss a focused use case, the available observations and end-user needs; agree consortium roles and doctoral research topics; then develop the full methodology, implementation plan, budget and call-specific proposal together.

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