UNITED NATIONS
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Mapping Disaster Resilience: GeoAI Best Practices from the UN-SPIDER Network

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UNITED NATIONS PLATFORM FOR SPACED-BASED INFORMATION FOR DISASTER MANAGEMENT AND EMERGENCY RESPONSE

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Mapping Disaster Resilience:

GeoAI Best Practices from the UN-SPIDER Network

UNITED NATIONS
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This Compendium is the product of a collaborative effort spanning six continents and a wide spectrum of technical and institutional expertise. The United Nations Office for Outer Space Affairs (UNOOSA) and the UN-SPIDER Programme extend their deepest appreciation to the twenty-seven Regional Support Offices whose analysts and managers contributed case studies, ground-truth data, and peer review. Their on-the-ground insights—ranging from flood nowcasting in the Mekong Delta to wildfire spread modeling in the Andes—form the empirical backbone of this publication and demonstrate the practical value of GeoAI for disaster risk reduction.

We likewise thank the national space agencies, disaster-management authorities, and academic laboratories that collaborated with the RSOs during data collection and model validation.

Under the guidance of **Lorant Czaran**, Officer-in-Charge of the Space Application Section, **Hamid Mehmood** led the writing and production team. The core team consisted of **Jumpei Takami** and **Thilanka Seneviratne**. Research was provided by a multidisciplinary team of interns: **Radulf Mohika**, **Wania Khan**, and **Sokaina Batool**.

FOREWORD

Ms. Aarti Holla-Maini
Director, United Nations Office
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From the vantage point of outer space, disasters reveal themselves with stark clarity: floodwaters that swallow deltas overnight, wildfire scars that snake across mountainsides, seismic ruptures that reshape entire landscapes. Today, Geospatial Artificial Intelligence (GeoAI) allows us to translate that orbital vantage into life-saving decisions on the ground —decisions that can shorten evacuation lead-times, guide first responders through chaos, and support communities as they rebuild for a more resilient future.

The United Nations Office for Outer Space Affairs (UNOOSA), through its UN-SPIDER Programme and the worldwide network of twenty-seven Regional Support Offices, is proud to present GeoAI Solutions for Disaster Risk Reduction: A Compendium of Best Practices. This publication captures, for the first time, a global stock-take of how open satellite data, cloud computing and modern machine-learning techniques are already transforming disaster-risk governance—from cyclone now-casting in the Bay of Bengal to landslide susceptibility mapping in the Himalayas and wildfire prediction in the Mediterranean. Each case study proves a simple point: when algorithms are shared, when data are open, and when local expertise is respected, even the smallest emergency-operations centre can wield the analytic power once reserved for the world's largest space agencies.

Yet technology alone is not enough. The Sendai Framework for Disaster Risk Reduction and the 2030 Agenda for Sustainable Development remind us that resilience is ultimately a human endeavour—built on partnerships that cross borders and disciplines, on trust in science, and on policies grounded in evidence rather than hindsight. The Compendium therefore offers more than workflows and accuracy metrics; it distils lessons on data equity, ethics and capacity-building so that every Member State, particularly the least developed and the most hazard-exposed, can join the GeoAI revolution on its own terms.

We extend our deepest gratitude to the analysts, planners and innovators across six continents who contributed the insights compiled here; to the national space agencies and disaster-management authorities that opened their archives and field logs; and to the private-sector and academic partners whose open models and cloud credits lowered the barriers to entry. Their collective work demonstrates that GeoAI is no longer a boutique research topic—it is a backbone technology for the decade of action that lies ahead.

It is our hope that this Compendium will inspire new collaborations, accelerate the mainstreaming of GeoAI in early-warning systems, and help turn satellite pixels into safer lives and livelihoods for all.

-Aarti Holla-Maini
Director, United Nations Office for Outer Space Affairs (UNOOSA)

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II. EXECUTIVE SUMMARY

Geospatial Artificial Intelligence (GeoAI)—the convergence of satellite-derived data with modern machine-learning techniques—has become a decisive factor in global disaster-risk governance. In little more than five years, the active Earth-observation satellite fleet has tripled, and open-weight vision models now convert petabytes of imagery into decision-ready layers in minutes. For the **United Nations Platform for Space-based Information for Disaster Management and Emergency Response (UN-SPIDER)** and its network of twenty-seven Regional Support Offices (RSOs), this technological acceleration marks a transformation, not merely an upgrade: hazards can now be detected in near real time, their impacts forecast weeks in advance, and policy responses grounded in defensible evidence rather than retrospective estimates.

This Compendium presents the first global stock-take of GeoAI practice across the UN-SPIDER community. Between March and May 2025, every RSO completed a structured submission template describing its most advanced workflows. After peer review and validation, eighteen best-practice cases were selected that together span rapid-onset hazards such as floods, wildfires and earthquakes, as well as slow-onset stresses including drought, coastal erosion and urban heat. Across these cases, the median time required to generate an operational product fell by 65 to 85 per cent relative to pre-GeoAI methods, while pixel-level accuracy improved by 8 to 15 percentage points. Such gains are not abstract: they directly advance Sendai Framework targets on mortality and economic loss, strengthen national adaptation planning under Article 7 of the Paris Agreement, and improve reporting on **Sustainable Development Goal indicators 11.5, 13.1 and 9.5.**

The Compendium's evidence reveals both momentum and persistent gaps. On the positive side, all RSOs now operate at least one containerised deep-learning pipeline on commercial or sovereign clouds; three RSOs have already integrated GeoAI outputs into national early-warning chains, trimming evacuation lead times by up to six hours in cyclone-prone deltas. Open-weight foundation models such as Prithvi and Satlas—coupled with disaster-response cloud credits—have lowered entry barriers to the point where analysts in low-income states can match the analytic throughput of space-faring nations. Yet data inequity, compute scarcity, model drift, and unresolved ethical issues remain significant obstacles, especially for small-island and land-locked developing States where ground truth is sparse and data-sovereignty laws tight.

To close these gaps, the report recommends an integrated programme of action for the period 2025-2028. At the centre of that programme is a **GeoAI Partnership Portal** hosted on the **UN-SPIDER Knowledge Platform**: a one-stop registry of open models, pooled cloud-compute quotas and focal-point contacts that will streamline collaboration among RSOs, governments, academic laboratories and private-sector providers. Complementing the portal, UN-SPIDER will curate a library of containerised reference pipelines—flood mapping, landslide detection, drought monitoring—complete with standardised model cards and licensing metadata so that any agency can deploy proven workflows with minimal configuration. Localisation is non-negotiable: every deployment will reserve a portion of indigenous ground truth for validation, and RSOs will organise community labelling campaigns and translate critical documentation into local languages to secure contextual fit.

Looking to the horizon framed by COP 30 (Belém, November 2025), the 2030 Sendai stock-take and the **SDG Summit of 2027**, GeoAI is poised to evolve in three fundamental directions. First, ensemble learning pipelines will move the field from historical damage mapping to sub-seasonal impact forecasts, giving governments the foresight to pre-position relief goods, adjust cropping calendars and plan climate-resilient infrastructure. Second, real-time analytics will feed directly into national policy dashboards, serving climate-budget tagging and loss-and-damage accounting under Article 8 of the Paris Agreement. Third, privacy-preserving federated learning will allow models to improve across borders without raw data ever leaving sovereign clouds—a critical capability for states with strict residency laws.

The Compendium's overall conclusion is unequivocal: GeoAI now sits at the heart of UN-SPIDER's mandate to make space-based information accessible, actionable and equitable. The distributed RSO model—sovereign data held locally, shared algorithms circulated globally, federated validation applied regionally—has proven its worth in translating cutting-edge science into life-saving practice. Institutionalising the actions set out in this report will ensure that GeoAI becomes not a boutique research interest but a durable, ethically governed backbone for disaster resilience and sustainable development at precisely the moment the planet's risk landscape demands it most.

III. INTRODUCTION AND CONTEXT

Background and Rationale

The past five years have seen an unprecedented acceleration in both the volume of space-borne data and the maturity of artificial-intelligence techniques able to exploit it. As of May 2025, more than 12,000 active satellites orbit Earth—triple the number in 2020—with roughly one-third dedicated to Earth-observation missions that stream petabytes of imagery every day. This data boom has outpaced conventional analytic workflows; many national disaster-management agencies still rely on manual photo-interpretation or ad-hoc scripting that cannot keep up with multi-sensor, multi-temporal archives.

GROWTH IN SPACE ACTIVITY AND AI RESEARCH (1960-2024)

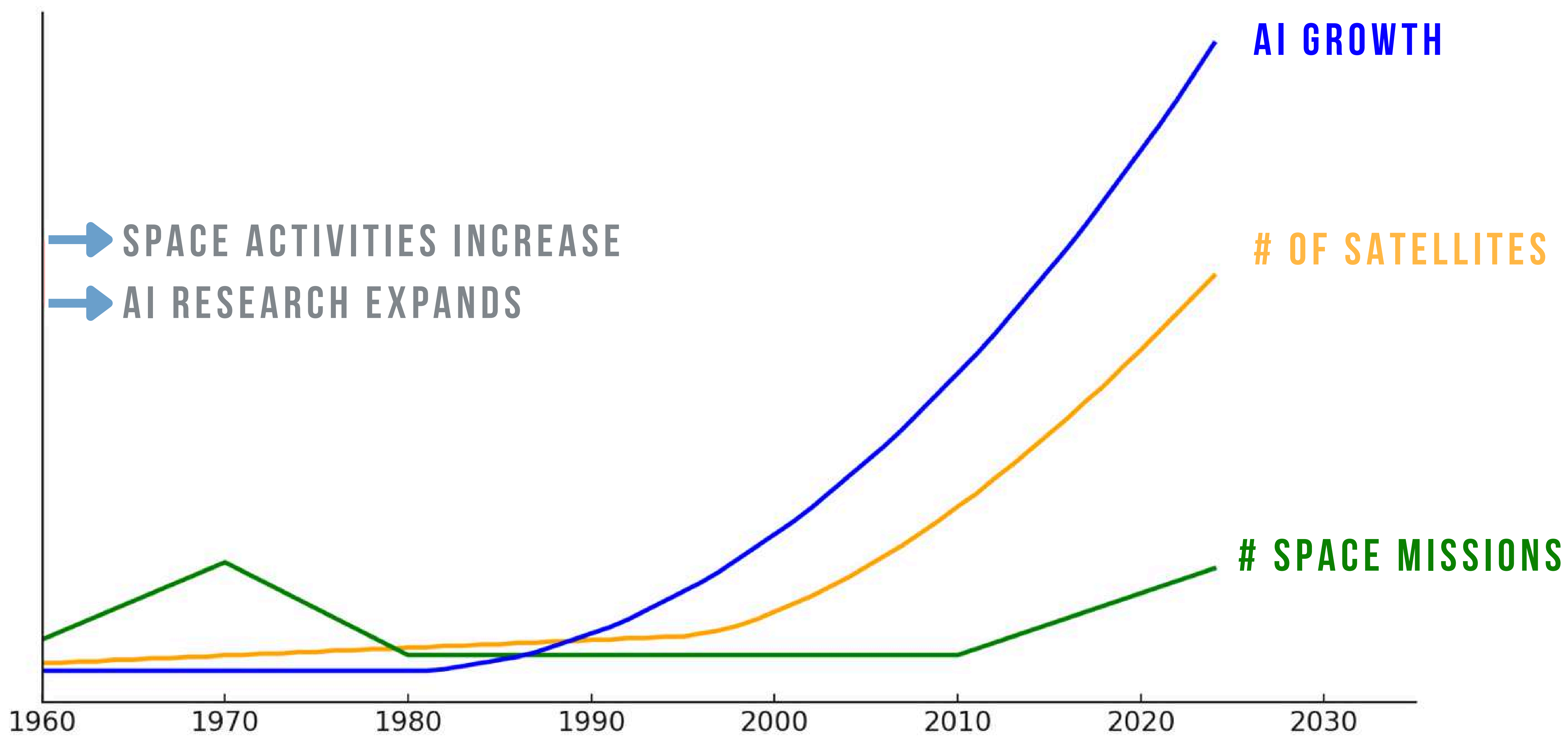


Figure: Trends in satellite launches, space missions, and AI research (1960–2024). The number of space missions peaked in the 1960s, while satellite launches and AI research have both accelerated in recent decades, reflecting the growing importance of GeoAI in analyzing space-based data.

Source:

- Stefan Hajkowicz et al., Artificial Intelligence Adoption in the Physical Sciences, Natural Sciences, Life Sciences, Social Sciences and the Arts and Humanities: A Bibliometric Analysis of Research Publications from 1960–2021, arXiv, June 15, 2023, https://doi.org/10.48550/arXiv.2306.09145.
- United Nations Office for Outer Space Affairs, Online Index of Objects Launched into Outer Space, accessed June 23, 2025.

GeoAI—AI methods purpose-built for spatial data—closes that gap. Deep convolutional networks, U-Net derivatives, and, more recently, vision transformers fine-tuned on planetary-scale corpora routinely deliver pixel-accurate land-cover maps, object detections, and change analyses in near-real time. Cloud-native platforms now allow these models to ingest terabytes of **Sentinel-1 SAR** or **Landsat-8 optical imagery** and return decision-ready layers within minutes, even over bandwidth-constrained regions. The operational payoff is evident: during the 2022 Pakistan floods, fully automated GeoAI pipelines produced **national-scale water-extent maps** and **impact metrics** within 24 hours of each major rainfall pulse—an order-of-magnitude speed-up over manual approaches and a critical input for **food-security assessments.**

This technological leap aligns with an equally urgent risk landscape. Climate-related hazards already account for roughly **three-quarters** of global disaster losses, and their frequency is projected to rise throughout the 2030s. Rapid urbanisation and infrastructure expansion in hazard-prone areas further amplify exposure. Meeting the Sendai Framework's targets, therefore, hinges on transforming raw Earth-observation data into timely, location-specific intelligence that local authorities can trust and act upon.

UN-SPIDER was created to "ensure that all countries, and in particular developing countries, have access to and develop the capacity to use all types of space-based information for disaster management." GeoAI now stands out as the most powerful—and, increasingly, the most accessible—pathway to that mandate for **three** interlocking reasons:

> **GEOAI** IS THE INTEGRATION OF ARTIFICIAL INTELLIGENCE TECHNIQUES SUCH AS MACHINE LEARNING, DEEP LEARNING, AND COMPUTER VISION WITH GEOGRAPHIC DATA AND SPATIAL ANALYSIS. IT ALLOWS FOR THE AUTOMATED DETECTION, PREDICTION, AND INTERPRETATION OF PATTERNS AND RELATIONSHIPS WITHIN GEOSPATIAL DATASETS. GEOAI ENHANCES THE SPEED, SCALE, AND ACCURACY OF SPATIAL INSIGHTS AND SUPPORTS A WIDE RANGE OF APPLICATIONS INCLUDING ENVIRONMENTAL MONITORING, URBAN PLANNING, DISASTER RESPONSE, AND CLIMATE MODELLING.

1. Scalability at Marginal Cost

Cloud-based GeoAI services leverage pay-as-you-go infrastructure, allowing a provincial emergency-operations centre to run the same flood-extent model that a G20 space agency uses, without capital expenditure on HPC (High-Performance Computing) clusters. A single Graphics Processing Unit (GPU)-hour can segment 200 km² of 10 m imagery, making nationwide analyses financially viable for low-income states.

2. Reduction of Technical Barriers

Pre-trained open models such as **Prithvi**, **Satlas** and **AWS GeoFMs** ship with documented APIs and "zero-shot" capabilities that work out-of-the-box, while low-code notebooks hide the complexity of CUDA drivers and data-format conversions. In pilot projects supported by UN-SPIDER Regional Support Offices, mid-career analysts have fine-tuned flood or landslide models after a three-day training, highlighting the approachability of **modern GeoAI stacks.**

3. Catalyst for Inclusive Innovation

Because model weights, training data, and reference workflows can be shared under permissive licences, **GeoAI** embodies the principles of **open science** and **South–South cooperation**. UN-SPIDER's role as a trusted convener positions it to broker data-sharing agreements, curate benchmark datasets, and coordinate regional hackathons that surface context-specific adaptations—e.g., mangrove-aware storm-surge modelling in the Mekong Delta or glacier-lake-outburst forecasting in Kyrgyzstan.

Integrating GeoAI across UN-SPIDER's advisory, capacity-building, and emergency-response lines of work will:

- **Accelerate early warning**
  - Model-driven now-casting can feed directly into national multi-hazard early-warning systems, shaving crucial hours off evacuation timelines.
- **Elevate evidence in policy dialogue**
  - Robust, reproducible analytics underpin funding requests to mechanisms such as the Green Climate Fund and the Loss and Damage Fund, strengthening developing countries' negotiating positions.
- **Future-proof capacity-building**
  - By training local institutions on modular, open-source GeoAI toolkits rather than platform-locked software, UN-SPIDER ensures that skills and workflows remain adaptable as technology evolves.

In short, GeoAI transforms UN-SPIDER's founding vision—**from "access to satellite data" to actionable, equitable intelligence at planetary scale**. Embedding these capabilities across technical-advisory missions, knowledge portals, and rapid-mapping services is therefore not merely an upgrade; it is a strategic necessity to help Member States navigate a decade of compounding **climate, social, and economic risks.**

Objectives and Scope

The GeoAI Compendium is conceived as a practical reference that consolidates emerging methods, case studies, and policy guidance on geospatial artificial intelligence. It enables Regional Support Offices (RSOs), national disaster-management agencies, and development partners to systematise GeoAI adoption, moving from pilot demonstrations to routine operations that directly support **disaster risk reduction (DRR)** and **sustainable-development objectives**.

Objectives

Promote knowledge exchange and peer learning

- Catalogue state-of-the-art algorithms, cloud platforms and open datasets in a format that RSOs can replicate or adapt.
- Document operational lessons—successes and challenges alike—to shorten the learning curve for new adopters.

Strengthen institutional capacity

- Provide implementation blueprints, sample code and training modules that can be embedded in UN-SPIDER technical-advisory missions.
- Offer modular teaching materials that can be localised to national languages, data policies and connectivity conditions.

Anchor GeoAI innovation in global frameworks

- **Sendai Framework**
    - Showcase approaches that improve hazard monitoring, exposure mapping and early warning, thereby contributing to Targets B and C on reducing disaster mortality and economic loss.
- **Paris Agreement**
    - Link each use case to specific SDG targets, with emphasis on SDG 11 (Sustainable Cities), SDG 13 (Climate Action) and SDG 9 (Industry, Innovation and Infrastructure).
- **2030 Agenda**
    - Highlight climate-adaptation applications—such as coastal-flood nowcasting and heat-stress analytics—that advance resilience and adaptive capacity under Article 7.

Facilitate partnership and resource mobilisation

- Provide evidence—impact indicators, cost-benefit metrics and success stories—that underpins funding proposals and south–south cooperation.
- Identify priority research gaps suitable for joint investment by governments, academia and the private sector.

The thematic scope spans the end-to-end GeoAI workflow, from data acquisition and preprocessing to model development, validation, deployment and governance. Rapid-onset hazards such as floods, earthquakes, landslides and wildfires sit alongside slow-onset stresses including drought, coastal erosion and urban heat. Case studies draw primarily from Asia–Pacific, Africa and Latin America—regions where RSOs have contributed ground truth and operational expertise—but the methods are global in applicability. The intended audience ranges from RSO analysts and space-agency engineers to disaster-management officials and academic researchers; purely commercial use-cases that remain proprietary fall outside the compendium's remit.

Each chapter combines narrative text with figures, call-out boxes and annotated code snippets rather than raw data dumps, ensuring that readers receive context, methodology and reproducible assets in a single package. Content is updated on a twelve-month cycle timed to feed new material into the annual RSO coordination meeting; major breakthroughs may be released as interim technical notes. All submissions undergo peer review by an editorial panel of RSO representatives, external experts and UN-SPIDER staff, and are published under permissive licences that respect privacy, data-protection regulations and open-science principles. By integrating technical rigour with clear policy linkages, the compendium positions GeoAI as a practical lever for measurable gains in risk reduction, climate adaptation and sustainable development.

Methodology

To ensure that the Compendium captures a balanced, evidence-based portrait of GeoAI practice across the UN-SPIDER network, content was gathered through a two-step call for contributions consisting of (**i**) a formal invitation e-mail and (**ii**) a structured submission template. The invitation—circulated to all **twenty-seven Regional Support Offices** (RSOs) on 15 March 2025—outlined the purpose of the Compendium, the visibility it would provide at upcoming fora such as AI for Good, and a firm submission deadline of 1 May 2025 RSOs were encouraged to nominate up to six projects that demonstrated diversity in thematic focus, geographic setting and GeoAI technique.

The Best-Practice Form in Annex I served as the primary data-collection instrument. It asked contributors to describe, in 200–300 words, the problem addressed, the GeoAI methods and satellite data employed, implementation partnerships, measurable outcomes and alignment with UN-SPIDER goals or specific SDG targets. Additional fields captured lessons learnt and links to publications or repositories, thereby standardising the level of technical and contextual detail across submissions. By prescribing this structure, the questionnaire reduced reporting bias and ensured that each case could be compared on a like-for-like basis.

Screening and Appraisal

All forms received by the deadline underwent a two-tier review:

1. **Completeness check** – Submissions were verified for mandatory fields (problem definition, technical approach, outcomes). Incomplete entries were returned to the originating RSO for clarification within seven days.
2. **Qualitative assessment** – An editorial panel—comprising UN-SPIDER staff, remote sensing and GIS experts—scored each practice against four criteria:

- Innovative use of GeoAI (novel models, data fusion, automation gains);
- Documented impact on disaster risk reduction or sustainable development goals;
- Replicability in data- or resource-constrained contexts;
- Contribution to local capacity-building (training components, open-source outputs).

Projects meeting at least three criteria at a "high" or "very high" level advanced to the Compendium. Where multiple entries covered similar hazards or methods, the panel selected the example with the stronger evidence base to avoid redundancy and maintain geographic balance.

Data Verification and Synthesis

For shortlisted practices, the editorial team performed light fact-checking—consulting publicly available datasets, peer-reviewed articles or partner-agency reports—to confirm quantitative claims such as accuracy scores or reductions in response time. Verified entries were then harmonised into a common narrative format that mirrors the Compendium's house style: context, methodology, results, enabling factors and policy linkage. Where appropriate, graphics and code snippets supplied by RSOs were edited for clarity and inserted as boxed elements.

Limitations

While the questionnaire approach delivered consistent, high-quality inputs, it relied on the self-reporting capacity of RSOs and therefore may under-represent emerging practices still in pilot phase or those constrained by data-sharing restrictions. The annual update cycle will provide opportunities to incorporate such projects as they mature.

By coupling a rigorous, template-driven survey with a transparent peer-review process, the Compendium ensures that only validated, policy-relevant and scalable GeoAI practices are showcased—laying a credible foundation for knowledge exchange, capacity development and future collaboration across the UN-SPIDER community.

GeoAI: Opportunities and Challenges

The rapid convergence of high-resolution Earth-observation satellites, cloud-native data infrastructures and foundation-scale AI models is opening a new strategic frontier for disaster-risk reduction (DRR) and climate resilience. For the UN-SPIDER community, GeoAI promises not only faster and more accurate hazard analytics but also fundamentally different ways of organising knowledge, partnerships and resources. Yet these gains arrive with a parallel set of technical, institutional and ethical concerns that must be managed if GeoAI is to deliver **equitable, sustainable impact.**

Opportunities

a. Speed-to-Insight

Vision transformers and **diffusion-based generative models** now ingest terabytes of multi-sensor imagery and return decision layers—flood extents, burn scars, damage masks—in minutes. This compression of the "sensor-to-action" timeline transforms emergency operations: civil-protection agencies can issue evacuation orders during the first tide cycle of a coastal storm rather than after water has already reached urban cores.

b. Global Coverage at Local Detail

Constellation growth means even small island developing States receive daily, metre-scale imagery; with cloud processing, RSOs can train a single segmentation model on regional data and deploy it simultaneously across dozens of provinces. Such scalability lets countries move from pilot demonstrations to routine, nationwide monitoring of hazards like landslides or drought-driven crop failure.

c. Multimodal Fusion

Contemporary GeoAI architectures jointly reason over optical and SAR imagery, DEMs, social-media feeds and meteorological forecasts. This fusion yields richer, more resilient outputs—for example, flood maps that integrate crowd-sourced photos to correct cloud-obscured satellite scenes, or earthquake impact layers that blend Sentinel-1 interferometry with building-stock inventories.

d. Lower Entry Barriers

Open-weight models (e.g., Prithvi for optical data, Satlas for multispectral change detection) and low-code notebooks shrink the skills gap. An analyst with basic Python proficiency can fine-tune a landslide detector in a single afternoon, using free GPU credits on public cloud sandboxes. This **democratisation** aligns squarely with UN-SPIDER's mandate to serve least-developed and disaster-prone countries.

e. Evidence for Finance and Policy

GeoAI outputs—damage tallies, exposure heatmaps, resilience indices—translate directly into quantified loss-and-damage claims, climate-adaptation proposals, or SDG indicator submissions. By standardising these analytics, RSOs can help ministries unlock concessional finance from facilities such as the **Green Climate Fund** or the **Loss and Damage Fund.**

Challenges

a. Data Inequity and Representativeness

Large models lean heavily on training sets drawn from data-rich geographies; rural Africa, small islands and mountainous interiors remain under-sampled. This imbalance can yield systematic under-detection of hazards or misclassification of land cover, perpetuating the very inequalities UN-SPIDER seeks to reduce.

b. Compute and Energy Costs

While inferencing costs are falling, pre-training or regional fine-tuning still demands **GPUs** or **TPUs** that remain scarce in many RSO host countries. Moreover, the carbon footprint of large-scale model runs can appear at odds with the climate-action narrative unless offset strategies or green-data centre partnerships are in place.

c. Model Transparency and Trust

GeoAI outputs, particularly from **deep neural networks**, are not inherently explainable. Emergency managers may resist acting on a landslide susceptibility map if they cannot trace which terrain attributes drove the model's high-risk score. Embedding interpretability layers—saliency maps, feature-importance rankings—into operational products is therefore essential.

d. Ethical and Legal Constraints

Multi-sensor fusion can inadvertently infringe on privacy (e.g., high-resolution imagery of private property) or trigger dual-use concerns. Licensing terms for commercial imagery may restrict redistribution of derivative products, complicating open-data commitments. A clear framework for consent, data-minimisation and licence compliance is needed before large-scale GeoAI deployments.

e. Maintenance and Lifecycle Management

Hazard regimes evolve—river courses shift, building stocks densify, climates warm—so model performance drifts. Without structured retraining pipelines and validation checkpoints, even a best-in-class flood model may degrade within a single monsoon season. **Sustained institutional funding** and **local talent pipelines** are therefore prerequisites, not afterthoughts.

f. Security Vulnerabilities

Adversarial attacks, model theft and data poisoning are no longer theoretical. Malicious actors could, for instance, inject fabricated SAR patches to mask illicit deforestation. RSOs need basic **AI-security hygiene** —checksum verification, input sanitisation, version control—to safeguard the integrity of operational products.

g. Constraints in Model Validation

GeoAI models—such as those used for flood, landslide, or crop mapping—depend on field data for validation and endorsement. However, in conflict-affected and hard-to-reach regions, collecting such ground truth data is often not feasible. This lack of on-the-ground verification weakens the reliability of the model results.

The sections that follow are arranged to take from who is doing the work, through what they are achieving, to how those achievements can be scaled and governed. Section IV profiles each Regional Support Office (RSO) and its partnership ecosystem, providing the institutional context behind every case study. Section V then presents the heart of the Compendium—eighteen best-practice GeoAI applications—grouped along the disaster-management cycle from risk assessment to recovery and cross-cutting services. Section VI distils the common enablers, gaps and forward-looking recommendations that emerged across those applications, while Section VII synthesizes the strategic implications for UN-SPIDER and its partners as the Sendai Framework enters its final stretch toward 2030. Finally, Section VIII contains annexes with the data-collection template, glossary and contributor directory to support replication and further research.

IV. RSO PROFILES AND PARTNERSHIPS

Regional Support Offices (RSOs) assist in implementing UN-SPIDER's mission to ensure that all countries can access and use space-based information to support disaster risk reduction and emergency response. Hosted by national or regional institutions with expertise in remote sensing, geospatial technologies, and applied research, RSOs operate across diverse geographic regions. They contribute technical expertise, local knowledge, and institutional capacity to develop and implement tools using satellite data and GeoAI for disaster risk reduction. Through targeted research and training initiatives, RSOs integrate global scientific advancements into national policies and local disaster management strategies. Their efforts support the Sendai Framework and the Sustainable Development Goals by enhancing preparedness, early warning systems, and recovery planning at national and regional levels.

Figure: UN-SPIDER Regional Support Offices Map

Figure: UN-SPIDER Regional Support Offices Meeting 2024

National Research and Innovation Agency (BRIN), Indonesia

The National Research and Innovation Agency (BRIN) serves as Indonesia's central institution for integrated research, development, application, and innovation. Mandated by President Joko Widodo, BRIN coordinates national science and technology efforts, formulates research policies and standards, manages research infrastructure, and safeguards intellectual property.

BRIN aims to strengthen Indonesia's research ecosystem by aligning with international standards, building scientific capacity, and promoting inclusive collaboration across academia, industry, and civil society. It also plays a strategic role in overseeing high-risk research activities, managing Indonesia's national science information system, and enabling the transfer and utilization of technology. BRIN focuses on a broad spectrum of research areas, including biodiversity conservation, climate change, sustainable agriculture, nuclear technology, space science, and geospatial intelligence.

Through these functions, BRIN supports the production of cutting-edge, solution-oriented research—making it a key driver of Indonesia's innovation agenda and a growing contributor to global scientific collaboration, including in the field of GeoAI.

Partnership with UNESCAP

BRIN partnered with the United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP) on a project to map and classify slum areas in Bandung City using satellite remote sensing and Geospatial Artificial Intelligence (GeoAI). UNESCAP, which supports inclusive and sustainable development across the Asia-Pacific region, collaborated with BRIN to apply a machine learning-based, local knowledge approach aligned with Sustainable Development Goal 11 (Sustainable Cities and Communities).

This initiative is part of BRIN's broader strategy to harness international partnerships and cutting-edge technology to address complex urban challenges. The project was part of the China-ESCAP Cooperation Programme (CECP) and included collaboration with local government and academic partners. BRIN developed mapping technology, provided satellite and ancillary data, and handled data processing, while UNESCAP supported training and capacity-building. Local agencies conducted observations, and regional stakeholders participated in training workshops introducing the platform.

Space Research Institute of the National Academy of Sciences of Ukraine and the State Space Agency of Ukraine (SRI NASU-SSAU)

The Space Research Institute of the National Academy of Sciences of Ukraine and the State Space Agency of Ukraine (SRI NASU-SSAU) is one of the country's leading institutions in geospatial intelligence, Earth observation, and space-based environmental monitoring. To support Ukraine's environmental security, SRI NASU-SSAU creates AI-driven geospatial systems for disaster management, climate adaptation, and land use monitoring.

SRI NASU-SSAU contributes to national and international scientific communities through new Land Cover/Land Use (LC/LU) datasets, harmonized data representations, and pilot simulations that support strategic policy, sustainability, and post-war recovery planning. Their practices improve evidence-based decision-making for recovery, adaptation, and land management by empowering stakeholders with tools for scenario-based analysis.

Partnership with the University of Geneva and Swiss National Science Foundation

The practice presented in this compendium was implemented under the Ukrainian-Swiss Joint Research Programme (USJRP), supported by the Swiss National Science Foundation (SNSF), with partners including the National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute" and the University of Geneva's Institute for Environmental Sciences. The Ukrainian institution contributes expertise in Earth observation, AI-driven analytics, and geospatial modeling, while the University of Geneva addresses urban expansion and forest expansion on cultivated lands. The collaboration co-develops a scalable architecture using satellite data, machine learning, climate indicators, and the Open Data Cube platform.

This initiative contributes to Sustainable Development Goals 13 (Climate Action), 15 (Life on Land), 11 (Sustainable Cities and Communities), 9 (Industry, Innovation and Infrastructure), and 17 (Partnerships for the Goals).

Space and Upper Atmosphere Research Commission (SUPARCO), Pakistan

The Pakistan Regional Support Office (Pak-RSO) is hosted by the Space Application Center for Response in Emergency and Disasters (SACRED) under the Pakistan Space and Upper Atmosphere Research Commission (SUPARCO). Supported by the National Disaster Risk Management Fund (NDRMF), SUPARCO applies national-scale practices to enhance urban planning, disaster risk reduction, exposure assessment, and sustainable development.

SUPARCO is mandated to conduct research and development in space science, space technology, and their peaceful applications in the country. It works towards developing indigenous capabilities in space technology and promoting space applications for socio-economic uplift of the country.

SUPARCO's GeoAI-driven practices demonstrate how Earth observation and AI can improve disaster preparedness and sustainable development outcomes across Pakistan's diverse landscapes.

Partnership with NDRMF and Other National Agencies

These initiatives were implemented by SACRED-SUPARCO under the NatCat Model Project with financial support from the NDRMF. Collaborations included national and provincial disaster management authorities (NDMA/PDMA), and the Forest Department in Northern Pakistan for forest species mapping. SUPARCO is also supporting NDMA and PDMA with tools to assess landslide susceptibility and improve planning for rescue and relief efforts during forest fires. It has contributed land use and crop data for exposure assessment and supported urban risk assessments in five major cities. By enhancing exposure datasets for early warning systems, these practices contribute to the Early Warnings for All (EW4All) initiative, as well as Priority 1: Understanding Risk and Priority 4: Build Back Better of the Sendai Framework for Disaster Risk Reduction.

SUPARCO's work also contributes to SDGs 2 (Zero Hunger), 9 (Industry, Innovation and Infrastructure), 11 (Sustainable Cities and Communities), 13 (Climate Action), 15 (Life on Land), and 17 (Partnerships for the Goals).

Asian Institute of Technology (AIT), Thailand

The Asian Institute of Technology (AIT) is a regional leader in graduate education and research, established in 1959 to promote sustainable development and technological innovation in Asia. Located in Thailand, AIT offers interdisciplinary programs and engages in advanced research across fields such as engineering, environment, and management. Its mission is to develop highly qualified professionals who can contribute to solving the region's most pressing challenges in disaster risk reduction, climate resilience, and sustainable development.

AIT is also home to the Geoinformatics Center (GIC), which plays a key role in applying geospatial technologies and Earth observation data to real-world problems. Through its initiatives in remote sensing, geographic information systems (GIS), and now Geospatial Artificial Intelligence (GeoAI), AIT continues to support regional and international efforts to strengthen disaster preparedness and evidence-based planning.

GeoAI Partnership: Transparent AI for Landslide Risk in Nepal

In partnership with the **University of Twente**, AIT developed a deep learning model to assess landslide susceptibility in Nepal after the 2015 Gorkha earthquake. AIT processed the data and built the online platform as part of an academic initiative, using open data and freely available tools. The results were made publicly accessible through a user-friendly Web-GIS platform using ESRI's ArcGIS Online. The project was developed in collaboration with various stakeholders and practitioners and received research and institutional support. It also engaged end users by providing tools and visualizations that support real-world decision-making. This tool has already been adopted in capacity-building workshops in Nepal and is informing updates to local hazard zoning practices.

AIT's work contributes to the achievement of Sustainable Development Goal 11 (Sustainable Cities and Communities) and SDG 13 (Climate Action). It highlights how academic research can be translated into practical tools that support disaster preparedness and sustainable development in vulnerable regions.

International Water Management Institute (IWMI), Sri Lanka

The International Water Management Institute (IWMI), a CGIAR Research Center, is a global leader in water management, sustainable agriculture, climate resilience, and disaster risk reduction. IWMI is headquartered in Colombo, Sri Lanka, with regional offices across Asia and Africa. IWMI works in partnership with governments, civil society and the private sector to develop scalable agricultural water management solutions that have a real impact on poverty reduction, food security, and ecosystem health.

The institute actively works to apply knowledge by collaborating with other research centers, policymakers, donors, partners, and communities to increase its impact. IWMI's scientists come from diverse fields, including water management, hydrology, economics, engineering, irrigation, GIS and remote sensing, software development, information management, communications, monitoring and evaluation, and uptake coordination.

IWMI develops AI-powered tools that integrate Earth observation, geospatial analysis, and stakeholder engagement to enhance early warning, anticipatory action, and climate adaptation in vulnerable regions.

Partnerships with National and Humanitarian Institutions

IWMI's GeoAI initiatives are implemented in collaboration with India's India Meteorological Department, National Disaster Management Authority, Indian Council of Agricultural Research, and Central Research Institute for Dryland Agriculture, as well as Sri Lanka's Disaster Management Centre and Department of Meteorology. Supported by CGIAR's Climate Resilience initiative, the projects emphasize co-design with local stakeholders, including Krishi Vigyan Kendras and disaster management cells for use-alignment and tools validation. Humanitarian partners such as World Vision are engaged in deployment, training, and operational trials.

These efforts contribute to Sustainable Development Goals 2 (Zero Hunger), 9 (Industry, Innovation and Infrastructure), 11 (Sustainable Cities and Communities), 13 (Climate Action), and 17 (Partnerships for the Goals). IWMI's GeoAI platforms bridge last-mile delivery gaps, enhance early action, and strengthen climate-resilient planning at local and national levels.

University of Central Lancashire (UC Lan), United Kingdom

The University of Central Lancashire (UC Lan) focuses on advancing disaster risk reduction and climate resilience through geospatial technologies and AI. With a strong emphasis on international collaboration, UC Lan brings together researchers, students, and institutions to co-develop innovative solutions that address global environmental challenges. Their work includes applications in mangrove conservation, hydro-disaster management, and sustainable agriculture.

UC LAN combines expertise in space-based technologies and disaster risk management, with a focus on applying Earth observation, remote sensing, and geospatial tools to support disaster preparedness, response, and recovery. The Centre works on developing practical solutions that integrate satellite data, mapping, and spatial analysis to monitor hazards, assess risks, and inform decision-making.

GeoAI Partnership 1: Research and Knowledge Exchange for Global Resilience

The UC Lan has facilitated a series of international exchanges and joint research efforts involving partners from Mauritius, Brazil, Ireland, and India. These collaborations focus on improving disaster risk reduction through the use of satellite data, AI, and geospatial tools. Visiting researchers and students have worked on a diverse range of topics including mangrove ecosystems, hydro-territorial disasters, and community resilience.

By hosting researchers from multiple countries and fostering interdisciplinary dialogue, the UC Lan has enabled new insights into climate and disaster challenges while strengthening the global research network. These efforts have led to peer-reviewed publications on mangrove mapping, resilience strategies, and disaster management, advancing both scientific understanding and policy relevance.

GeoAI Partnership 2: AI-Powered Soil Temperature Prediction in Uzbekistan

In response to the challenges of climate change and limited ground-based data in arid regions, UC Lan led a collaborative project to predict soil temperature in Nukus, Uzbekistan. This work, conducted in collaboration with partners from Sri Lanka, Japan, Russia, and Uzbekistan, offers a scalable solution for agricultural planning and biodiversity conservation. The findings were published in Nature Scientific Reports and support broader sustainability goals in food security and climate resilience.

ERATOSTHENES Centre of Excellence (ECoE), Cyprus

The ERATOSTHENES Centre of Excellence (ECoE) is a research centre operating as a Digital Innovation Hub for Earth Observation, Space technology, and geospatial information for multi-hazard risk assessment and climate resilience. ECoE is a member of various international networks, such as Copernicus Academy, ISPRS, GEO, MedRIN (NASA), ACTRIS/EARLINET, EARSeL, NEREUS, etc., and aspires to serve as a reference point in the Eastern Mediterranean, the Middle East, and North Africa region.

The ECoE integrates remote sensing, data management and processing technologies, applied research, educational services, and entrepreneurship support. Its operations are underpinned by two critical infrastructures: an Earth Observation Satellite Data Acquisition Station (DAS) and a Ground-Based atmospheric remote sensing Station (GBS). The Centre uses satellite data from Copernicus, Unmanned Aeriel Vehicles (UAV)-derived data, and national-scale datasets to support environmental monitoring and decision-making. Finally, ECoE has developed and operates the Cyprus Earth Observation Data Cube (https://cyprusdatacube.com/) that manages various datasets from ESA (Sentinel-1, Sentinel-2) and NASA (MODIS) missions.

The activities of the Disaster Risk Reduction Cluster of the ERATOSTHENES CoE, include the systematic monitoring of hazards, the development of Early Warning and Decision Support Systems dealing with earthquakes, landslides, coastal/soil erosion, forest fires, floods, drought and epidemics.

Partnerships with National Authorities and Research Organizations/Academia

ERATOSTHENES CoE coordinates and participates in numerous disaster risk reduction related H2020/Horizon Europe (EXCELIOR, AI-OBSERVER, etc.) and ESA-funded projects (STEPS), as well as capacity building activities, utilizing a significant network of stakeholders from the quadruple helix (Government, Academia/research, Industry, and Civil society). The list of national authorities includes the Cyprus Geological Survey Department, the Department of Lands and Surveys, the Department of Meteorology, Civil Defence, the Department of Forests, the Department of Public Works, the Water Development Department, etc. as well as many Municipalities and District offices. International partners include the German Aerospace Center (DLR), the National Observatory of Athens, the University of Rome Tor Vergata, the Cyprus University of Technology, the Aristotle University of Thessaloniki, the University of Sheffield, etc.

These initiatives contribute to SDG 3 (Good Health and Well-being), SDG 6 (Clean Water and Sanitation), SDG 9 (Industry, Innovation and Infrastructure), SDG 11 (Sustainable Cities and Communities), SDG 13 (Climate Action), SDG 14 (Life Below Water), SDG 15 (Life on Land), and SDG 17 (Partnerships for the Goals).

German Aerospace Center (DLR), University of Bonn (ZFL), Germany

The German Aerospace Center (DLR), in collaboration with the Center for Remote Sensing of Land Surfaces (Zentrum für Fernerkundung der Landoberfläche - ZFL), an interdisciplinary research center of the University of Bonn, leads pioneering research in Earth observation and GeoAI applications to support disaster risk reduction and urban resilience. To advance disaster mitigation and management, DLR developed a deep learning-based approach for large-area building exposure modeling.

The German Space Agency is the national hub for Germany's space activities, embedded within DLR. It coordinates the country's contributions to international space missions, including collaborations with ESA (European Space Agency) and the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) while driving innovation in satellite technology, Earth observation, and space exploration.

The Center for Remote Sensing of Land Surfaces (ZFL) is an interdisciplinary center of the University of Bonn dedicated to research and teaching in the fields of remote sensing, geoinformation sciences and spatial modelling. In a complementary fashion to their academic activities, ZFL staff offer advice concerning general remote sensing questions and assist in solving complex problems.

Partnership with the Pontificia Universidad Católica de Chile and the German Federal Ministry of Education and Research

Implemented under the RIESGOS 2.0 project and funded by the German Federal Ministry of Education and Research (BMBF), this initiative is a collaboration between DLR and the Research Center for Integrated Disaster Risk Management (CIGIDEN) at the Pontificia Universidad Católica de Chile (UC Chile). Scientists from CIGIDEN helped define classification schemes based on the locally built environment. This practice contributes to both climate and non-climate related disaster mitigation and management and demonstrates the potential of multimodal GeoAI to strengthen disaster preparedness and reduce vulnerabilities.

DLR contributes to Sustainable Development Goals 11 (Sustainable Cities and Communities) and 13 (Climate Action).

Wuhan University (WHU), China

Wuhan University in China (WHU) plays a major role in using space-based technology to help prepare for and respond to disasters. Known for its strong background in satellite data and mapping, Wuhan University supports national and local emergency agencies across China by providing accurate and timely information during disasters such as floods and earthquakes.

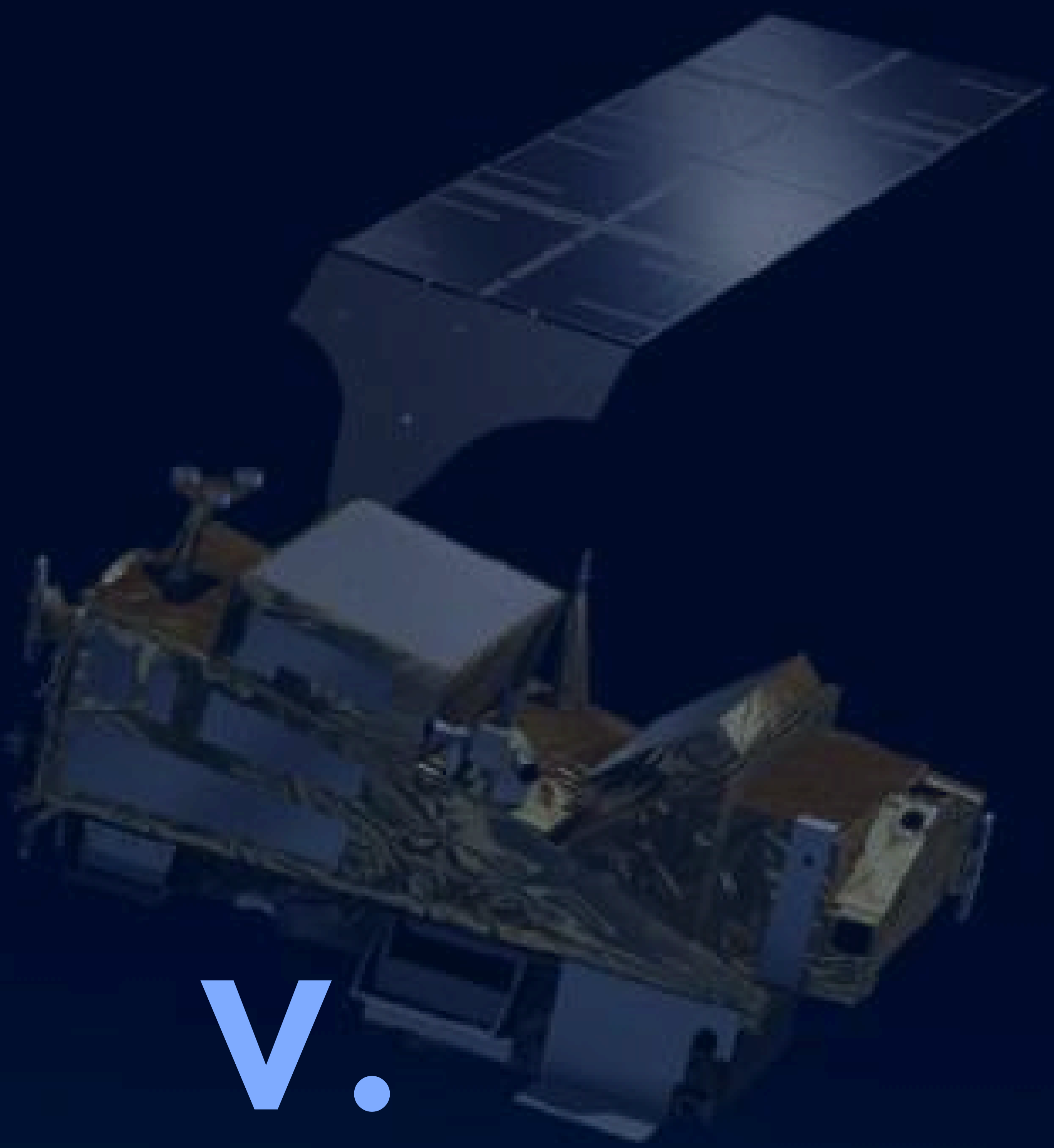
WHU leads key projects in automated damage assessment systems that use artificial intelligence to detect buildings and infrastructure affected by disasters. The University's expertise has already been used in real-world disaster responses across China, showing how advanced technology can make a practical difference in crisis situations. By reducing response time and increasing the accuracy of damage assessments, it helps save lives and improve the efficiency of recovery efforts.

A key takeaway from WHU's work is the importance of using different types of data—satellites, drones, and terrain maps—to create reliable and fast tools that help communities recover more effectively.

GeoAI Partnership: AI-Based Damage Assessment for Earthquakes and Floods in China

WHU uses satellite images, drone footage, and data analysis tools to monitor areas affected by disasters and support recovery efforts. They work closely with organizations like the National Disaster Reduction Center of China (NDRCC) to share this information quickly so that emergency teams can respond faster and more effectively. The university delivers geospatial damage maps and statistical summaries to guide rescue and recovery, using standardized criteria and ground validation methods. The office also contributes to global knowledge-sharing through training sessions, research partnerships, and the development of practical tools that can be used in other countries facing similar challenges. Their work is also supported through international mechanisms such as the Group on Earth Observations (GEO) and the International Charter on Space and Major Disasters.

This work directly supports UN-SPIDER's mission to make space-based information more accessible for disaster risk reduction, especially in developing countries. It also contributes to global goals such as making cities safer (SDG 11), taking action on climate change (SDG 13), and promoting innovation and infrastructure (SDG 9).



V. GEOAI BEST PRACTICES AND INNOVATIVE APPLICATIONS

Section A: Risk Assessment and Hazard Mapping

Overview

Hazard profiling and risk analytics are essential for identifying high-risk areas and guiding proactive, data-driven disaster management aligned with the SDGs. Advances in AI/ML (e.g., Random Forest, U-Net, LSTM) combined with satellite data (e.g., Sentinel-1, CHIRPS) enable accurate, scalable multi-hazard risk assessments. This integration helps governments and responders act quickly, protect infrastructure, and build community resilience.

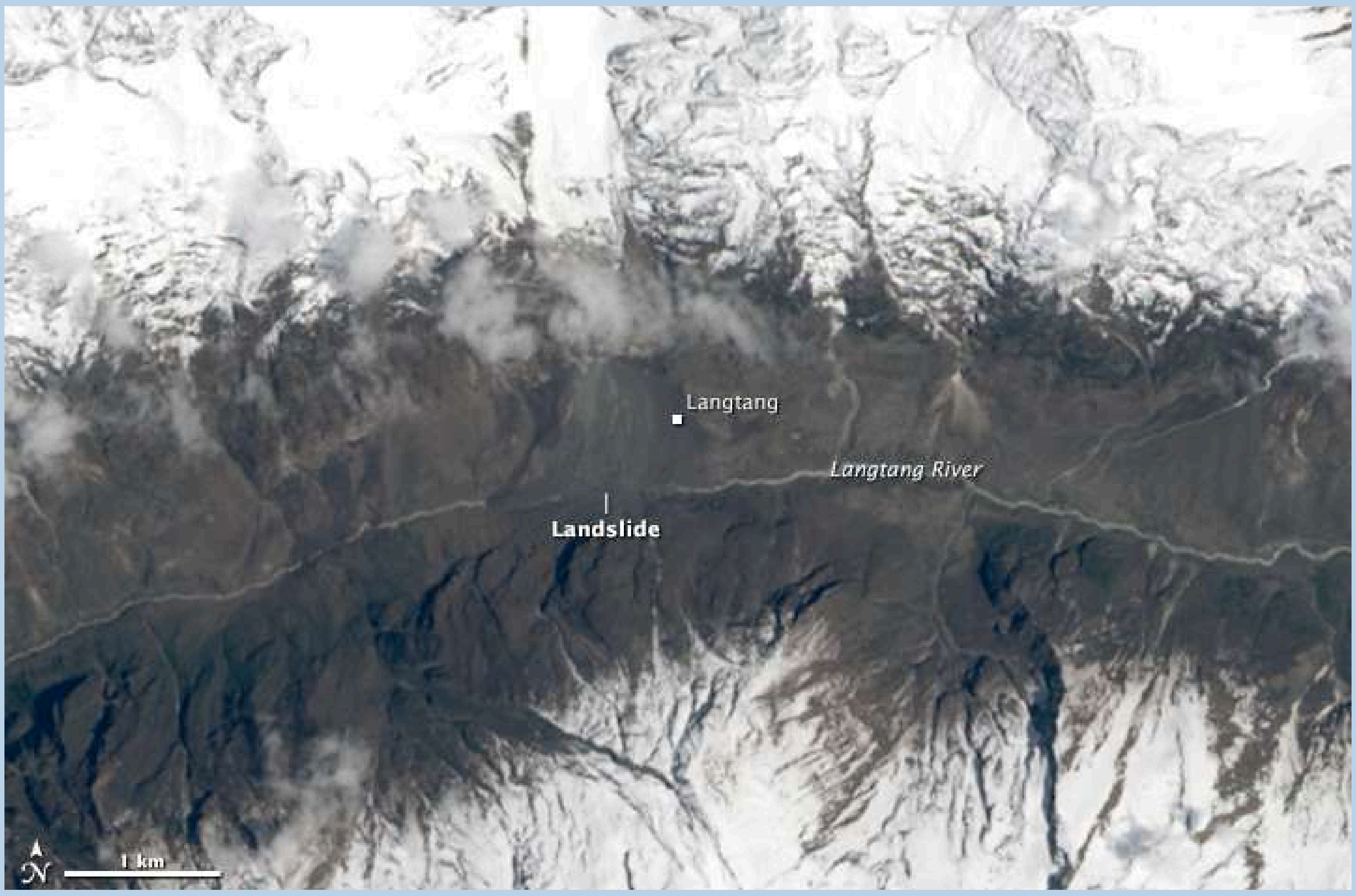


Figure: Landslide in Langtang Valley following 25 April 2015 earthquake in Nepal
(c) UN-SPIDER Knowledge Portal

AIT | AI-DRIVEN LANDSLIDE MODELLING IN NEPAL

Title of GeoAI Practice

Making Landslide Predictions Understandable: AI–Driven Landslide Modeling in Nepal

Challenge or Problem Addressed

Landslide susceptibility models often struggle with balancing interpretability and predictive power. Traditional statistical approaches provide transparency but may lack accuracy, while more advanced machine learning models often behave as "black boxes," making it difficult to understand how predictions are generated. This practice addresses the need for models that are both reliable and explainable, particularly in high-risk, data-limited settings. The integration of SHAP into the modeling workflow allows for both global and local interpretations of model behavior, helping decision-makers trust and understand the results, which is crucial for planning and disaster risk reduction.

Brief Description

This project uses a transparent deep learning model to predict landslide risk in Nepal after the **2015 Gorkha earthquake**. By training a neural network on **13 environmental factors** and geological predictors, aggregated at the slope-unit level, to produce susceptibility scores for over 16,000 terrain units. It identifies areas most likely to experience landslides, and what makes this approach special is its use of SHapley Additive exPlanations (**SHAP**) — a technique that shows how each factor influences the prediction — providing users with insights into the influence of each input factor on individual predictions, making the results more transparent and actionable. An interactive online map helps planners and disaster managers explore the results and use them in local planning.

THIS MODEL DOESN'T JUST PREDICT LANDSLIDES — IT **EXPLAINS** THEM. USING SHAP, EACH PREDICTION IS TRACEABLE, BUILDING TRUST IN AI FOR DISASTER RISK REDUCTION.

Technical Approach and Methods

The study utilized a variety of open-source and remote sensing datasets, including a detailed landslide inventory from the Gorkha earthquake, rainfall data from CHIRPS, terrain variables from SRTM-derived digital elevation models, and soil properties from the SoilGrid database. Geological data from the USGS were also included. These datasets were aggregated at the slope-unit level using the r.slopeunits tool, which delineates terrain into hydrologically and geomorphologically consistent mapping units. A fully connected artificial neural network with **12 hidden layers was designed to process 13 normalized features,** including both continuous and categorical data. The model was trained using weighted binary cross-entropy to address class imbalance and optimized using the Adam optimizer. SHAP was applied post-training to generate interpretable outputs, revealing the contribution of each predictor to the final susceptibility score of each mapping unit. The results were deployed in an **ArcGIS Online interface** that allows users to explore model predictions and associated explanations interactively.

AIT | AI-DRIVEN LANDSLIDE MODELLING IN NEPAL

Impact and Outcomes

The explainable deep learning model demonstrated high predictive performance, confirming its utility for post-earthquake landslide susceptibility assessment. The ability to interpret model outputs using **SHAP** helped identify slope steepness, ground shaking, and soil texture as key contributors to landslide risk in the study area. These findings are not only scientifically meaningful but also useful for hazard mitigation planning. The interactive **Web-GIS platform** has increased accessibility to the model's outputs and helped local planners and engineers better understand landslide risks. The tool has already been used in training events in Nepal and is helping improve local hazard maps. Early feedback suggests that the system has begun informing updates to local hazard zoning practices, highlighting its practical applications.

Alignment with SDGs

AIT | AI-DRIVEN LANDSLIDE MODELLING IN NEPAL

Lessons Learned and Recommendations

One of the key insights from this practice is that neural networks do not need to be overly complex to be effective. By using a relatively simple architecture, the model remained interpretable without sacrificing accuracy. This reinforces the importance of balancing model sophistication with clarity, especially in applied contexts. Spatially aware validation techniques, such as regional cross-validation, were also essential in assessing the model's generalization capacity. Without these, performance estimates could be misleading due to spatial clustering in the data. Another important takeaway is the benefit of using slope units rather than arbitrary grid cells for landslide modeling, as they better reflect the terrain's natural structure. Looking ahead, incorporating physics-informed constraints into deep learning models could improve both accuracy and trustworthiness, especially for applications in dynamic or climate-sensitive regions.

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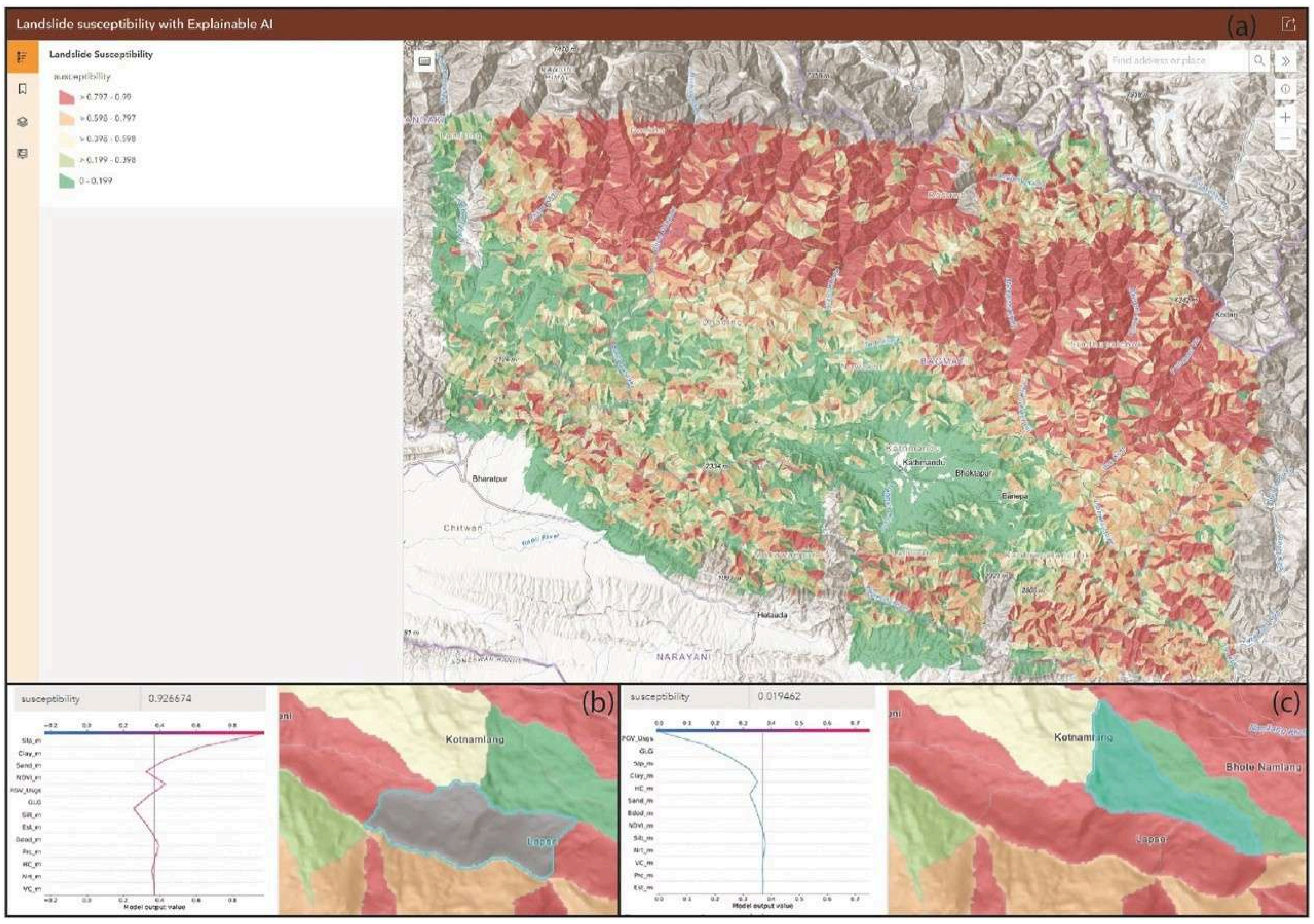

Figure: Landslide Susceptibility with Explainable AI

BRIN | SLUM MAPPING IN BANDUNG CITY

Title of GeoAI Practice

Slum mapping in Bandung City, Indonesia

Brief Description

The rapid growth of the urban population in Bandung City has contributed to the development of slums due to inadequate housing facilities and poor urban planning. However, it is still unclear how these slums are spatially and temporally distributed and how they evolve. Therefore, it is essential to map their distribution and trends effectively. The National Research and Innovation Agency of Indonesia (BRIN) and UNESCAP conducted a project aimed at classifying slum areas in Bandung City using satellite remote sensing imagery and Geospatial Artificial Intelligence (GeoAI), specifically employing a **machine learning-based local knowledge approach**. This classification exercise supports Sustainable Development Goal 11, which focuses on promoting sustainable cities and communities. High-resolution satellite remote sensing data and a **knowledge-based classifier** were used to differentiate between slum and non-slum settlements, as well as to classify commercial and industrial areas. The data processing was carried out using the Google Earth Engine (GEE) platform.

Challenge or Problem Addressed

In 2020, slum settlements in Bandung City covered an area of 4,919.47 km^2, and in 2021, they reduced to 4,680.31 km^2. Fragmentation, outdated information, or a lack of available data often hindered the ability of local governments and relevant agencies to gather accurate slum data. This limitation made effective planning and resource allocation challenging. The developed tool is essential for quicker and more precise identification and prioritization of intervention areas, promoting strategic and efficient decision-making.

Technical Approach and Methods

To identify settlement areas, first, the 2021 RGB and Near-Infrared SPOT-6 satellite imagery (spatial resolution of 1.5 meters) was processed using machine learning classifiers available on GEE and the Statistical Machine Intelligence and Learning Engine (SMILE) with the Random Forest algorithm. The classification process began with the identification of the building class. Subsequently, the classification was repeated to identify the industrial building class.

The second is to classify slum settlements. Based on the **local knowledge gathered from field observations** in Bandung City, we found that slum areas are characterized by their proximity to rivers, road access, and railways. A decision tree model was employed to classify settlement areas into slum or non-slum categories. The **classification of slum areas** is based on the closeness of the settlement to roads, rivers, and railways, determining whether it falls within the designated buffer zones. The accuracy of the slum classification results was evaluated by comparing them to the results from the field observations.

BRIN | SLUM MAPPING IN BANDUNG CITY

Impact and Outcomes

This initiative has enhanced the capacity of the related local government staff in Bandung City to integrate spatial and statistical data for slum mapping using GeoAI. Mapping slums will aid in planning infrastructure development projects, such as roads, water supply, sanitation facilities, and electricity distribution. Data collected through slum mapping can inform policy-making about housing, urban development, poverty alleviation, and social welfare. This matter could offer valuable insights into the needs and challenges that slum dwellers experience.

Alignment with SDGs

1 NO POVERTY

11 SUSTAINABLE CITIES AND COMMUNITIES

Lessons Learned and Recommendations

The project has incorporated satellite remote sensing imagery and GeoAI to enhance the accuracy of slum mapping in Bandung City, adopted local knowledge to guarantee accuracy and inclusivity, and utilized the open GEE platform. However, data processing requires high and complex processing capacity. Future efforts focus on more practical training for the stakeholders to confirm the practice's long-term sustainability.

FROM ROADS TO ELECTRICITY, SLUM MAPPING ENABLES **DATA-DRIVEN DECISIONS** THAT DIRECTLY IMPACT THE LIVES OF UNDERSERVED COMMUNITIES IN BANDUNG CITY.

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BRIN | SLUM MAPPING IN BANDUNG CITY

Figure: Examples of slum areas (top row) and capacity building activities related to slum area mapping (bottom row)

ECOE | LANDSLIDE SUSCEPTIBILITY ASSESSMENT IN PAPHOS, CYPRUS

Title of GeoAI Practice

Landslide Suspectibility Assessment in Paphos, Cyprus

Brief Description

In response to the multiple seismic events and landslides' occurrence in Cyprus, driven by the activity of the tectonic plates in the region and the complex terrain in Cyprus, the ERATOSTHENES Centre of Excellence, in the framework of AI-OBSERVER (https://ai-observer.eu/) Horizon Europe project, developed a Geo-AI tool to assess the landslide risk/susceptibility in Cyprus. Based on the information collected by the Cyprus Geological Survey Department's landslide inventory, the Trachypedoula village and the surrounding area was selected as a representative case study. Leveraging various satellite-based, auxiliary data and AI techniques, the initiative developed a high-quality landslide susceptibility assessment tool, that can be applied across the island, enhancing disaster preparedness, mitigation measures and resilience.

THIS WORK ADDRESSES THE UPDATE OF THE CYPRUS LANDSLIDE INVENTORY, AS WELL AS INFORM THE RESPONSIBLE AUTHORITIES, INDUSTRY, ACADEMIA AND THE PUBLIC REGARDING THE **CAPABILITIES AND ADVANTAGES OF REMOTE SENSING** IN REAL-WORLD CONDITIONS.

Challenge or Problem Addressed

According to the landslide inventory provided by the Cyprus Geological Survey Department, Paphos District is the most prone area to landslides area on a national level. The village of Trachypedoula, located in Paphos District, is one of the most landslide-prone regions in Paphos. Evidently, among the most common factors that contribute to the landslide occurrence is the intense rainfall. The lack of local rain-gauge stations in the area leads to uncertainties related to the actual triggering factors and conditions of the landslide. The application filled this gap, i.e., the lack of precipitation data in the region, and complementary with other data, addresses the limitations related to landslides triggering/conditioning factors at local and national level. Furthermore, the developed tool is a cost-effective and scalable solution, leveraging the state-of-the-art technologies, minimizing, at the same time, the devastating impact of landslides (e.g., loss of lives, damage to critical infrastructure, buildings and landscape, etc.).

ECOE | LANDSLIDE SUSCEPTIBILITY ASSESSMENT IN PAPHOS, CYPRUS

Technical Approach and Methods

Copernicus Sentinel-1 Synthetic Aperture Radar (SAR) satellite images were used, as well as a Digital Elevation Model (DEM), with 25m spatial resolution, provided by the Department of Lands and Surveys of Cyprus. Using the DEM, several geomorphologic parameters were acquired, such as slope, aspect, relief and the drainage network. Other auxiliary data, and more specifically the faults, the geology/lithology and the landslide inventory obtained by the Cyprus Geological Survey Department, were also used in the methodology. Moreover, the precipitation data from the Cyprus Department of Meteorology and data from meteorological satellites, such as the GPM IMERG Late Precipitation L3, were used to develop a Neural Network that would enable us to obtain precipitation values for each satellite image pixel in the case study area. Last but not least, the Land Use/Land Cover was derived from the National Land Cover Database (USGS), while the road network was obtained from the Cyprus Lands and Surveys Department. All data were used as an input for a Multicriteria-Decision Analysis that was conducted in a Geographic Information Systems (GIS) environment.

Impact and Outcomes

The developed GeoAI tool has improved awareness to stakeholders, industry companies and end users, providing valuable insights to support decision makers, enhance preparedness, mitigation measures and resilience in landslide-prone areas. Following that, efforts by means of information days and presentations targeting local authorities, governmental organizations and private companies are currently carried out, to increase the impact and communicate the efficiency and effectiveness of the developed tool.

Alignment with SDGs

9 INDUSTRY, INNOVATION AND INFRASTRUCTURE

11 SUSTAINABLE CITIES AND COMMUNITIES

13 CLIMATE ACTION

ALL DATA WERE USED AS AN INPUT FOR A MULTICRITERIA-DECISION ANALYSIS THAT WAS CONDUCTED IN A **GEOGRAPHIC INFORMATION SYSTEMS (GIS)** ENVIRONMENT.

Lessons Learned and Recommendations

The main challenge of this study is the integration of multiple and different datasets in terms of formatting, data sources and scales into a unified framework. The latter required different processing software and knowledge (AI, GIS, InSAR, geostatistics, etc.). Following this, the validation of the results was an also challenging part, since ground-truth data were only provided by the governmental authorities (e.g., landslide inventory and precipitation data). This validation was crucial for ensuring the reliability and accuracy of the results. Future work will include an updated landslide inventory provided by the Geological Survey Department and potential ground-truth data in areas where GNSS Stations are located.

ECOE | LANDSLIDE SUSCEPTIBILITY ASSESSMENT IN PAPHOS, CYPRUS

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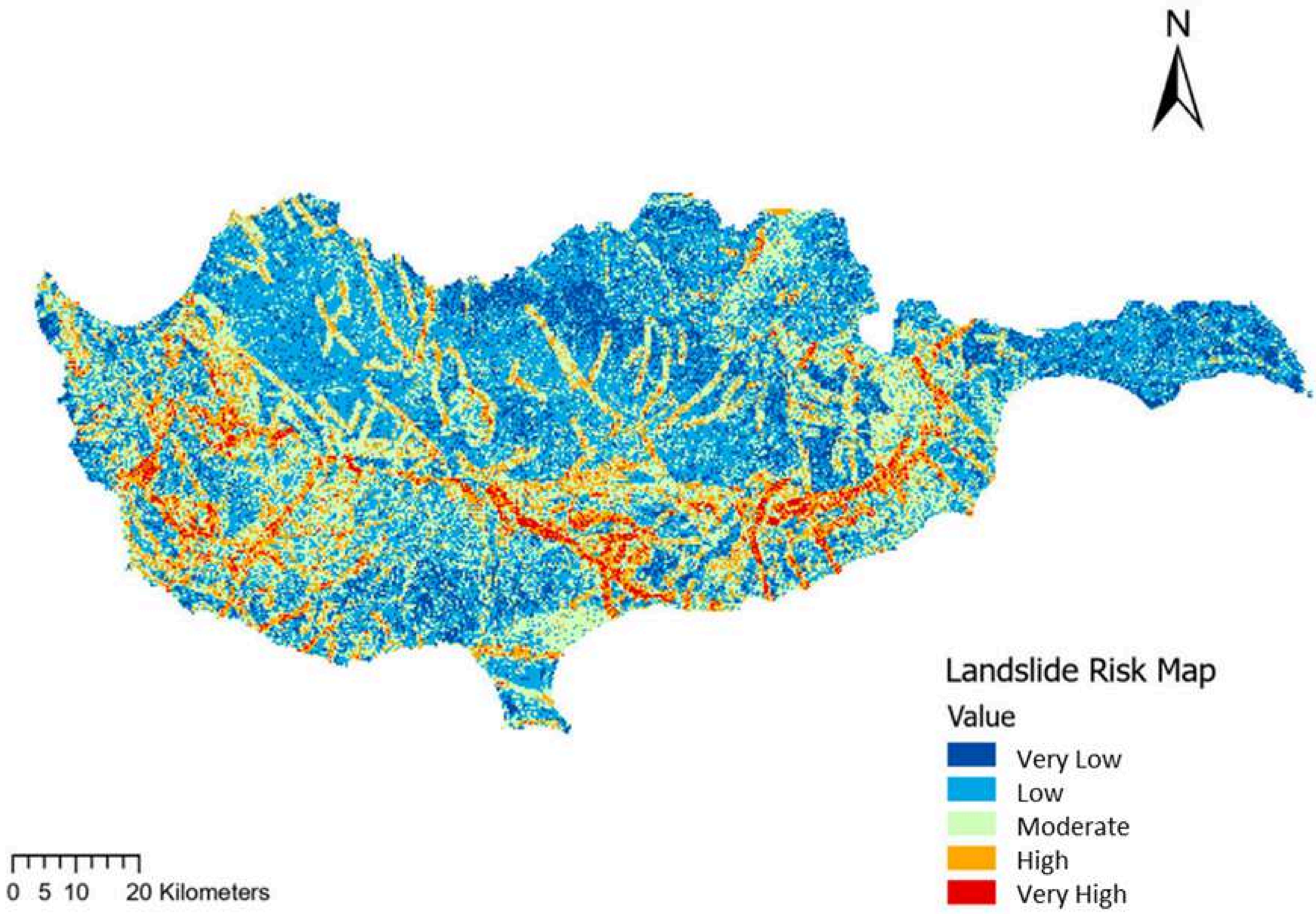

Figure: Landslide susceptibility assessment in Cyprus

ECOE | WEB-BASED TOOL TO ASSESS FLOOD SUSCEPTIBILITY IN CYPRUS

Title of GeoAI Practice

Web-based tool to assess flood susceptibility in Cyprus

Brief Description

The outcomes of a probabilistic framework have been uploaded to a web-based platform that a) involves the generation of realizations of the criteria weights by sampling methods that model the structural dependence of multicriteria correlated data (i.e., experts' opinions who assess the relative importance of several factors with respect to flood probability) and uses these realizations to estimate the spatial distribution of the expected flood susceptibility. Seven criteria have been selected according to the literature, namely, terrain elevation, slope, flow accumulation, rainfall intensity, distance from the drainage network, land use/land cover and soil. The samples of weighting coefficients are used to assess flood susceptibility in Cyprus via multicriteria decision analysis (MCDA). The results revealed that 50 % of the study area is classified as either highly susceptible or very highly susceptible to flooding, with the majority of these regions being present in the southern and southeastern parts of the study area. With respect to the validation dataset, the known flood-prone areas are classified as having either "Very High" (12–14 %) or "High" (>78 %) probabilities of flood occurrence. The proposed probabilistic framework can be directly applied in other biogeographical regions and geological contexts.

Challenge or Problem Addressed

It aims to model the spatial variation of a complex natural phenomenon, such as flooding, by compromising different perspectives of the multiple actors/stakeholders with respect to the significance of several factors on flooding. These opinions are incorporated into a stochastic multicriteria decision analysis to estimate the flood susceptibility via weighted linear combination. The applicability of the proposed methodology is validated in the island of Cyprus. The outcomes of this study are provided to the Cypriot authorities and will be considered during the revised flood management plans.

BY COMBINING EXPERT JUDGMENT WITH PROBABILISTIC MODELING, THIS APPROACH IDENTIFIES FLOOD-PRONE AREAS WITH UP TO 78% CERTAINTY — GUIDING SMARTER, DATA-DRIVEN DECISIONS.

ECOE | WEB-BASED TOOL TO ASSESS FLOOD SUSCEPTIBILITY IN CYPRUS

Technical Approach and Methods

Multiple datasets from various sources were selected to assess flood susceptibility in Cyprus. More specifically, terrain elevation, flow accumulation and terrain slope determined through a Digital Elevation Model (25m resolution) that was provided by the Department of Lands and Surveys, rainfall intensity calculated by daily precipitation values from 90 ground-based stations for 2011-2023, provided by the Department of Meteorology. Moreover, the distance from drainage network was calculated by the drainage network that was provided by the Water Development Department, and soil type, depth and texture were provided by the Geological Survey Department. Last but not least, Land Use Land Cover was obtained from the Copernicus Land Monitoring Service (CORINE). An overview of the proposed methodology combining these datasets is presented in the figure below. On-going work is conducted to use the standardized maps of these factors to partition the study area into clusters according to their similarity/dissimilarity via unsupervised machine learning methods (i.e., K-means clustering algorithm). For each study area, a set of weight coefficients is determined depending on the standardized values, which are then used to construct susceptibility maps. More details will be provided in subsequent months (work is currently under review).

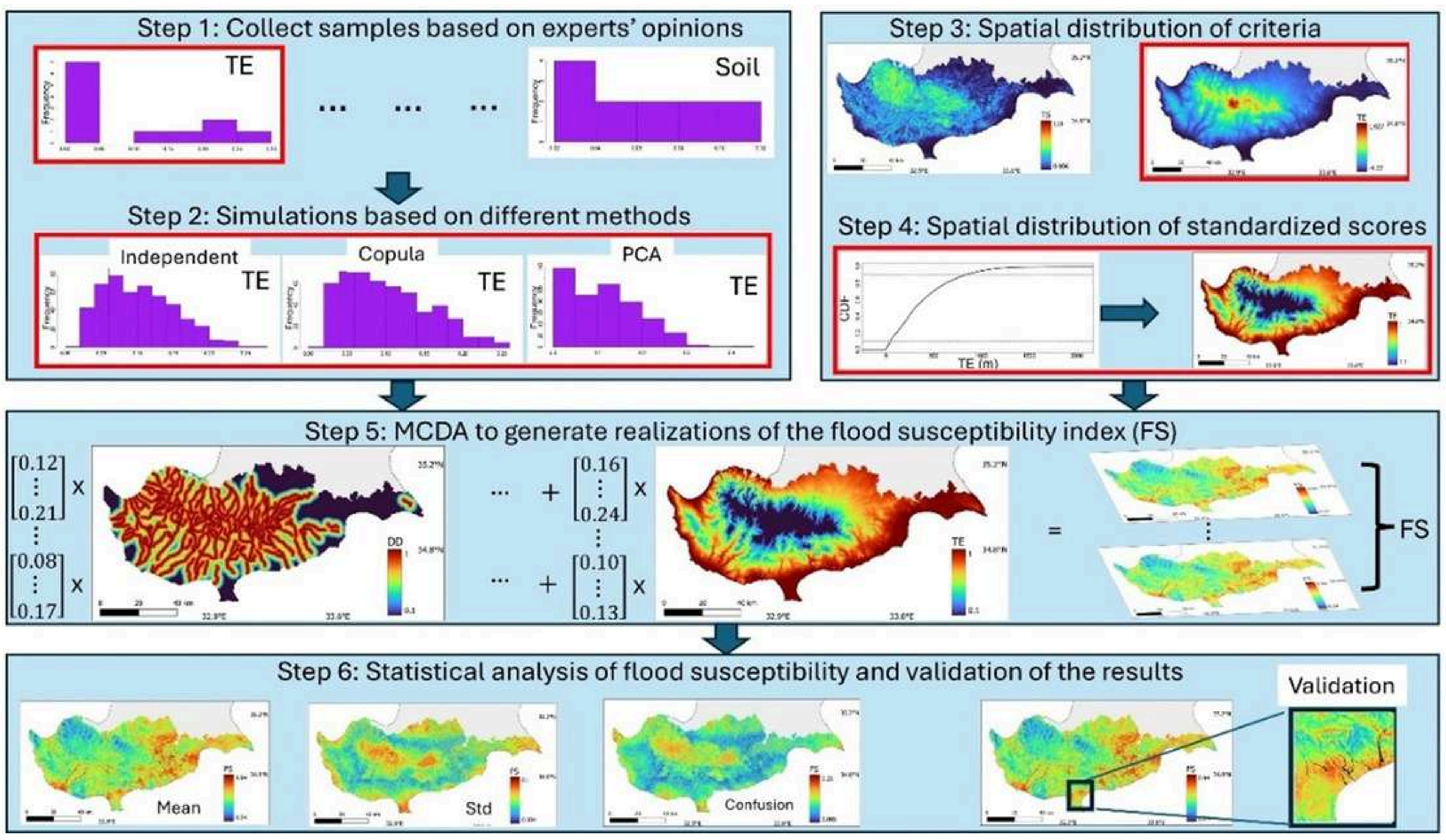

Figure: Flood susceptibility assessment methodology

ECOE | WEB-BASED TOOL TO ASSESS FLOOD SUSCEPTIBILITY IN CYPRUS

Impact and Outcomes

The outcomes of this application are discussed and validated by the water authorities and will be considered during the compilation of the revised flood management plan. Particularly, the results revealed that 50 % of the study area is classified as either highly susceptible or very highly susceptible to flooding, with the majority of these regions being present in the southern and southeastern parts of the Republic of Cyprus. With respect to the validation dataset, the known flood-prone areas are classified as having either "Very High" (12–14 %) or "High" (>7880 %) probabilities of flood occurrence. It is also expected to assist the authorities in urban planning, and the insurance sector to better assess the risks and impact of flood events, resulting in more fair and reliable insurance policies. The proposed maps can be easily revised through time to account for future modifications (e.g. land use development, rainfall variations, construction of infrastructures that change the drainage network, etc).

Alignment with SDGs

Lessons Learned and Recommendations

The proposed methodology can also be directly incorporated into more advanced decision-making methods. Furthermore, it can be used to study other natural hazards (i.e., landslides, fires, earthquakes), enabling planners to incorporate multihazard probabilistic risk assessment in the decision-making process. Additionally, it can assist the authorities in partitioning the area of interest in zones on the basis of susceptibility levels, thus contributing to the design of efficient mitigation measures in different contexts (i.e., urban, urban, rural). Finally, the proposed probabilistic framework can be applied in other biogeographical regions and geological contexts for which information regarding important climatic and nonclimatic drivers is available, to enable the generation of multiple realizations of the criteria weights on the basis of pairwise comparisons of multiple stakeholders and different multivariate sampling methods.

ECOE | WEB-BASED TOOL TO ASSESS FLOOD SUSCEPTIBILITY IN CYPRUS

Additional References or Resources

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- Water Development Department Geoportal: https://geoportal-wdd.hub.arcgis.com/

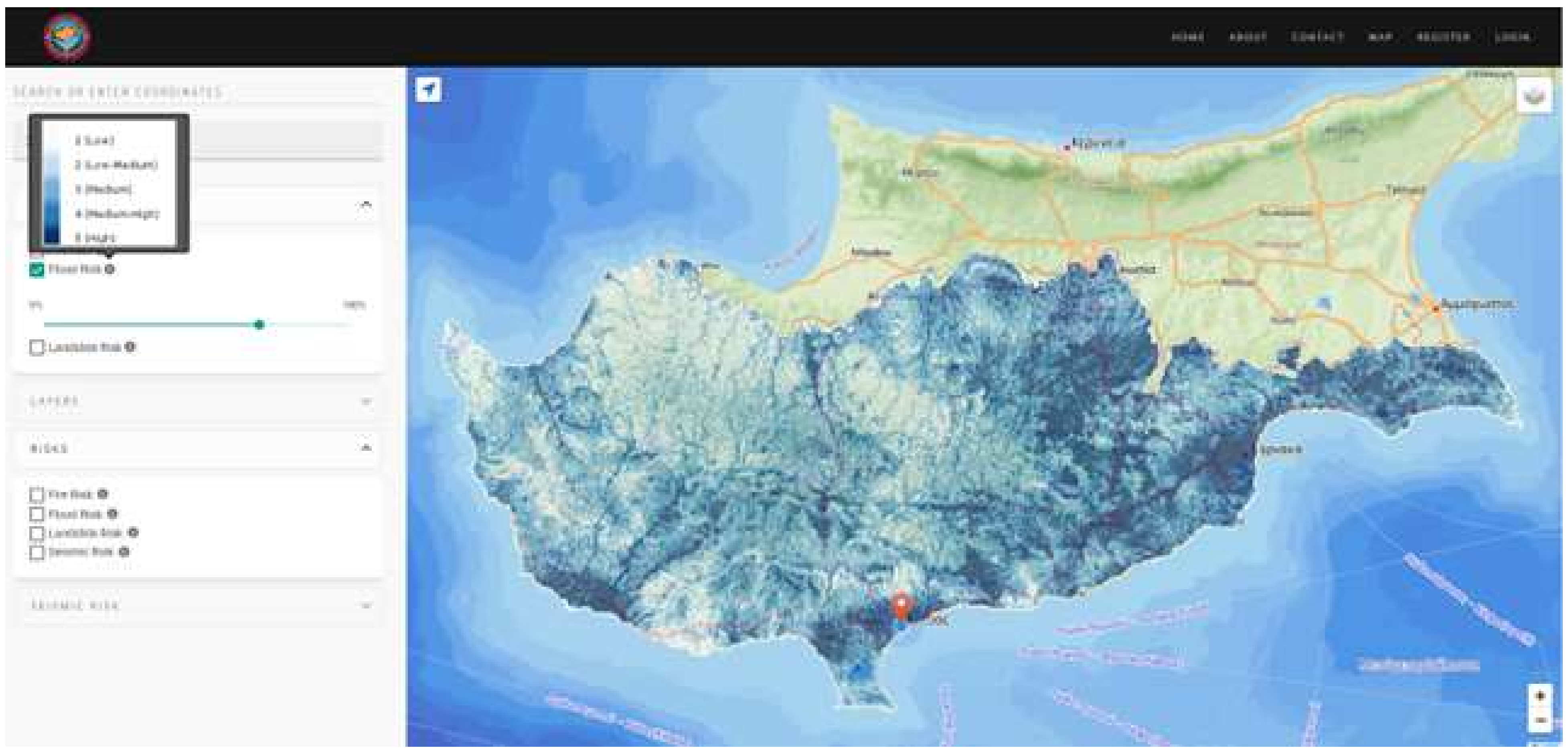

Figure: Flood susceptibility assessment in Cyprus

SUPARCO | EARTHQUAKE INDUCED LANDSLIDE SUSCEPTIBILITY MAPPING IN NORTHERN PAKISTAN

Title of GeoAI Practice

Earthquake Induced Landslide Susceptibility Mapping in Northern Pakistan Using Multi Criteria and AI Based Models

Brief Description

This proposed GeoAI practice will assess earthquake induced landslide susceptibility in the Kashmir region, an area highly vulnerable due to active seismicity and rugged terrain. The study will integrate Remote Sensing and GIS techniques to prepare thematic raster layers of key landslide conditioning factors such as slope, aspect, elevation, TWI, LULC, lithology, and proximity to roads, rivers, streams, and fault lines. These factors will be analysed using the Analytical Hierarchy Process (AHP) for multi criteria evaluation and AI based models for data driven analysis. By integrating expert knowledge with artificial intelligence, the project aims to produce accurate susceptibility maps and identify dominant contributing factors. The results will support improved planning, risk mitigation, and informed decision making in earthquake prone regions.

Challenge or Problem Addressed

This proposed future study aims to enhance the level of detail in landslide susceptibility assessment for Muzaffarabad and surrounding earthquake affected regions by incorporating refined spatial datasets and advanced analytical techniques. By integrating both expert driven (AHP) and AI based models, the study will overcome limitations of traditional methods, offering improved accuracy and detail. It will contribute to better disaster preparedness and risk reduction strategies by understanding the natural and anthropogenic landslide event controlling factors.

> THE OUTCOMES ARE EXPECTED TO **SUPPORT** SUSTAINABLE LAND USE PLANNING AND **INFORM** FUTURE POLICY INTERVENTIONS IN HIGH-RISK MOUNTAINOUS AREAS.

Technical Approach and Methods

The methodology will use geospatial raster and vector data derived from satellite imagery, high resolution DEM, soil data and geological datasets. The AHP method will facilitate expert driven factor prioritization through pairwise comparisons. Simultaneously, AI based models such as Random Forest or Support Vector Machines will identify patterns between past landslide events and contributing factors. This hybrid approach will enable robust susceptibility mapping with greater accuracy and generalizability.

SUPARCO | EARTHQUAKE INDUCED LANDSLIDE SUSCEPTIBILITY MAPPING IN NORTHERN PAKISTAN

Impact and Outcomes

The Kashmir region is highly susceptible to landslides due to its mountainous terrain, active seismicity, rainfall and anthropogenic factors. The anticipated outcomes include high resolution landslide susceptibility maps that enhance risk awareness and disaster preparedness in northern Pakistan. These maps will support quicker identification of high-risk zones and assist decision makers in prioritizing response and mitigation strategies.

Alignment with SDGs

Lessons Learned and Recommendations

This initiative is currently under implementation and aims to deliver accurate landslide susceptibility maps to disaster managers for timely mitigation measures in most potential risk areas. One of the foreseeable challenges is the availability of temporal inventory with causes as well as the availability of very high-resolution digital terrain models and geological maps.

SUPARCO | DEEP LEARNING-BASED APPROACH FOR LANDUSE/LANDCOVER (LULC) CLASSIFICATION

Title of GeoAI Practice

Deep Learning Based Approach for Comprehensive Landuse/Landcover (LULC) Classification using High Resolution Satellite Imagery

Brief Description

This study leverages state-of-the-art deep learning and high-resolution satellite imagery to produce a detailed, pixel-level land-use/land-cover (LULC) map across thirteen thematic classes—from built-up urban areas and irrigated crops to snow and natural wetlands. Multi-seasonal high resolution satellite imagery along with ground validation surveys and ancillary spatial data layers were used. An attention-augmented U-Net CNN with a backbone of an EfficientNet at the core of the workflow is engineered to identify both fine-scale spatial detail as well as broader contextual information. This resulting LULC product is deployed through OGC compliant web services for NatCat Risk Calculator platform with per-pixel confidence estimates for disaster managers, planning and development department, environment protection agencies, with up-to-date, high accuracy maps for making informed decisions.

Challenge or Problem Addressed

Complexity of spectral differentiation in mixed land uses e.g. natural wetlands and flooded croplands.

Technical Approach and Methods

- **Data Sources & Pre-processing**
  - High resolution satellite imagery RGB+NIR (1m - 1.5m)
  - Ground surveyed data and ancillary spatial data layers
- **Architecture**
  - Attention-augmented U-Net with EfficientNet to enable extraction of fine spatial features and contextual cues like urban and vegetation patterns
  - Convolutional block attention modules
- **Deployment & Service Integration**
  - Platform: Containerized inference pipeline
  - Output Delivery: OGC-compliant WMS/WFS endpoints integrated into the NatCat Risk Calculator platform
  - User Access: REST API for interactive web-map widgets for disaster managers and other relevant agencies

SUPARCO | DEEP LEARNING-BASED APPROACH FOR LANDUSE/LANDCOVER (LULC) CLASSIFICATION

Impact and Outcomes

The platform's LULC layers with high resolution – matched to probabilistic hazard models – have enhanced situational awareness for the disaster managers, allowed NDRMF Planning and Development to target and finance risk mitigation investments better spatial planning of new projects and created a reliable land-cover baseline.

Lessons Learned and Recommendations

- Landcover database is the second most important database after population for incorporating in planning and development.
- This study highlights the importance of accurate spatial information for informed decision-making in spatial planning, effective disaster risk reduction (DRR), and prioritization of DRR projects.
- This study demonstrated how geometric and radiometric pre-processing and comprehensive ground truth quality check enhances the model's robustness.
- Multi-seasonal imagery was critical for differentiating flooded croplands, irrigated vs. rainfed fields, permanent snow identification.

Alignment with SDGs

11 SUSTAINABLE CITIES AND COMMUNITIES

15 LIFE ON LAND

THIS PROJECT **PRODUCES** ACCURATE, MULTI-SEASONAL LAND-USE/LAND-COVER MAPS THAT **SUPPORT** DISASTER RISK REDUCTION, RESILIENT URBAN PLANNING, AND ENVIRONMENTAL CONSERVATION.

Additional References or Resources

NatCat Model Platform:
https://natcat.ndrmf.pk/login/index.php

UC LAN I AI IN THE PREDICTION OF SOIL TEMPERATURES (UZBEKISTAN)

Title of GeoAI Practice

AI in the prediction of Soil Temperatures

Brief Description

Many developing regions worldwide struggle with reliable data measurements and records due to inadequate instrumentation and natural disasters like droughts and floods. To address these challenges, an effective prediction model is essential. Uzbekistan, vulnerable to climate change from its arid climate, can benefit significantly from this research, which introduces an integrated model to predict soil temperature at the surface and at a depth of 10 cm based on crucial climatic factors in Nukus. We trained eight machine learning models to identify the most effective one, with the Long Short-Term Memory (LSTM) model proving superior in accuracy. Notably, our model can predict soil temperature at 10 cm depth without requiring ground measurements, relying instead on climatic data and predicted surface temperatures. This innovative approach has the potential to transform planning and promote sustainable food production in arid regions like Nukus, Uzbekistan.

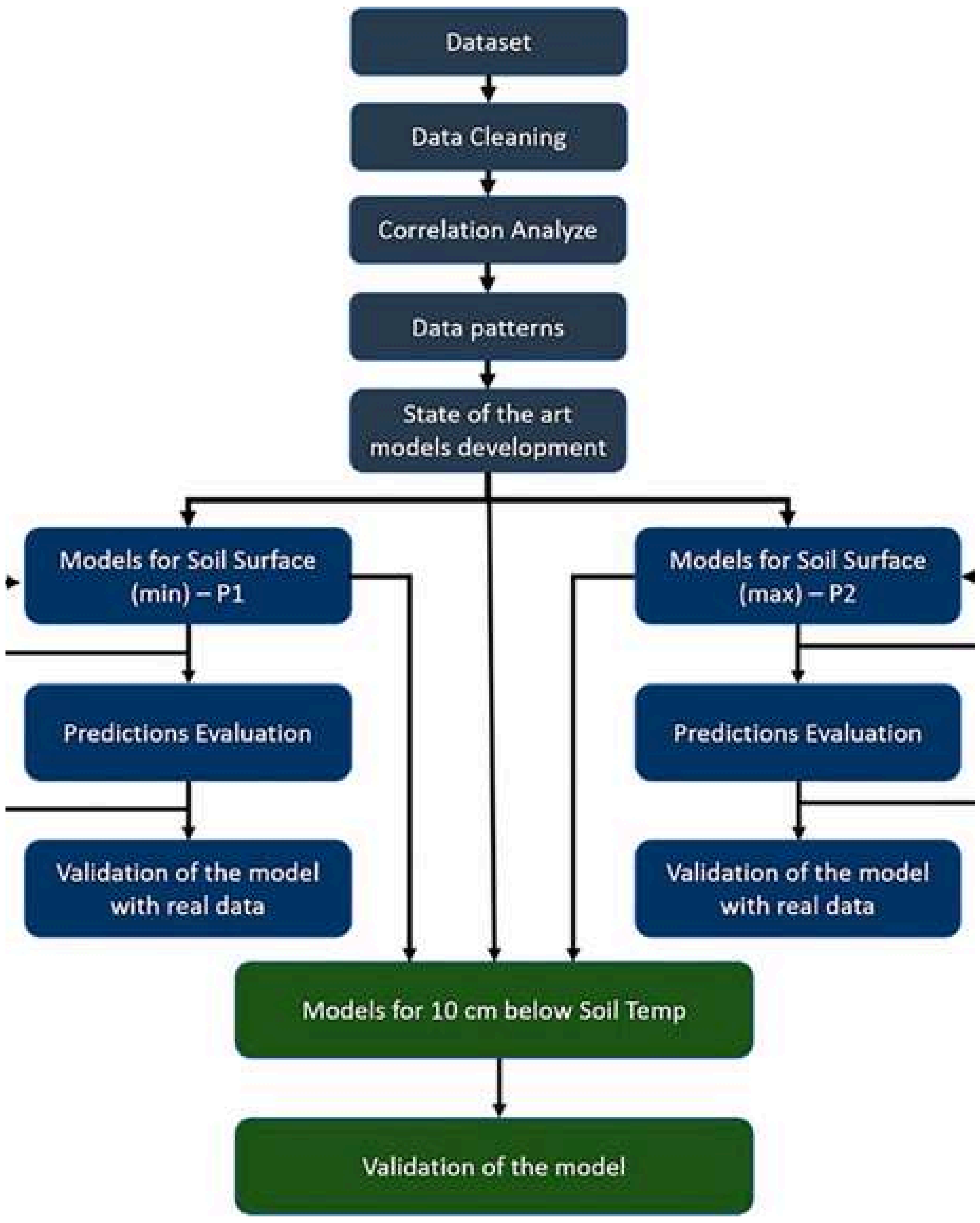

Figure: Overall methodology workflow to predict the soil temperatures

Challenge or Problem Addressed

Soil is a three-phase system consisting of solids, water, and air. The long-term balance of physical components of soil is highly essential not only to humans but also to all other living things of the world. Therefore, it is important to understand the anthropogenic activities that directly and indirectly impact the balance of the soil system.

Technical Approach and Methods

Several (8) state-of-the-art machine learning models were utilized to predict the surface and 10 cm depth soil temperature. Eight state-of-the-art machine learning models including XGBoost, CatBoost, LSTM, ANN, Bi-LSTM, Ridge Regression, Lasso Regression, and ElasticNet were utilized in formulating the two equations. Figure in the above presents the overall methodology which was carried out to predict the soil temperatures.

UC LAN I AI IN THE PREDICTION OF SOIL TEMPERATURES (UZBEKISTAN)

Impact and Outcomes

Accurate models were developed to predict soil temperature levels at both surface and 10 cm depth for Nukus, Uzbekistan. State-of-the-art machine learning algorithms were used in developing the prediction models. The model developed to predict temperature levels at 10 cm depth is capable of using climatic parameters and predicted soil surface temperature levels as inputs. Therefore, measuring soil surface temperature is not needed to understand the soil behaviour at 10 cm depth. This showcases the greater novelty of the research applied here. However, time-to-time measurements are encouraged to validate the model from time to time under changing climatic conditions. The research presented here can be used to improve the sustainability aspects of food production in arid areas like Nukus, and Uzbekistan. In addition, similar models can be developed for the whole country and understand the soil behaviour. The projected results can be used to develop a countrywide sustainability model not only to look at food production but also to improve biodiversity. Therefore, the findings of this research lead to achieving success in several Sustainable Development Goals.

SMART SOIL PREDICTION EMPOWERS FARMERS WITH DATA-DRIVEN DECISIONS, HELPING UZBEKISTAN ADAPT TO **CLIMATE CHANGE** AND IMPROVE CROP PLANNING.

Alignment with SDGs

13 CLIMATE ACTION

15 LIFE ON LAND

17 PARTNERSHIPS FOR THE GOALS

Lessons Learned and Recommendations

- Soil temperature at 10 cm depth has to be interlinked with the agricultural specialist to understand the best crop types.
- The crop types have to technologically enhanced to climate resilience.
- Frequent monitoring is required to validate the temporal variation of the prediction model with changing climates.
- More spatial data have to incorporated in a holistic prediction model.

Additional References or Resources

Mampitiya, L., Rozumbetov, K., Rathnayake, N. et al. Artificial intelligence to predict soil temperatures by development of novel model. Sci Rep 14, 9889 (2024). https://doi.org/10.1038/s41598-024-60549-x

ZFL I MULTI-HAZARD EXPOSURE MODELLING WITH MULTIMODAL GEO-IMAGE DATA AND DEEP LEARNING

Title of GeoAI Practice

Multi-hazard exposure modeling with multimodal geo-image data and deep learning

Brief Description

Effective disaster mitigation and management strategies require up-to-date exposure models that capture spatially explicit information on vulnerability-relevant characteristics of buildings. This practice explores the potential of heterogeneous multimodal geo-image data—including street-level imagery (SLI), very high-resolution optical remote sensing data, and a normalized digital surface model—for generic large-area building characterization as needed for multi-hazard risk assessment. Specifically, a deep learning-driven methodology for the synergistic integration of multi-sensor data and efficient multi-criteria building classification is introduced. Using the earthquake-prone metropolis of Santiago de Chile as a case study, the contribution of the employed geo-image modalities to the automated derivation of reliable exposure information is assessed. Five target variables are considered: height, lateral load-resisting system material, seismic building structural type, roof shape, and block position. The employed data and methods facilitate the automation of large-area building exposure modeling with high spatial and thematic resolution.

Challenge or Problem Addressed

Up-to-date exposure information is crucial for designing adaptation strategies and disaster management plans before and after an event, based on risk analyses and damage assessments. However, due to the vast number of buildings, their heterogeneous structural designs, and high spatio-temporal dynamics, maintaining a comprehensive inventory database across large areas is a complex task. Traditional data collection methods are not capable to meet this challenge. Drastic transformation processes (population growth, urbanization and climate change), combined with limited exposure data, necessitate the use of relevant datasets and the development of automated approaches to enable, large scale efficient vulnerability-related characterization of the built environment.

Technical Approach and Methods

An object-based deep multimodal multitask learning methodology, enables the synergistic fusion of multimodal data (i.e., SLI, very high-resolution optical remote sensing data, and a normalized digital surface model) for efficient multi-criteria building classification. Task-wise Modality Attention fusion synergistically integrates multimodal information by optimizing the feature representations for each inference task according to its specific requirements. The challenge of incomplete SLI data, is addressed through a transformer-based SLI Spatial Context Encoder, which captures spatial correlations between physical-structural building attributes.

ZFL I MULTI-HAZARD EXPOSURE MODELLING WITH MULTIMODAL GEO-IMAGE DATA AND DEEP LEARNING

Impact and Outcomes

The proposed data and methods enable the automated, large-scale extraction of exposure information, providing a unique combination of spatial and thematic resolution with high reliability. This is critical for conducting comprehensive multi-hazard risk analyses. The required spatial resolution of the exposure model depends on the spatial extent, available spatial resolution, and intensity variability of the natural hazards under consideration. Increasing the spatial resolution of the exposure model enhances adaptability to these requirements. At the same time, a high thematic resolution is crucial to adequately capture the specific vulnerabilities of buildings to different natural hazards.

Alignment with SDGs

11 SUSTAINABLE CITIES AND COMMUNITIES

13 CLIMATE ACTION

FUSING SATELLITE IMAGERY WITH DEEP LEARNING UNLOCKS **HIGH-RESOLUTION, AUTOMATED EXPOSURE MAPPING** — A GAME-CHANGER FOR MULTI-HAZARD RISK ANALYSIS.

Lessons Learned and Recommendations

SLI-based information is revealed especially valuable for achieving precise and thematically distinct structural characterization of buildings, either through its direct use or by SLI spatial context encoding. This underscores the critical importance of the rich semantic content in SLI for extracting structural attributes relevant to vulnerability assessment, utilizing the geo-image modalities explored in this practice. The findings of this research demonstrate that the integration of ground-level SLI and top-down remote sensing data using tailored deep learning models represents a promising approach for automating the generation of large-scale exposure models with high spatial and thematic resolution—an essential prerequisite for effective disaster mitigation and management, particularly in the context of multi-hazard vulnerability and risk assessment.

ZFL | MULTI-HAZARD EXPOSURE MODELLING WITH MULTIMODAL GEO-IMAGE DATA AND DEEP LEARNING

Additional References or Resources

The exposure model exemplified by the seismic building structural type (SBST):

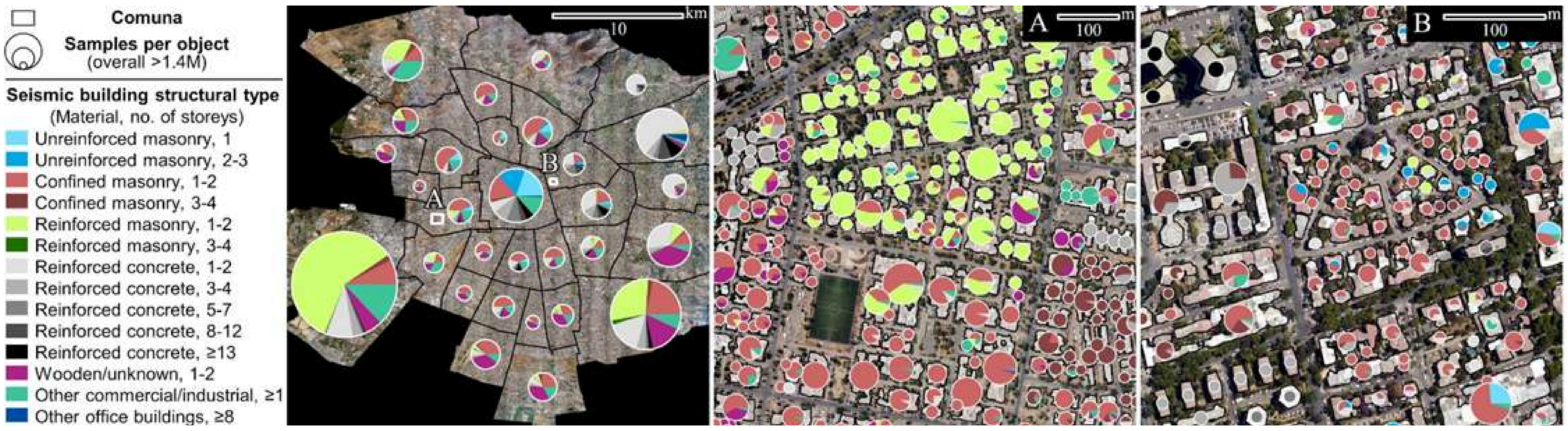

Figure: Spatial distribution of SBSTs across Santiago de Chile. Left: data points aggregated at the comuna administrative level; center and right (zoom boxes A and B, respectively): aggregation at the building object level.

- Aravena Pelizari, P., Geiß, C., Aguirre, P., Santa María, H., Merino Peña, Y., Taubenböck, H., 2021. Automated building characterization for seismic risk assessment using street-level imagery and deep learning. ISPRS Journal of Photogrammetry and Remote Sensing 180, 370–386. https://doi.org/10.1016/j.isprsjprs.2021.07.004
- Aravena Pelizari, P., Geiß, C., Groth, S., Taubenböck, H., 2023. Deep multitask learning with label interdependency distillation for multicriteria street-level image classification. ISPRS Journal of Photogrammetry and Remote Sensing 204, 275–290. https://doi.org/10.1016/j.isprsjprs.2023.09.001
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Section B: Early Warning Systems and Preparedness

Overview

Forecasting, real-time analytics, and alert systems are key to effective early warning, enabling timely action to reduce disaster impacts. Satellite-based analytics help detect risks like drought and fire early, allowing governments, responders, and farmers to act proactively. AI-driven models enhance accuracy and localization of early warnings, supporting community-level preparedness. Tools like the AI-powered SADMS chatbot deliver tailored drought alerts, helping local users plan irrigation and protect crops. Overall, AI enables timely, location-specific responses, turning early warning into early action.

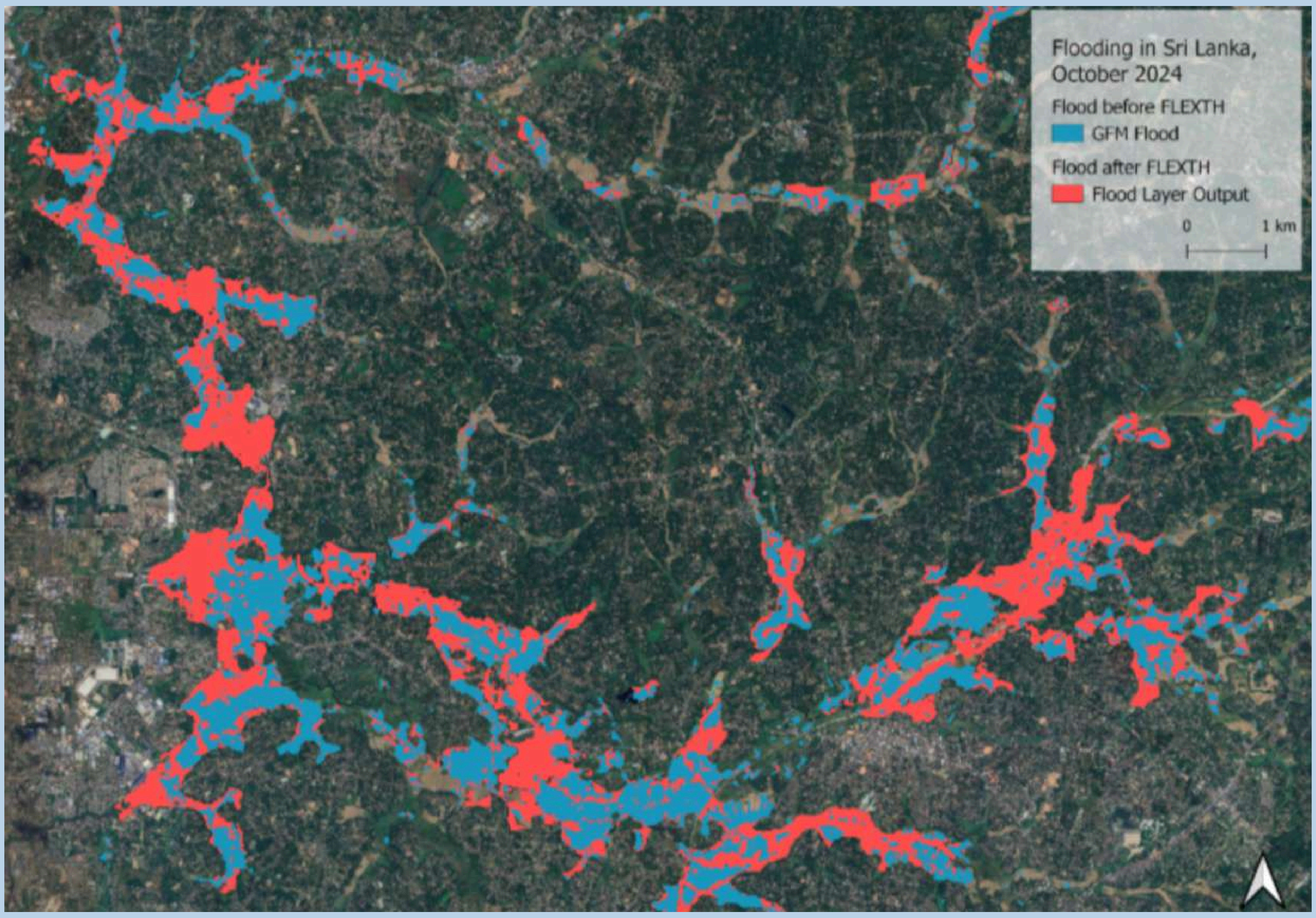

Figure: October Floods 2024, Sri Lanka
(c) UN-SPIDER Knowledge Portal

ECOE | LEVERAGING MACHINE LEARNING FOR WILFDIRE RISK ASSESSMENT USING MULTIMODEL GEOSPATIAL DATA IN CYPRUS

Title of GeoAI Practice

Leveraging Machine Learning for Wildfire Risk Assessment Using Multimodal Geospatial Data in Cyprus

Brief Description

Cyprus is located in the Eastern Mediterranean, which is an area where forest fires frequently occur, especially during the dry and hot summer months. Factors such as prolonged drought, high temperatures, strong winds, steep slopes, and dry flammable vegetation significantly increase the fire risk. Effective wildfire risk prediction and management require timely, early warning systems and accurate, spatially explicit information about vegetation conditions, which play a critical role in determining fire behaviour. Within the framework of the EXCELSIOR Horizon Europe project (https://excelsior2020.eu/), the ERATOSTHENES Centre of Excellence developed a Geo-AI tool aimed at predicting the fire risk across Cyprus. This tool was developed using a comprehensive multimodal dataset covering 2001 to 2023, incorporating anthropogenic, environmental, meteorological, topographic, and fire-related features. A range of machine learning and deep learning algorithms were tested to identify the most accurate algorithm.

Challenge or Problem Addressed

Cyprus faces an increasing wildfire threat, particularly during its hot and dry summers. From 2000 until today, Cyprus has experienced significant tree cover loss due to forest fires, with 2021 marking the most catastrophic year on record. The increased frequency and intensity of these fires are driven by a combination of climatic conditions, complex topography and human activities. Traditional fire prediction systems often lack the spatial resolution, time and data integration necessary for effective fire prevention and management. This gap has substantial economic, social and environmental implications, including high restoration costs, damage to infrastructure and threats to human safety. This model addresses this challenge by developing a cutting-edge GeoAI tool that delivers next-day fire risk predictions at a 500m spatial resolution. Specifically, the fire risk GeoAI tool aims to improve wildfire risk prediction and Cyprus's disaster early warning system to support decision making for fire prevention, emergency planning and resource allocation while also contributing to broader goals such as climate resilience, environmental monitoring and sustainable land management.

THE TOOL IS DESIGNED TO SUPPORT STAKEHOLDERS AND POLICYMAKERS IN DESIGNING **EFFECTIVE** FIRE PREVENTION STRATEGIES AND **IMPROVING** WILDFIRE MANAGEMENT.

ECOE | LEVERAGING MACHINE LEARNING FOR WILFDIRE RISK ASSESSMENT USING MULTIMODEL GEOSPATIAL DATA IN CYPRUS

Technical Approach and Methods

The research leveraged a multimodal dataset comprising data from 2001 to 2023, encompassing anthropogenic, environmental, meteorological, topographic, and fire-related features. These parameters are well-known fire drivers and can be used for the monitoring of wildfires (pre-fire and post-fire). Key anthropogenic features included road density and locations for picnics and camping, while topographical factors encompassed slope, elevation, and aspect. The environmental factors considered were land cover, vegetation indices, and the forest-agriculture interface. Additionally, meteorological data such as temperature, wind speed and direction, and precipitation were included in the analysis. The collected data were pre-processed, to ensure spatial and temporal consistency across the dataset. This involved cleaning, normalizing, and harmonizing all variables to match the spatial resolution of MODIS vegetation indices at 500m using the nearest neighbour technique. Regarding the temporal resolution, data from various sources collected between 1 January 2001, to 1 January 2023, were aggregated and interpolated to a daily resolution based on the nearest ERA5 data which are available on a daily basis. Based on this approach, daily minicubes were created for each date within the selected time frame, representing the values for each feature at a 500m spatial resolution. After the preparation of the dataset, a range of machine learning and deep learning algorithms (e.g. Random Forests, SVM, CNNs etc) were tested to identify the most accurate algorithm. The model performance was evaluated using metrics such as precision, recall, F1-score, and AUC, ensuring optimal selection for daily fire risk forecasting.

Impact and Outcomes

The Fire Risk GeoAI tool project, which provides daily fire predictions, aims to significantly improve forest and fire management nationally. Also, will offer fire risk predictions with spatial resolution at 500m (at least). This would help to develop more targeted and effective fire prevention strategies, which help save millions in economic costs associated with uncontrolled wildfires. One of the significant impacts of a forest fire is the negative economic effect due to damage to the environment (high cost for restoration actions), to urban areas (high cost for repairs and rebuilding), tourism, and the economic cost of putting out the fires. Moreover, the most significant impact of forest fires relates to social effects such as death, health issues, property loss, and livestock, etc. By improving fire management capabilities, the fire risk GeoAI tool enhances the safety of communities, especially those in fire-prone areas.

ECOE | LEVERAGING MACHINE LEARNING FOR WILFDIRE RISK ASSESSMENT USING MULTIMODEL GEOSPATIAL DATA IN CYPRUS

Alignment with SDGs

3 GOOD HEALTH AND WELL-BEING

11 SUSTAINABLE CITIES AND COMMUNITIES

13 CLIMATE ACTION

15 LIFE ON LAND

17 PARTNERSHIPS FOR THE GOALS

Lessons Learned and Recommendations

The development and implementation of the fire risk prediction tool provided valuable insights about the opportunities and challenges of applying GeoAI in environmental monitoring. A key lesson learned is the importance of integrating diverse data sources into a unified framework to capture the complex dynamics that lead to the occurrence of wildfires. Additionally, another critical aspect is to ensure data quality, consistency and resolution alignment, which requires significant pre-processing efforts. Also, the selection of suitable machine learning algorithms and performance metrics played a vital role in achieving reliable predictions. Future work should focus on real-time data integration, higher spatial resolution products like Sentinel-2 and the operational deployment of fire prediction tools through cloud platforms or early warning dashboards.

Additional References or Resources

- GreenHIT project: A Green - Holistic IoT platform for Forest Management and Monitoring - https://mdl.frederick.ac.cy/Home/Projects/Details/GreenHIT
- Prodromou, M., Girtsou, S., Leventis, G., Koumoulidis, D., Tzouvaras, M., Mettas, C., and Hadjimitsis, D., 2024. Multimodal Dataset for Wildfire Risk Prediction in Cyprus. In IGARSS 2024-IEEE International Geoscience and Remote Sensing Symposium, https://doi.org/10.1109/IGARSS53475.2024.10642963.
- Prodromou, M., Girtsou, S., Leventis, G., Koumoulidis, D., Tzouvaras, M., Mettas, C., Apostolakis, A., Kaskara, M., Kontoes, H., and Hadjimitsis, D.: Creation of data cube for the analysis of wildfires in Cyprus using open access data, EGU General Assembly 2024, Vienna, Austria, 14–19 Apr 2024, EGU24-22445, 2024. https://doi.org/10.5194/egusphere-egu24-22445.
- Prodromou, M.; Gitas, I.; Mettas, C.; Tzouvaras, M.; Themistocleous, K.; Konstantinidis, A.; Pamboris, A.; Hadjimitsis, D. Remote-Sensing-Based Prioritization of Post-Fire Restoration Actions in Mediterranean Ecosystems: A Case Study in Cyprus. Remote Sens. 2025, 17, 1269. https://doi.org/10.3390/rs17071269

ECOE | LEVERAGING MACHINE LEARNING FOR WILFDIRE RISK ASSESSMENT USING MULTIMODEL GEOSPATIAL DATA IN CYPRUS

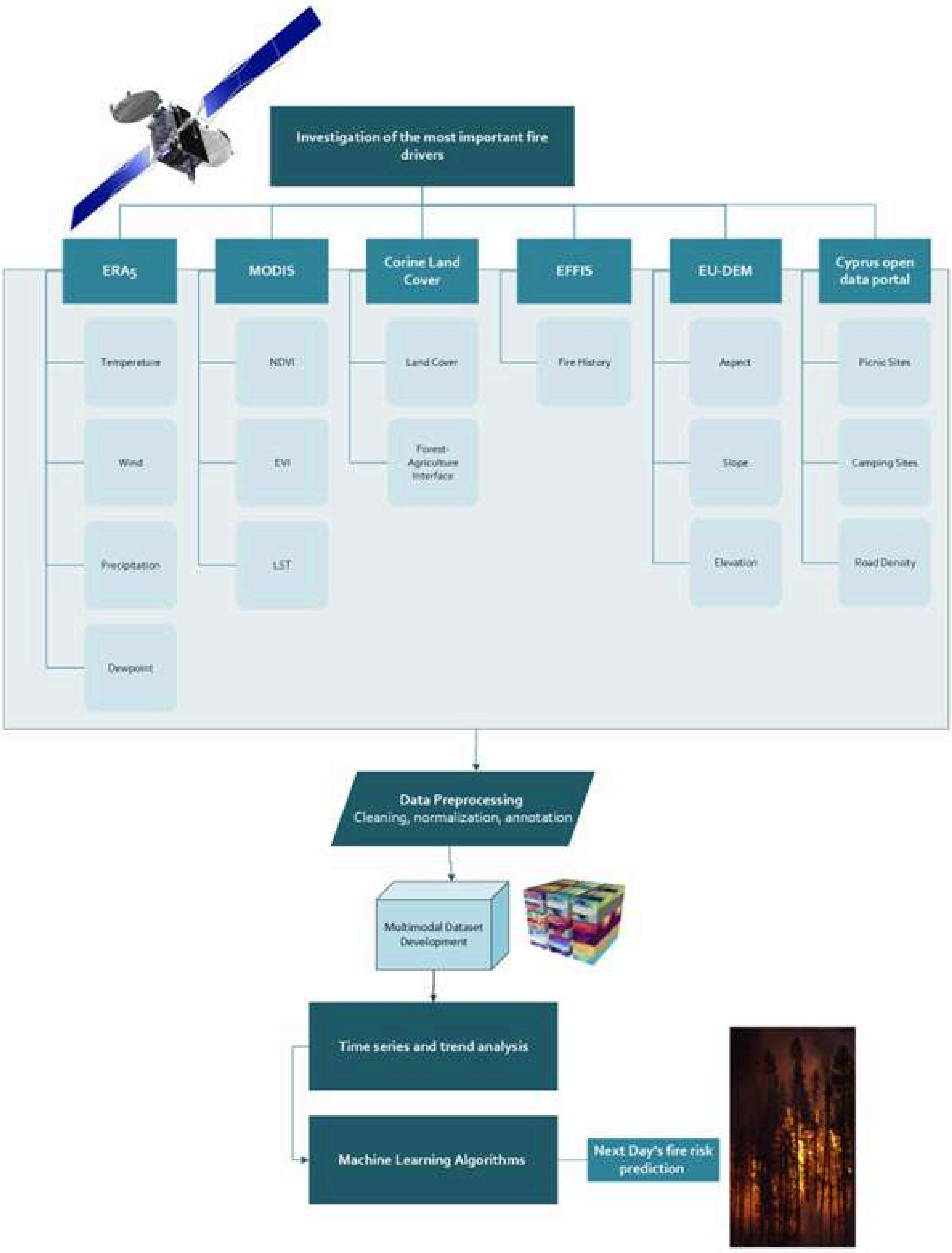

Figure: Wildfire risk assessment methodology

IWMI | AI FOR ACTION: TRANSFORMING DROUGHT PREPAREDNESS AND DECISION-MAKING IN INDIA

Title of GeoAI Practice

AI for Action: Transforming Drought Preparedness and Decision-Making in India

Brief Description

Drought is a recurrent and escalating challenge in India, disproportionately affecting smallholder farmers. To address gaps in anticipatory action and contingency planning, this project developed an AI-powered chatbot integrated with the South Asia Drought Monitoring System (SADMS). The chatbot interprets drought indices —SPI, VHI, SMAI, TCI—alongside real-time satellite data and district contingency plans to provide localized advisories in regional languages. Leveraging DeepSeek-V3 and a LangChain AI agent, it delivers context-aware recommendations spanning crops, livestock, and water resources. Deployed across drought-prone states like Maharashtra and Tamil Nadu, the system supports farmers and local agencies in taking early action. By turning complex data into user-friendly insights, the platform bridges the last-mile delivery gap and sets a precedent for AI-enabled resilience at scale.

Challenge or Problem Addressed

India experiences recurring seasonal droughts, yet district-level contingency plans are often static and underutilized. Local stakeholders lack real-time decision support, especially in rural and linguistically diverse areas. The project tackles fragmentation in data dissemination and inadequate localized advisories, particularly affecting smallholder farmers.

Impact and Outcomes

The AI tool has enhanced early drought response by delivering over 5,000 localized advisories to farmers and officials during pilot phases. It has improved lead time for input decisions, fostered institutional uptake, and shaped contingency planning at district levels. Positive feedback from users prompted scale-up to additional districts and adaptation for use in climate-smart agriculture advisories.

Technical Approach and Methods

The AI system uses DeepSeek-V3 fine-tuned via LoRA and instruction tuning, with a Retrieval-Augmented Generation (RAG) setup to draw from government contingency plans. The LangChain agent integrates real-time satellite data (NDVI, CHIRPS, SMAP) via Google Earth Engine, and correlates it with drought indices from SADMS. Population maps and KVK locations help prioritize high-risk areas. The chatbot supports multilingual interaction using AI4Bharat language models, ensuring inclusive access.

IWMI | AI FOR ACTION: TRANSFORMING DROUGHT PREPAREDNESS AND DECISION-MAKING IN INDIA

Alignment with SDGs

Lessons Learned and Recommendations

Building AI solutions for rural drought management must combine data science with deep user insight. Co-design with farmers and extension agents ensured adoption. Challenges included inconsistent data across states and the need for continuous tuning of language models. Future efforts should focus on integration with national e-agriculture platforms, and ensure sustainable funding for long-term deployment.

AI-POWERED DROUGHT ADVISORIES TRANSFORM COMPLEX SATELLITE AND CLIMATE DATA INTO **LOCALIZED, MULTILINGUAL GUIDANCE** THAT HELPS SMALLHOLDER FARMERS AND LOCAL AGENCIES IN INDIA TAKE **TIMELY, INFORMED ACTION** AGAINST DROUGHT.

Additional References or Resources

- South Asia Drought Monitoring System (SADMS): http://dms.iwmi.org
- AI for Action Project Overview: https://www.iwmi.cgiar.org/what-we-do/ai-drought
- LangChain: https://www.langchain.com/
- AI4Bharat Language Tools: https://ai4bharat.org
- Sentinel Data via GEE: https://developers.google.com/earth-engine/datasets

AWARE PLATFORM: AI-ENABLED ANTICIPATORY ACTION FOR DROUGHT AND FLOOD RISK IN SRI LANKA

Title of GeoAI Practice

AWARE Platform: AI-Enabled Anticipatory Action for Drought and Flood Risk in Sri Lanka

Brief Description

The AWARE (Early Warning, Early Action and Early Finance) Platform is an AI-enhanced decision support system designed to strengthen early warning and early action mechanisms for drought and flood risks in Sri Lanka. Developed by the International Water Management Institute (IWMI), the platform integrates satellite-based hazard monitoring, socio-economic exposure data, and AI-driven forecasting models to support timely, location-specific anticipatory actions. AWARE synthesizes multi-source data—including rainfall anomalies, vegetation health, hydrological trends, and disaster impact records—into actionable advisories for humanitarian organizations, disaster managers, and local authorities. Through AI-powered simulations and interactive dashboards, users can visualize evolving risks and trigger pre-defined contingency actions, such as resource allocation, community outreach, or early financing. The system has been piloted with the Disaster Management Centre and other national stakeholders in Sri Lanka and is being expanded to support humanitarian actors and anticipatory financing instruments.

Challenge or Problem Addressed

Despite progress in early warning systems, Sri Lanka faces gaps in translating forecasts into early, preventive actions—especially for slow-onset disasters like droughts. Disaster management agencies often lack real-time, integrated platforms to assess risk, prioritize hotspots, and coordinate action across sectors. AWARE addresses the 'last mile' gap in early warning by offering a centralized platform that combines hazard forecasting, exposure mapping, and AI-generated advisories to support anticipatory decision-making.

THE AWARE PLATFORM USES AI-POWERED FORECASTING AND SATELLITE DATA TO **DELIVER TIMELY, LOCATION-SPECIFIC ADVISORIES** THAT HELP SRI LANKAN AUTHORITIES AND HUMANITARIAN ACTORS TAKE EARLY ACTION AGAINST DROUGHT AND FLOOD RISKS.

AWARE PLATFORM: AI-ENABLED ANTICIPATORY ACTION FOR DROUGHT AND FLOOD RISK IN SRI LANKA

Technical Approach and Methods

The platform leverages AI models trained on historical flood and drought data to simulate potential future scenarios. It integrates satellite products (e.g., MODIS NDVI, CHIRPS rainfall, SMAP soil moisture) and national datasets via Google Earth Engine. AWARE uses machine learning classifiers and ensemble forecasting for early warning generation. AI is also applied to rank risk-prone areas based on exposure (population, infrastructure) and vulnerability indicators. A dashboard enables users to view alerts, run scenario-based simulations, and trigger early actions linked to contingency plans. The platform is hosted on cloud infrastructure with API access for institutional partners.

Alignment with SDGs

11 SUSTAINABLE CITIES AND COMMUNITIES

13 CLIMATE ACTION

17 PARTNERSHIPS FOR THE GOALS

Impact and Outcomes

The platform has enabled the identification of high-risk zones up to two weeks in advance of drought or flood onset. It has informed early deployment of drought kits and coordination of emergency water distribution in pilot districts. AWARE has also contributed to capacity-building of disaster responders through simulated anticipatory action exercises. Its success has spurred interest in regional scaling to other South Asian countries.

Lessons Learned and Recommendations

AI integration must be context-aware and inclusive of institutional workflows. Building trust with government and humanitarian users is key for operational uptake. Challenges included limited local data availability, technical capacity gaps, and the need for continuous updates. Future recommendations include automating trigger thresholds, integrating community feedback systems, and linking the platform to disaster finance mechanisms.

Additional References or Resources

- AWARE Platform: https://www.iwmi.cgiar.org/projects/aware
- AWARE Technical Brief https://hdl.handle.net/10568/137194
- Drought Monitoring Tools: http://dms.iwmi.org
- CGIAR Climate Resilience Initiative: https://www.cgiar.org/initiative/climate-resilience
- Anticipatory Action Briefs: https://www.anticipation-hub.org/news/aware-a-digitally-enabled-governance-platform-for-effective-anticipatory-action-ahead-of-climate-shocks

SUPARCO | FOREST FIRE VULNERABILITY MAPPING IN NORTHERN PAKISTAN

Title of GeoAI Practice

Deep Learning-Based Mapping of Forest Fire Vulnerability Hotspots Using Multi-Source Satellite Imagery in Northern Pakistan

Brief Description

To enhance forest fire preparedness and mitigation, this practice is being developed with a GeoAI framework that integrates optical, thermal, SAR, and ancillary data to map forest fire vulnerability hotspots at high resolution (10–30 m). Utilizing Sentinel-2 and Landsat-8 imagery for vegetation indices (NDVI, NDMI), MODIS/VIIRS thermal data for land surface temperature, and Sentinel-1 SAR for moisture content, the model feeds multi-temporal composites into a hybrid CNN-LSTM architecture. Topographic features (slope, elevation) and human activity layers (roads, settlements) augment spectral inputs. The trained network produces probability maps of fire likelihood, followed by clustering (DBSCAN) to delineate continuous vulnerability zones.

Challenge or Problem Addressed

Forest fire frequency and intensity are increasing due to climate change, yet many regions lack fine-scale vulnerability maps to prioritize preventive measures. Traditional fire risk models often rely on coarse data or expert judgment. This practice fills the gap by automating hazard assessment with diverse remote sensing sources and deep learning to identify hotspots before ignition occurs.

Technical Approach and Methods

Data Sources

- Sentinel-2 (10 m) and Landsat-8 (30 m) for NDVI, NDMI, NBR; MODIS/VIIRS (1 km) for LST; Sentinel-1 SAR for moisture; DEM-derived slope and elevation.

Pre-processing

- Radiometric calibration, atmospheric correction, cloud masking, and monthly composite generation of dryness indices.

Model Architecture

- Hybrid CNN-LSTM—CNN layers extract spatial patterns, followed by LSTM units to capture temporal trends.

Training & Labels

- Historical fire hotspots from MODIS/VIIRS Active Fire Data; data augmentation with synthetic dryness scenarios.

Hotspot Extraction

- Pixel-wise fire probability maps post-processed with DBSCAN clustering to delineate vulnerability zones.

SUPARCO | FOREST FIRE VULNERABILITY MAPPING IN NORTHERN PAKISTAN

Impact and Outcomes

- Informed allocation of firebreak construction and fuel reduction programs, reducing response times.
- Enhanced community early warning via risk dashboards integrated into the national incident management system.

Lessons Learned and Recommendations

This initiative aims to leverage GeoAI based techniques in order to efficiently identify hotspots for possible fire events using hyperspectral and multispectral imagery. However, temporal resolution remains a key challenge in continuous monitoring of fire events.

Alignment with SDGs

13 CLIMATE ACTION

15 LIFE ON LAND

GEOAI-DRIVEN FOREST FIRE MAPS IDENTIFY VULNERABILITY HOTSPOTS, ENABLING EARLY WARNING SYSTEMS AND TARGETED PREVENTION MEASURES TO PROTECT FORESTS AND COMMUNITIES.

SUPARCO | HIGH-RESOLUTION FIELD-SCALE CROP MAPPING

Title of GeoAI Practice

Multi-Temporal-Sequence Deep Learning Based Approach for High-Resolution Field-Scale Crop Mapping

Brief Description

This practice incorporates multi-temporal high-resolution satellite imagery and advanced sequence aware deep learning into the delivery of field scale crop classification in heterogeneous agricultural landscapes. High resolution multispectral imagery (RGB+NIR) with 1m – 1.5m spatial resolution, which is acquired at key phenological stages, are radiometrically and geometrically pre-processed, and then stacked into ordered time series tiles. The model uses semantic-segmentation neural network with ConvLSTM modules which enables the network to learn both spatial textures and temporal phenology. Deployed as containerized microservice and exposed as OGC-compliant WMS/WFS endpoints on the NatCat Risk Calculator platform delivering per-pixel crop-type maps. NatCat Risk Calculator uses these crop-type layers as key elements at risk for exposure and risk/loss assessment, hence allowing probabilistic flood and drought risk assessments to incorporate current spatial distributions of crop species and therefore refine loss estimations and vulnerability analysis at district and tehsil levels.

Challenge or Problem Addressed

- At a single date, many crops show similar spectral signatures. To differentiate between the two types of crop, it is very important to track the phenological changes across crop life cycle. ConvLSTM helps in learning both spatial textures and temporal phenology.
- Mixed cropping areas demand both high spatial resolution as well as temporal context to map the field level crops and field verification.

DEEP LEARNING-BASED CROP MAPPING ENABLES ACCURATE FLOOD AND DROUGHT RISK ASSESSMENTS IN COMPLEX AGRICULTURAL LANDSCAPES.

SUPARCO | HIGH-RESOLUTION FIELD-SCALE CROP MAPPING

Technical Approach and Methods

Data Acquisition & Pre-processing

- High resolution satellite imagery (1m – 1.5m with multispectral bands RGB+NIR)
- Ground surveyed data and ancillary spatial data layers
- Radiometric correction
- Multi-Temporal stacking with 4-6 cloud free scenes per season.

Sequence-Aware Neural Architecture

- U-Net encoder–decoder with EfficientNet.
- ConvLSTM modules inserted at the bottleneck and between each encoder–decoder skip connection, allowing the model to learn temporal dependencies in feature maps.
- Temporal attention gates to weigh critical phenological phases (e.g., peak greenness) for each crop class.

The training pipeline uses weighted focal loss to make the training resistant to the class imbalance problem and is trained using Adam optimizer. To increase model robustness, spatial augmentations (random rotations, flips, scale jitter), and spectral perturbations (band dropout, brightness/contrast) were performed.

Classified per pixel outputs are published through OGC-compliant WMS/WFS endpoints in NatCat Risk Calculator platform.

Impact and Outcomes

- Enhanced Crop mapping and monitoring
- Up-to-date crop inventories with production estimates
- Provision of insurers with robust crop-type baselines for disaster related insurance

Alignment with SDGs

Lessons Learned and Recommendations

This study demonstrated how learning temporal phenological changes across cropping seasons aids in accurately detecting and mapping field-level crop types for risk/loss estimation.

Additional References or Resources

- NatCat Model Platform: https://natcat.ndrmf.pk/login/index.php

Section C: Emergency Response and Rapid Damage Assessment

Overview

GeoAI enables rapid damage mapping and relief coordination by analyzing satellite imagery in near real time. It can automatically detect impacts such as building collapse or flooding, improving response speed and accuracy in major disasters. Quick-turnaround analytics provide responders and planners with real-time insights, allowing fast decision-making and resource allocation. Tools like nighttime satellite imagery and AI models enhance situational awareness, supporting both immediate relief and long-term recovery planning.

Figure: Earth Observation of night time lights for flood risk management
(c) UN-SPIDER Knowledge Portal

WHU | DISASTER-AFFECTED BODIES FINE-SCALE DAMAGE ASSESSMENT USING HIGH-RESOLUTION REMOTE SENSING

Title of GeoAI Practice

Disaster-Affected Bodies Fine-Scale Damage Assessment Using High-Resolution Remote Sensing: Case Studies of Earthquakes and Floods in China

Brief Description

High-resolution remote sensing image has emerged as a pivotal tool for precise post-disaster damage assessment, particularly in evaluating the destruction of disaster-affected bodies such as building, road et.al. This approach leverages sub-meter satellite imagery (e.g., WorldView-3, GF-2) to detect structural deformations, collapses, or inundation patterns with exceptional accuracy. In earthquake-prone regions like Gansu, China, pre- and post-event optical imagery (e.g., 0.3–0.5m resolution) identifies micro-cracks in buildings or road displacements, as observed in the 2023 Jishishan earthquake. For flood monitoring, Multi-temporal fusion of Gaofen (GF) series satellites (e.g., GF-2) further enhances dynamic flood extent analysis. Machine learning algorithms, trained onopen-source and self-constructed datasets, automate damage classification by cross-referencing multi-source imagery. Challenges such as rapid data acquisition and cloud interference are mitigated by China's domestic satellite constellations (e.g., Jilin-1) and edge-computing UAVs. Integrated into national disaster frameworks, HRRS exemplifies China's technical resilience, enabling prioritized emergency responses and data-driven reconstruction.

Challenge or Problem Addressed

High-resolution remote sensing (HRRS) faces significant challenges in assessing Disaster-Affected Bodies damage post-disasters. Cloud cover, particularly during floods, obstructs optical imagery, necessitating reliance on lower-resolution SAR data. Rapid data acquisition is constrained by satellite revisit cycles, delaying emergency responses. Processing sub-meter imagery demands immense computational resources and efficient algorithms. Machine learning models require extensive labeled datasets, which are scarce for rare or complex disaster scenarios, limiting generalization across diverse terrains and building types. Field validation post-disaster is often logistically unfeasible. Despite advancements in AI and sensor technology, these hurdles impede HRRS's potential for real-time, precise damage evaluation.

Technical Approach and Methods

Deep Learning-Integrated Object-Oriented Damage Assessment Method for Disaster-Affected Structures Using High-Resolution Remote Sensing Imagery. This method employs a deep learning-integrated object-oriented framework to evaluate structural damage caused by disasters. Pre-disaster high-resolution optical imagery (e.g., Google Earth) establishes baseline building footprints, while post-disaster multi-source data (Jilin-1, GF-2 satellites, and UAV imagery) capture post-event conditions.

WHU | DISASTER-AFFECTED BODIES FINE-SCALE DAMAGE ASSESSMENT USING HIGH-RESOLUTION REMOTE SENSING

Impact and Outcomes

This approach significantly enhances national disaster loss assessment by integrating multi-scale, high-resolution data (e.g., Jilin-1, UAVs) with AI-driven analysis, enabling precise quantification of structural damage across urban and rural areas. Concurrently, it revolutionizes traditional workflows by replacing manual, time-intensive surveys with automated, scalable solutions. Emergency management agencies (e.g., National Disaster Reduction Center) now prioritize tasks dynamically, while provincial departments leverage standardized GIS reports to accelerate decision-making. By bridging technical innovation with administrative needs, the method fosters a paradigm shift toward agile, data-driven disaster governance, reducing assessment cycles from weeks to days and minimizing human error in critical post-disaster scenarios.

Alignment with SDGs

BY COMBINING HIGH-RESOLUTION REMOTE SENSING WITH DEEP LEARNING, CHINA'S DISASTER MANAGEMENT AGENCIES CAN **RAPIDLY AND ACCURATELY ASSESS STRUCTURAL DAMAGE**, REPLACING MANUAL SURVEYS WITH AUTOMATED, DATA-DRIVEN WORKFLOWSTHAT ACCELERATE POST-DISASTER RESPONSE AND RECONSTRUCTION.

Lessons Learned and Recommendations

A key lesson from implementing this approach is the pivotal importance of real-time data accessibility and reliable acquisition of high-resolution remote sensing (HRRS) imagery for effective disaster damage assessment. While satellites like Jilin-1 and UAVs enable rapid post-disaster data collection, challenges persist. It is necessary to combine near-real-time SAR for all-weather monitoring, UAVs for local details, and open-access platforms (e.g., Gaofen series) for wide-area coverage.

Additional References or Resources

- Z. Zheng, Y. Zhong, J. Wang, A. Ma, and L. Zhang, "Building damage assessment for rapid disaster response with a deep object-based semantic change detection framework: From natural disasters to man-made disasters," Remote Sensing of Environment, vol. 265, p. 112636, 2021

WHU | DISASTER EVALUATION USING NIGHTTIME LIGHT DATA

Title of GeoAI Practice

Disaster Evaluation using nighttime light data

Brief Description

In the era of climate change with increasingly number of natural disasters, UN-SPIDER leveraged nighttime light remote sensing data and other geospatial datasets, combined with advanced AI techniques, to monitor power loss and recovery following disaster events such as the Turkey-Syria earthquake, the Morocco earthquake, the Pakistan flood, and the Libya flood. By applying time series algorithms, this work was able to assess the immediate impact of these disasters and track the pace and heterogeneity of recovery trajectories across different regions. This data-driven approach provides a rapid and objective alternative to traditional field-based assessments, particularly valuable in data-scarce regions. The results have offered critical insights for humanitarian aid, emergency response, and long-term reconstruction efforts, and have been presented through peer-reviewed academic publications and with international organizations.

Challenge or Problem Addressed

Rapid urbanization has made cities not only hubs of population and economic activities but also areas with higher exposure to natural disasters. This practice aims to address challenges in urban disaster management, particularly by assessing the extent of damage (e.g., power outages) and the heterogenous recovery processes, thereby supporting the achievement of Sustainable Development Goal 11, which focuses on making cities inclusive, safe, resilient, and sustainable.

Technical Approach and Methods

Both the Visible Infrared Imaging Radiometer Suite (VIIRS) nighttime light data and high-resolution nighttime light datasets, including SDGSAT-1 (RGB: 40 m) and Yangwang-1 (37 m) were utilized in this work. Enhanced daily VIIRS images, processed through angular effect correction and gap-filling, provided large-scale insights into power dynamics. High-resolution nighttime light images after intercalibration enabled fine-grained and detailed analysis of power loss and recovery within cities. The intercalibration process could adopt either linear regression models or more advanced machine learning models to improve temporal consistence across nighttime light images. Building on the pre-processed datasets, spatiotemporal pattern mining techniques were further applied to identify the heterogeneity of disaster impacts and recovery processes across different regions, thereby supporting targeted post-disaster planning and response.

WHU | DISASTER EVALUATION USING NIGHTTIME LIGHT DATA

Impact and Outcomes

The integration of multi-source nighttime light datasets and spatiotemporal analysis techniques yielded several notable impacts. It significantly enhanced situational awareness by enabling rapid and evidence-based assessments of disaster-induced power loss. The high spatial and temporal resolution of the nighttime light datasets allowed for the identification of spatial disparities and temporal delays in recovery, facilitating more equitable and targeted allocation of relief resources. These directly contribute to strengthening disaster resilience and advancing disaster risk reduction efforts.

Lessons Learned and Recommendations

The project yielded vital insights into the assessment of disaster impacts and recovery processes by leveraging nighttime earth observations, especially with high-resolution nighttime light data which enabled more detailed analysis. However, the limited availability of ground-truth data for validation remains a constraint, underscoring the importance of strengthening collaborations with local governments and agencies to access relevant statistical and survey data. In the future, early and sustained engagement with stakeholders is essential to align analytical outputs with operational and policy needs. This will help ensure that the insights derived from nighttime light remote sensing data can effectively inform disaster response, guide recovery strategies, and support long-term resilience-building initiatives.

NIGHTTIME LIGHT DATA REVEALS WHAT THE DARK HIDES — ENABLING **FASTER**, **FAIRER**, AND **EVIDENCE-BASED** DISASTER RESPONSE WHEN POWER AND VISIBILITY ARE LOST.

Alignment with SDGs

11 SUSTAINABLE CITIES AND COMMUNITIES

13 CLIMATE ACTION

WHU | DISASTER EVALUATION USING NIGHTTIME LIGHT DATA

Additional References or Resources

- Jia, M., Li, X., Gong, Y., Belabbes, S., & Dell'Oro, L. (2023). Estimating natural disaster loss using improved daily night-time light data. International Journal of Applied Earth Observation and Geoinformation, 118, 103173. https://doi.org/10.1016/j.jag.2023.103173
- UNITAR-UNOSAT. (n.d.-a). Flood analysis: Nyala, South Darfur, Sudan – Situation as of 18 August 2022 [Map]. https://unosat.org/products/3497
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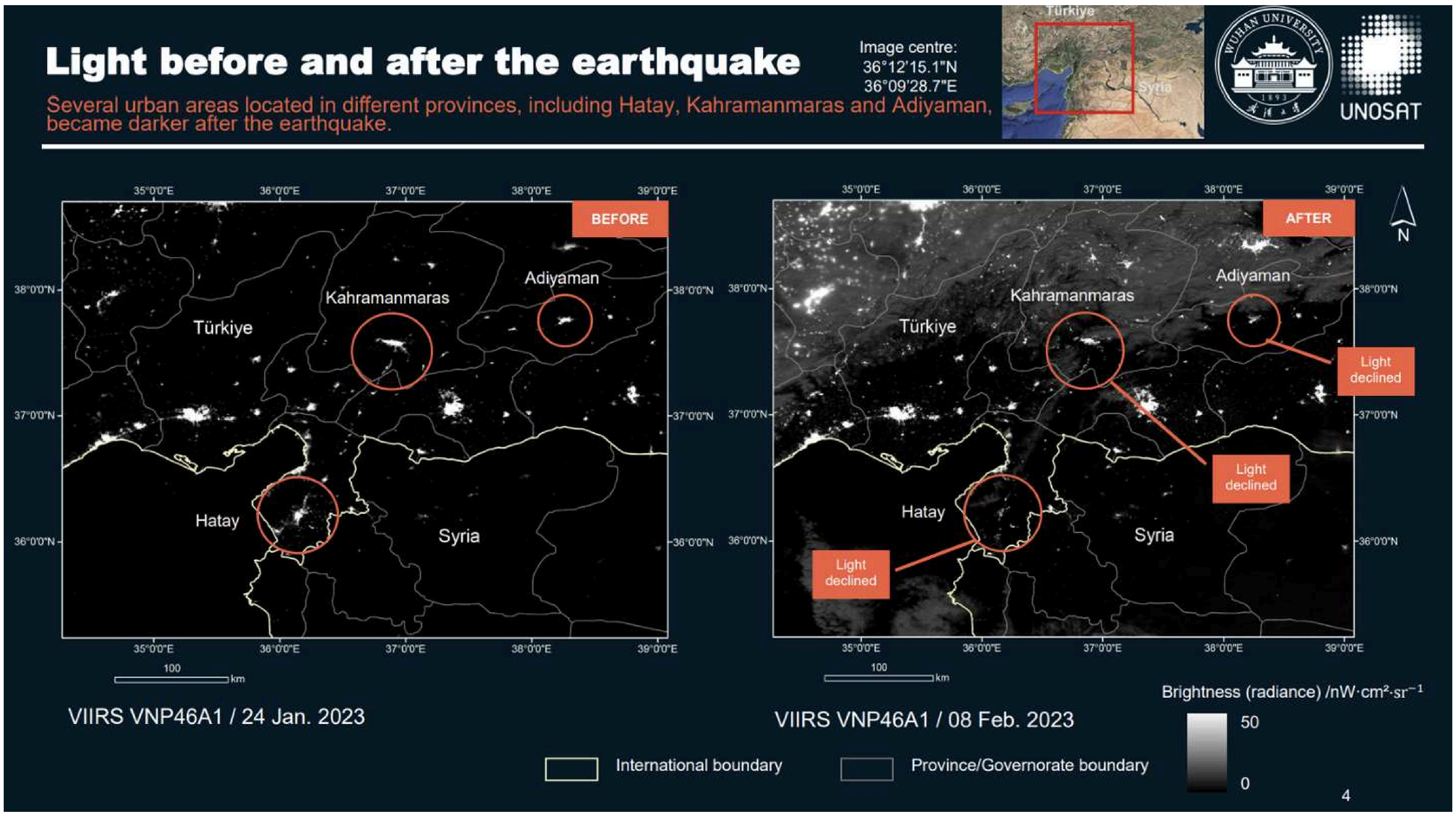

Figure: Power loss using VIIRS nighttime light data

WHU | DISASTER EVALUATION USING NIGHTTIME LIGHT DATA

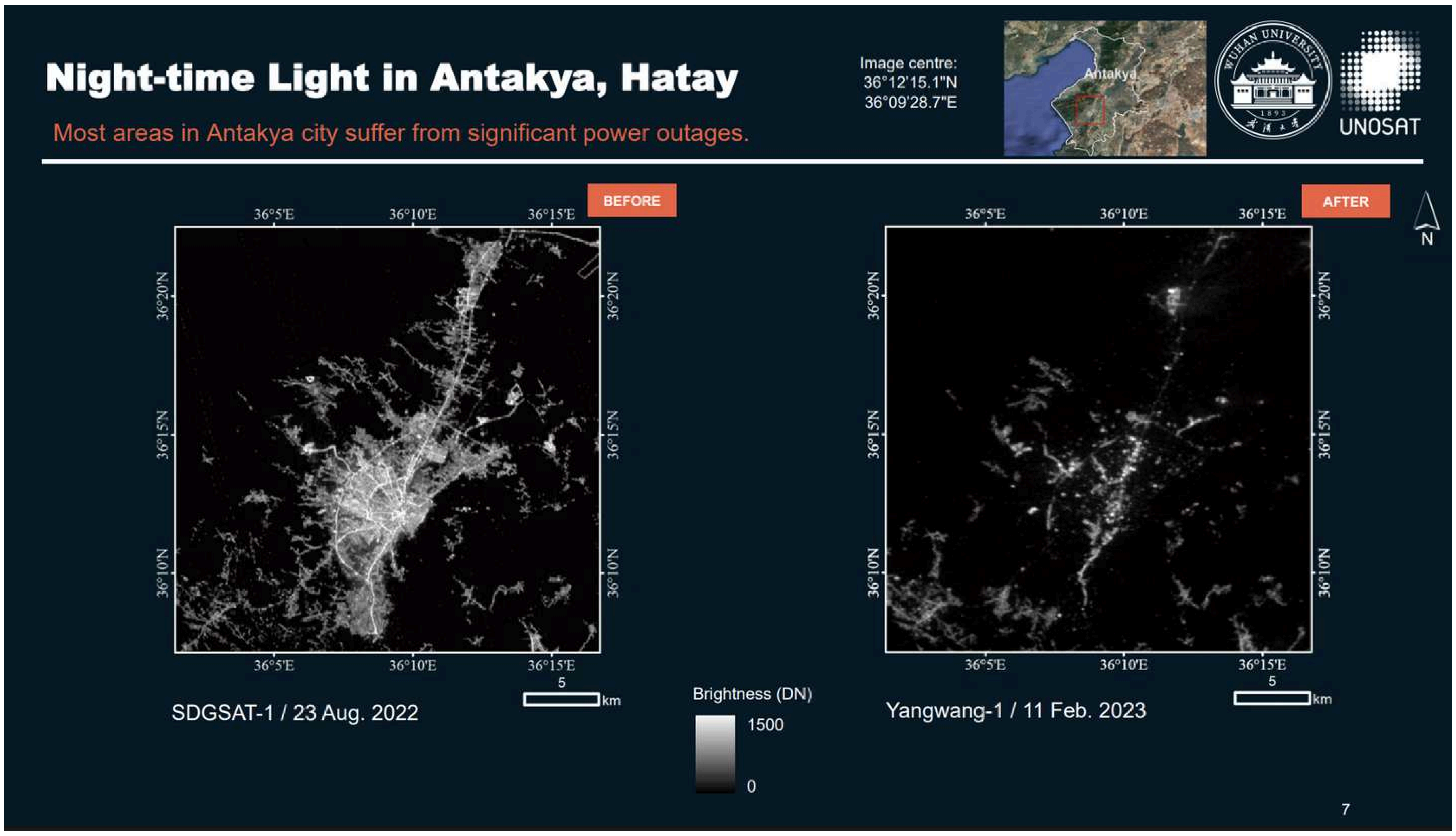

Figure: Power loss using high resolution nighttime light data

Section D: Recovery, Reconstruction, and Resilience Building

Overview

Post-disaster recovery must address both immediate humanitarian needs and long-term rebuilding to avoid recurring vulnerabilities. Integrating disaster risk reduction and climate resilience—such as improved building codes and early warning systems—helps ensure safer, more sustainable recovery. Geospatial and AI technologies support this by providing damage maps, risk assessments, and satellite imagery that guide reconstruction. These tools help prioritize interventions, inform land-use planning, and ensure resources reach the most affected areas, accelerating recovery and building lasting resilience.

Figure: Satellite imagery used for assessment and aid relief efforts after earthquake hit Port-Au-Prince
(c) UN Earth Observation and Imagery

ECOE | EARTHQUAKE RISK ASSESSMENT FOR THE PROTECTION OF CRITICAL INFRASTRUCTURE IN CYPRUS

Title of GeoAI Practice

Earthquake risk assessment for the protection of critical infrastructure in Cyprus

Brief Description

Cyprus is located at the boundary between the Eurasian, Arabian and African plates within a complex tectonic setting, with at least 16 destructive earthquakes and many other smaller ones in the last 2000 years. Largest earthquakes mostly occurred at the southern part of the island, causing damage in Paphos, Limassol and Famagusta, with the latest deadliest earthquake occurring in 1953 (Mw6.1), leading to 40 fatalities, 100 injuries and extensive damage to 158 villages and the city of Paphos. According to the National Risk Assessment of Cyprus, earthquakes is the natural disaster with the second most important monetary impact and the first in terms of population affected. The earthquake/seismic events are closely monitored in Cyprus by the Geological Survey Department through a network of 14 seismological stations.

Challenge or Problem Addressed

Ageing of critical infrastructure, such as public buildings (hospitals, schools, etc.) as well as roads and bridges can potentially amplify the impact of earthquakes, and thus their systematic monitoring is of great importance. In this direction, an AI-based algorithm was developed to assess earthquake vulnerability at the Paphos General Hospital. The General Hospital in Paphos is a critical infrastructure given its role in providing essential healthcare services, particularly during emergencies. Therefore, the structural resilience of this building is of paramount importance. The Paphos General Hospital, built in the late 20th century features a reinforced concrete structure that is typical of its construction period. However, the age of the building, combined with the higher seismic demands of a multi-storey healthcare facility, makes it potentially vulnerable to seismic events. As Paphos is situated in a seismically active area, with historical earthquakes ranging from moderate to high magnitudes, assessing the building's earthquake risk is essential to ensure the safety of its occupants and the continuity of critical healthcare services during such events.

ECOE | EARTHQUAKE RISK ASSESSMENT FOR THE PROTECTION OF CRITICAL INFRASTRUCTURE IN CYPRUS

Technical Approach and Methods

Seismic risk assessment for Cyprus is based on event-based probabilistic seismic risk analysis and eventual selection of seismic scenarios for given return periods. The current study was included in the 2018 National Risk Assessment of Cyprus, following the EC requirements and guidelines. This analysis is performed with the relevant algorithm of Openquake platform, which first incorporates stochastic event-based hazard analysis for extended earthquake catalogues and models of the area. The exposure model employed is built and elaborated by local resources, whereas the vulnerability model developed for local building typologies was used with additional considerations. The data used for the calculation of earthquake vulnerability are described next. Geology, geological zones, seismic zones and the location of seismological stations are provided by the Cyprus Geological Survey Department. Moreover, the construction material, the number of floors and the year of construction are also used as an input to the earthquake risk assessment pipeline. The produced vulnerability assessment index is then enriched by the incorporation of AI and image processing techniques to determine the structural condition and climate-induced degradation state using street level images of structural and non-structural elements, e.g., beams, columns, infill walls etc, identify and correlate damage levels with an extensive image databases (images of structural damage at various levels), and update vulnerability status based on real-time assessments.

Impact and Outcomes

The developed GeoAI tool has led to enhanced situational awareness for relevant stakeholders and end users, providing valuable and timely information to support data-driven decisions regarding infrastructure protection and resilience. Moreover, the developed methodology has resulted in the timely detection of vulnerable areas to earthquakes. To further increase its impact, capacity building is currently being provided to local authorities dealing with infrastructure protection and resilience practices, building permit provides, as well as to first and second responders.

Alignment with SDGs

ECOE | EARTHQUAKE RISK ASSESSMENT FOR THE PROTECTION OF CRITICAL INFRASTRUCTURE IN CYPRUS

Lessons Learned and Recommendations

The development of the earthquake risk assessment tool provided valuable insights about the opportunities and challenges of applying GeoAI in environmental monitoring. The integration of datasets of various formats and scales originating from various data sources into a unified framework was quite challenging, requiring significant pre-processing efforts. The selection of appropriate training datasets was also very important to ensure the development of a reliable tool that would provide accurate results. Future work will include real-time data integration and the operational tool deployment through cloud platforms or early warning dashboards.

THIS PRACTICE INTEGRATES DIVERSE DATASETS FOR MORE ACCURATE HAZARD PREDICTION, ADDRESSING KEY CHALLENGES IN **DATA FRAGMENTATION AND MODEL RELIABILITY.**

Additional References or Resources

- Kazantzidou-Firtinidou, D., Kyriakides, N., Votsis, R., & Chrysostomou, C. Z. (2022). Seismic risk assessment as part of the National Risk Assessment for the Republic of Cyprus: From probabilistic to scenario-based approach. Natural Hazards, 112(1), 665–695. https://doi.org/10.1007/s11069-021-05200-y.
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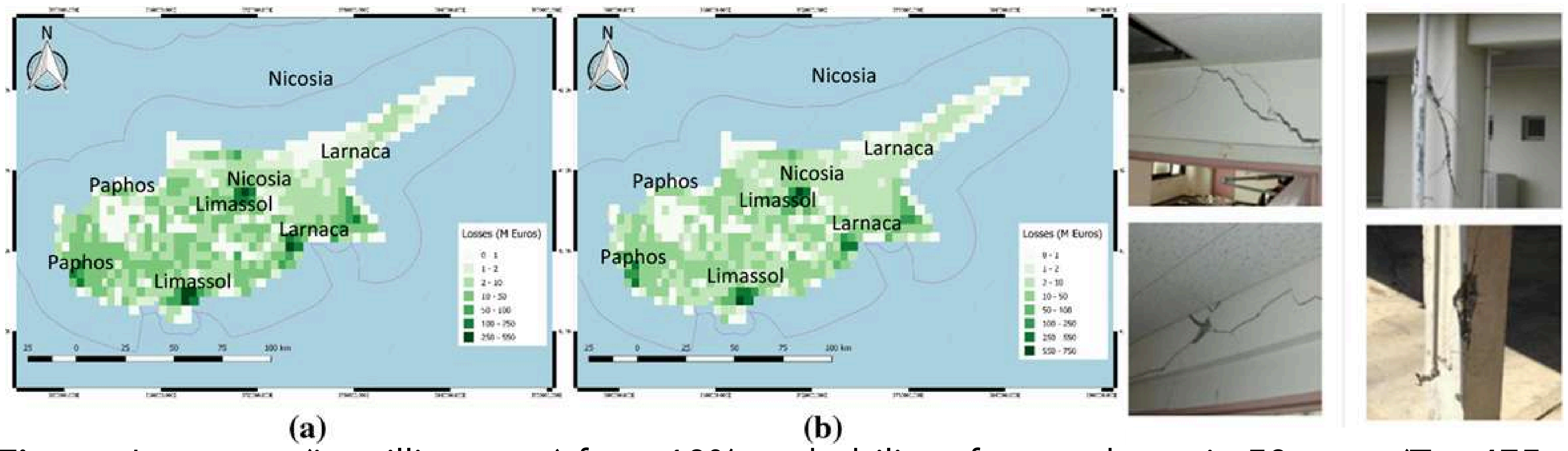

Figure: Loss map (in million euro) for a 10% probability of exceedance in 50 years (T = 475 years) and b for 2% probability of exceedance in 50 years (T = 2500 years)

SUPARCO | BUILDING TYPOLOGY CLASSIFICATION IN MAJOR URBAN AREAS

Title of GeoAI Practice

Deep Learning–Based Framework for Integrating Satellite Imagery and Elevation Data to Classify Building Typology in Major Urban Areas

Brief Description

Accurate building typology classification is essential for disaster risk reduction, urban planning, and infrastructure resilience. This practice presents a GeoAI framework that fuses high-resolution optical satellite imagery with very high resolution Digital Surface Model (DSM) data to automatically classify buildings into typologies such as residential low-rise, residential mid-rise, residential high-rise, commercial, and industrial. A dual-branch convolutional neural network extracts spectral-textural features from satellite imagery and geometric features from digital surface models. Late-stage feature fusion enhances the model's discriminative power in complex urban environments. Trained on annotated footprints derived from Google's Open Buildings across multiple cities, this study aims at achieving significant accuracy. The resulting building typology maps would support targeted emergency response planning and infrastructure monitoring, and can be updated periodically to reflect urban growth dynamics.

Challenge or Problem Addressed

Many regions lack up-to-date, spatially explicit information on building typologies, limiting the accuracy of hazard exposure models and response planning. Manual surveys are time-consuming and costly, while existing datasets are often outdated or incomplete. This practice addresses the need for an automated, scalable approach to generate high-resolution building typology maps in diverse urban contexts.

Technical Approach and Methods

- **Data Sources:** Satellite imagery (1 m resolution), Digital Surface Model (DSM).
- **Model Architecture:** Dual-branch CNN—one branch processes multispectral image patches around each footprint, the other processes elevation profiles derived from DEM rasters. Feature vectors are fused via concatenation and passed through fully connected layers with attention-based weights.
- **Training and Validation:** Footprints and typology labels from Open Buildings. Augmentation includes rotation, scaling, and synthetic noise.
- **Tools & Frameworks:** TensorFlow 2.x, GDAL for raster handling, Pandas, Rasterio.

SUPARCO | BUILDING TYPOLOGY CLASSIFICATION IN MAJOR URBAN AREAS

Impact and Outcomes

- Accurate urban vulnerability modeling, informed evacuation and resource allocation plans.
- Enhanced disaster exposure assessments reducing manual data collection time.

Alignment with SDGs

9 INDUSTRY, INNOVATION AND INFRASTRUCTURE

11 SUSTAINABLE CITIES AND COMMUNITIES

Lessons Learned and Recommendations

This initiative played pivotal role in urban risk assessment against climate-induced disasters. GeoAI based building typologies for urban centers rendered impressive results in planned regions while building typology classification become difficult in unplanned regions. Hence, further effort is required to train model for unplanned and rural areas so that desired outcomes can be produced at national level.

FROM SATELLITE TO STRUCTURE — THIS DUAL-BRANCH AI MODEL CLASSIFIES BUILDINGS ACROSS ENTIRE CITIES, OFFERING A SCALABLE SOLUTION FOR **HAZARD MAPPING** AND **URBAN PLANNING**.

Additional References or Resources

NatCat Model Platform:
https://natcat.ndrmf.pk/login/index.php

UC LAN | RESEARCH AND KNOWLEDGE EXCHANGE FOR DISASTER AND CLIMATE RESILIENCE (MAURITIUS, BRAZIL, ETC.)

Title of GeoAI Practice

UC LAN - Research and knowledge exchange for disaster and climate resilience (Mauritius, Brazil, etc.)

Brief Description

These Research and Knowledge Exchange (RKE) activities will significantly enhance the collaborative research culture among various organizations, academic institutions, and researchers across multiple countries. By fostering these connections, we will facilitate the sharing of best practices and innovative ideas. Furthermore, these events will focus on producing more robust and innovative solutions for disaster risk reduction (DRR). This includes leveraging satellite data to improve early warning systems, inform emergency response strategies, and enhance resilience in vulnerable communities. Overall, these initiatives will not only advance scientific understanding but also contribute to impactful real-world applications in disaster management and mitigation.

Challenge or Problem Addressed

A series of impactful recommendations will be presented to policymakers and decision-makers in Brazil, Ireland, India, and Mauritius. These strategies aim to significantly strengthen efforts to mitigate the impacts of coastal disasters, climate change, flooding, and cyclones—ultimately safeguarding communities and preserving ecosystems.

Technical Approach and Methods

The team has employed a diverse array of satellite imagery, machine learning techniques, and GeoAI tools to support this work.

Impact and Outcomes

The research team secured collaborative funding and has published several articles in leading international journals, including:

- Modelling Mangrove Dynamics in Mauritius: Implications for Conservation and Climate Resilience.
- Community Resilience to Socio-Environmental Disasters in Itajaí Valley, Brazil.
- Mangrove Mapping and Monitoring Using Remote Sensing Techniques Towards Climate Change Resilience.

UC LAN | RESEARCH AND KNOWLEDGE EXCHANGE FOR DISASTER AND CLIMATE RESILIENCE (MAURITIUS, BRAZIL, ETC.)

Lessons Learned and Recommendations

Lessons Learned:

- We must have clear agreement between the making official agreement between originations.

Recommendations:

- Cultivate robust partnerships among diverse organizations to powerfully advance transdisciplinary research and significantly enrich academic activities.

COLLABORATIVE RESEARCH USING SATELLITE DATA AND AI-DRIVEN GEOSPATIAL TOOLS IS ADVANCING **DISASTER RISK REDUCTION STRATEGIES** AND **INFORMING CLIMATE RESILIENCE POLICIES** ACROSS BRAZIL, IRELAND, INDIA, AND MAURITIUS.

Alignment with SDGs

- 11 SUSTAINABLE CITIES AND COMMUNITIES
- 13 CLIMATE ACTION
- 15 LIFE ON LAND
- 17 PARTNERSHIPS FOR THE GOALS

Additional References or Resources

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- Nathawat, R., Singh, S.K., Sajan, B. et al. Integrating Cloud-Based Geospatial Analysis for Understanding Spatio-Temporal Drought Dynamics and Microclimate Variability in Rajasthan: Implications for Urban Development Planning. J Indian Soc Remote Sens (2025). https://doi.org/10.1007/s12524-025-02139-6

Section E: Cross-Cutting Applications Supporting UN-SPIDER Mandate

Overview

GeoAI enables climate adaptation, environmental management, and disaster prevention by integrating satellite data, AI, and socioeconomic indicators. It supports monitoring of sea-level rise, greenhouse gas emissions, and ecosystem health, as well as agricultural conditions affecting food security. Vulnerability mapping helps identify at-risk populations for targeted support. These applications enhance multi-hazard preparedness and contribute to sustainable and inclusive development.

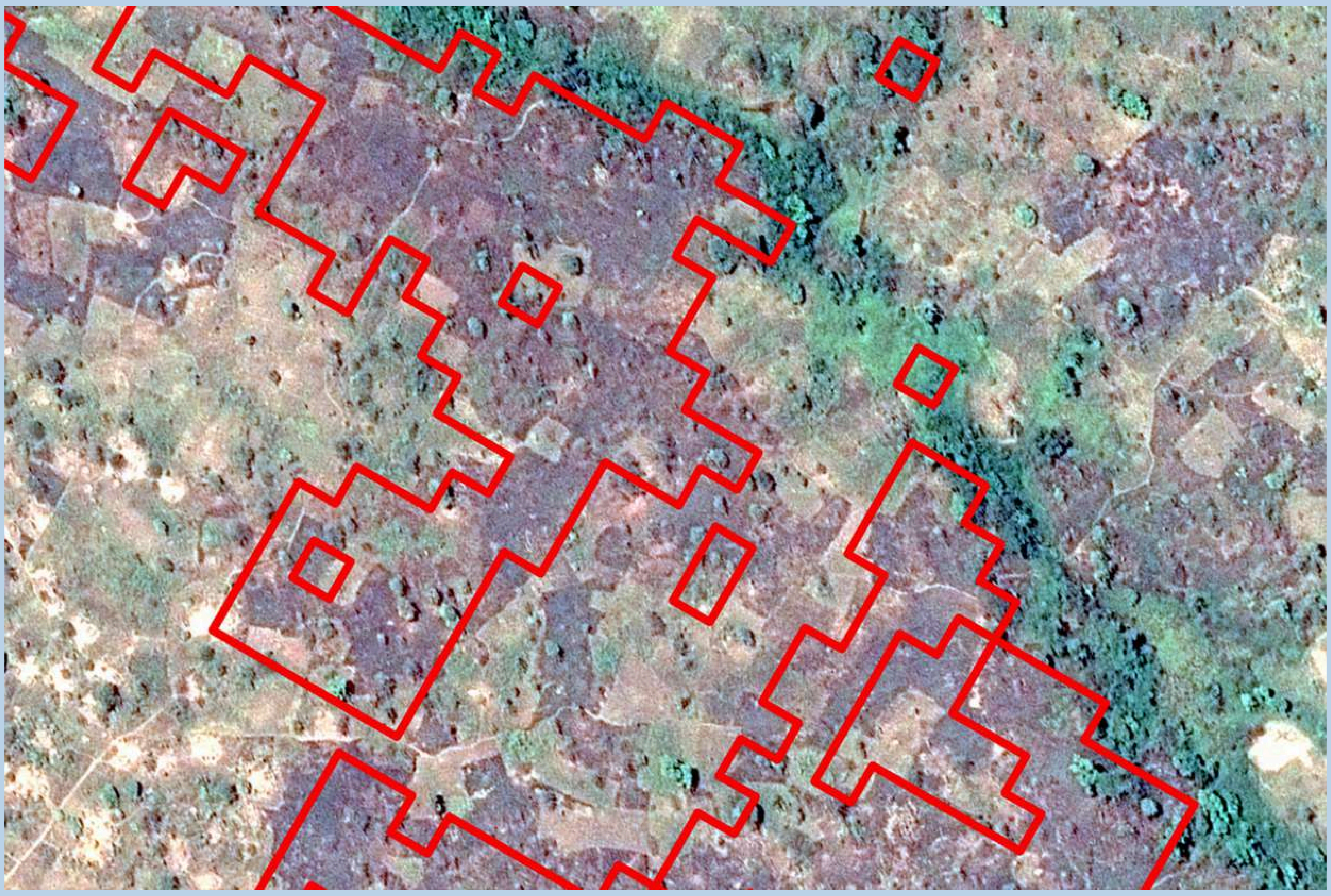

Figure: Analyses of imagery shows alleged intentional burnt field in Yambio province
(c) UN Earth observation and imagery

ECOE | ENHANCED COASTAL MONITORING AND RISK ASSESSMENT FOR SUSTAINABLE MANAGEMENT IN CYPRUS

Title of GeoAI Practice

Enhanced Coastal Monitoring and Risk Assessment for Sustainable Management in Cyprus

Brief Description

This initiative targets the monitoring and evaluation of coastal erosion and near coastline land change processes in Limassol and Paphos District, Cyprus, areas of high ecological, archaeological, and socio-economic value. By incorporating satellite, UAV, and ground observations, the initiative offers stakeholders vital information on coastal processes. The local municipalities, the Department of Public Works, and the Department of Fisheries and Marine Research need high spatial and temporal resolution monitoring to enable sustainable coastal management, protection of infrastructure, and conservation of biodiversity. Historical and time-series datasets are employed to monitor changes, assist planning, and aid conservation to ensure that the coastal zone is managed efficiently and sustainably.

Challenge or Problem Addressed

The practice responds to the imperative of an integrated high-precision monitoring system to identify coastal erosion, measure the functionality of coastal protection structures, and examine their socio-economic and ecological implications. It is intended to give early warning and risk assessment for residential areas, public facilities, and essential habitats, against the heightened vulnerability to natural and man-induced changes.

Technical Approach and Methods

A variety of geospatial datasets were used for this specific practice, exploiting multiple sources. More specifically, satellite data from Copernicus (Sentinel-1 and 2) and Planetscope images from Planet Labs were used for continuous coastal monitoring. Moreover, data from UAV surveys were used using multispectral and RGB sensors for detailed shoreline and habitat assessments. Historical Orthophotos from 1963, 1993, 2014, and 2019 were used to provide baseline comparisons, and coastline shapefiles were used to determine temporal shoreline delineations and measure erosion and accretion. The above datasets were generated using advanced Machine Learning methods, such as diffusion models to identify temporal coastline changes. Finally, GNSS ground truth campaigns were conducted to calibrate and validate the satellite and UAV data-based results.

ECOE | ENHANCED COASTAL MONITORING AND RISK ASSESSMENT FOR SUSTAINABLE MANAGEMENT IN CYPRUS

Impact and Outcomes

The developed application/tool has led to enhanced situational awareness for coastal stakeholders, providing valuable and timely information to support data-driven decisions regarding infrastructure, conservation, and land-use planning. Moreover, it has led to early detection of vulnerable areas affected by erosion or environmental degradation. To increase impact, capacity building is currently being provided to local authorities dealing with coastal management practices. This approach is expected to lead to a strengthened basis for sustainable development and coastal conservation policies.

Alignment with SDGs

13 CLIMATE ACTION

14 LIFE BELOW WATER

15 LIFE ON LAND

17 PARTNERSHIPS FOR THE GOALS

HIGH-RESOLUTION MONITORING IS HELPING CYPRUS AUTHORITIES DETECT **COASTAL EROSION AND LAND CHANGES** IN LIMASSOL AND PAPHOS, ENABLING **DATA-DRIVEN DECISIONS** FOR SUSTAINABLE COASTAL MANAGEMENT AND CONSERVATION.

Lessons Learned and Recommendations

The combination of satellite, UAV, and ground-based data improved monitoring accuracy and reliability. Long-term historical data are vital for understanding trends and planning resilient responses. Active stakeholder engagement is key to translating technical information into effective management actions. Future practices should continue investing in building technical capacity at the local level for sustainable monitoring.

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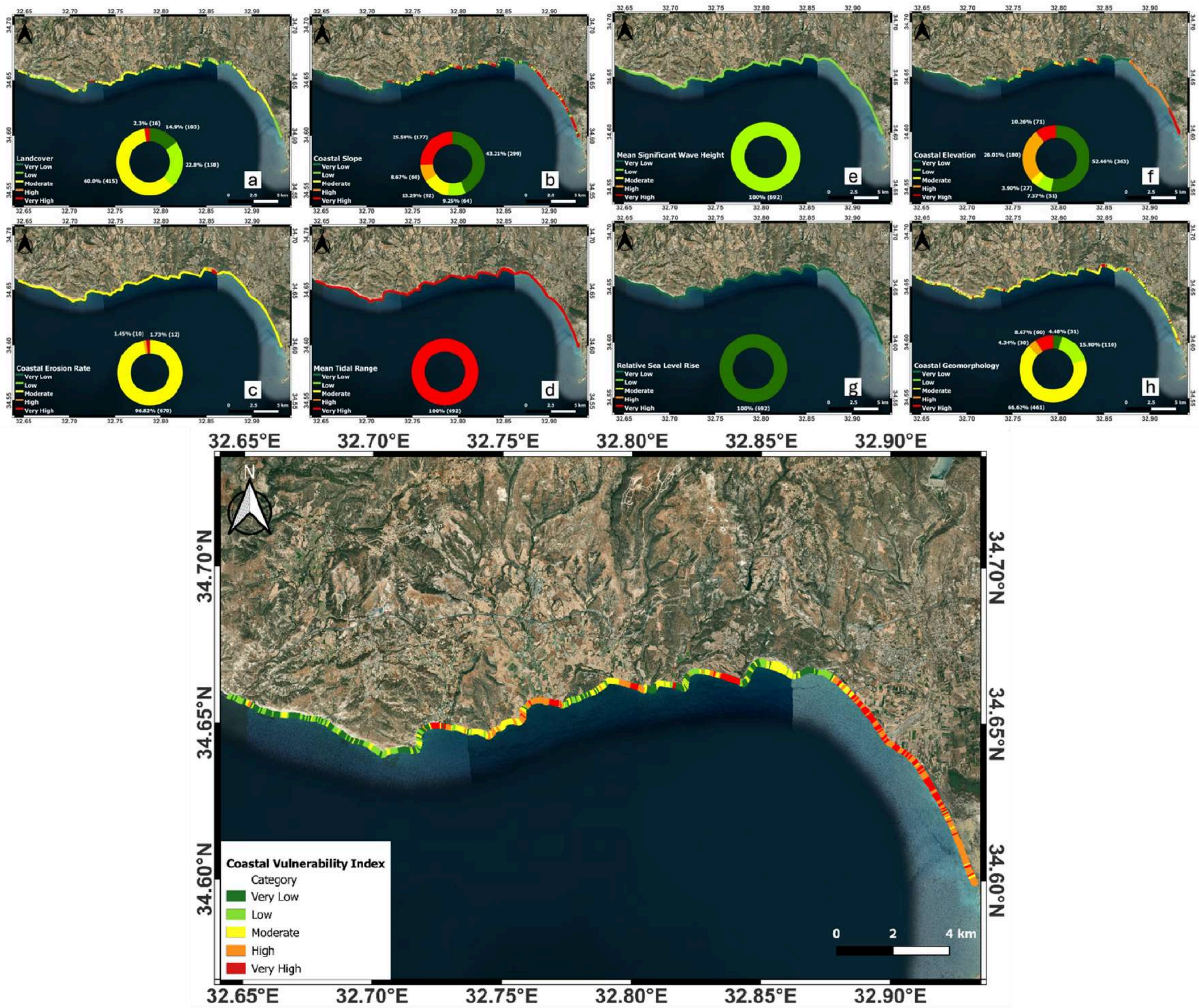

Figure: Coastal Vulnerability Index (CVI) map for the western Limassol coast.

ECOE | AI-DRIVEN SAR MONITORING FOR RAPID DETECTION OF MEDITERRANEAN OIL SPILLS

Title of GeoAI Practice

AI-Driven SAR Monitoring for Rapid Detection of Mediterranean Oil Spills

Brief Description

This practice uses artificial intelligence and satellite remote sensing to detect oil spills in the ocean quickly and automatically. Oil spills are harmful to ocean health and can damage coastal ecosystem and economies. The technique uses Synthetic Aperture Radar (SAR) imagery combined with deep learning models to find and map oil slicks almost in real-time. This method is faster and more reliable than manual checks, especially during bad weather. It helps authorities and responders quickly understand the size of a spill, watch its spread, and plan ways to control it. This approach helps reduce disaster risks by limiting environmental damage, speeding up response efforts, and strengthening marine safety systems.

Challenge or Problem Addressed

Traditional ways of spotting oil spills are often slow, need a lot of human effort, and can be hindered by bad weather or when it's dark. Finding oil spills quickly and accurately is very important to act fast and keep the environment safe. This is especially crucial now, as there are more activities in the ocean and an increase in shipping. There's a growing need for a system that can expand easily, operates automatically, and is reliable. Such a system can help reduce the harm oil spills cause to marine life and communities living along the coast.

Technical Approach and Methods

This method uses Sentinel-1 SAR imagery, which works in all weather conditions, whether it's cloudy, rainy, or during nighttime. This technology allows for clear viewing no matter the situation. We employ advanced deep learning techniques to analyze these images. Specifically, we use Mask R-CNN and U-Net models. Mask R-CNN is used to detect and outline specific areas in the images, like oil spills, in detail. U-Net helps capture small details and the overall picture, making it easier to identify actual oil spills and not confuse them with other similar occurrences. Combining these methods increases accuracy and reduces errors, ensuring they operate efficiently in various marine and weather conditions. For handling large amounts of data automatically, we utilize cloud computing. The primary tool for this process is the Python programming language. This setup allows for quick and efficient data processing on a large scale. The dataset used was openly accessible to the public. A significant challenge was obtaining a balanced dataset, particularly in terms of acquiring a sufficient number of confirmed oil spill-like areas to match the number of oil spill samples. To address this issue and maintain the dataset's validity, images from confirmed oil spill incidents from previous studies were used. The 116 incidents of oil spills recorded between 2014 and 2019 were reviewed, and 50 incidents were selected based on the variety of oil spill sizes and the availability of images with different contrasts.

ECOE | AI-DRIVEN SAR MONITORING FOR RAPID DETECTION OF MEDITERRANEAN OIL SPILLS

Impact and Outcomes

Using the aforementioned datasets and technologies, detection and response times was improved from days to just hours or even minutes. This means that oil spill events can be controlled faster. Additionally, classification of oil spills based on their area, for the quick assessment of their size and the determination of response actions was performed. The developed pipelines have achieved extremely high detection accuracy, with deep learning models providing up to 99% precision in controlled studies. Information extracted from these enhanced tools was provided to decision-makers to understand situations, so they can make smarter choices based on solid facts. By making detection more accurate, false alarms were reduced helping researchers and responsible authorities to focus on real issues. Moreover, training on these new technologies was offered to boost the skills of local authorities. This in turn can lead to the update of the rules for handling marine disasters and protecting the environment.

Alignment with SDGs

FROM DAYS TO MINUTES — AI-ENHANCED SAR TOOLS NOW DETECT OIL SPILLS WITH UP TO **99% ACCURACY**, HELPING AUTHORITIES ACT FAST AND PROTECT MARINE ECOSYSTEMS.

Lessons Learned and Recommendations

The use of SAR data is crucial for accurate detection and minimization of errors, as it also operates effectively under all weather conditions. Consistently updating models with new categorized data makes them more effective and able to handle new situations. Engaging with stakeholders and providing good training for users is essential to ensure operational success. It's important to make AI workflows a regular part of national and regional marine safety programs and to expand open datasets for more research and better development.

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ECOE | AI-DRIVEN SAR MONITORING FOR RAPID DETECTION OF MEDITERRANEAN OIL SPILLS

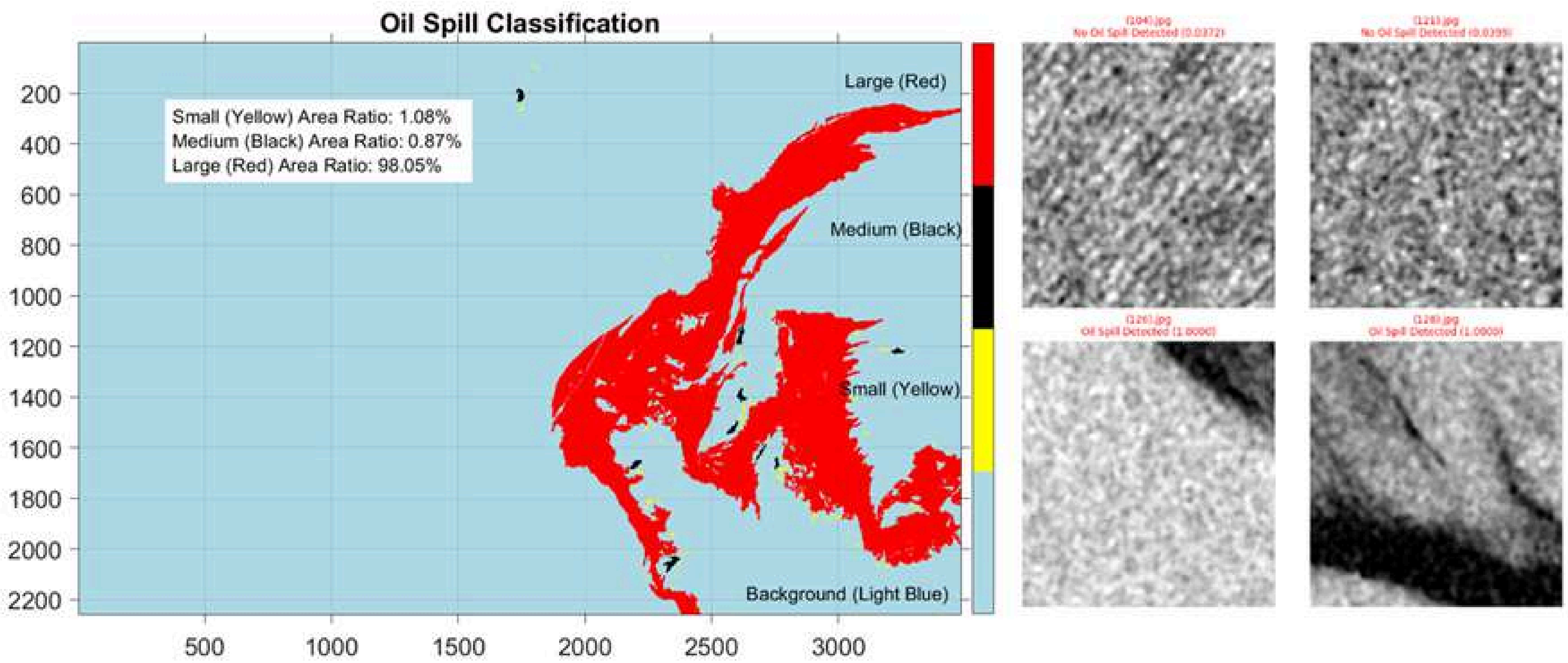

Figure: AI-driven SAR monitoring for oil spill detection and classification

SRI NASU-SSAU | DT4LC | DIGITAL TWIN FOR LAND COVER CHANGE MONITORING

Title of GeoAI Practice

DT4LC – Developing Scalable Digital Twin Models for Land Cover Change Detection Using Machine Learning and Digital Twin for Monitoring Land Cover Changes in Ukraine and Switzerland.

Brief Description

In response to climate change and war-induced environmental disruptions, the DT4LC project focuses on developing a GeoAI-powered platform to monitor land cover change in Ukraine and Switzerland. Jointly led by Ukrainian and Swiss research teams, this initiative develops scalable digital twins that integrate satellite data, AI-driven analytics, and socio-economic indicators to track rapid and gradual land use transformations. Leveraging Open Data Cube infrastructure, harmonized datasets, and semantic ontologies, DT4LC enables near real-time detection of sudden disruptions (e.g., floods, wildfires, war-induced damage) via vegetation index forecasting, while also supporting long-term mapping of trends like urban expansion and agricultural shifts through machine learning-driven land cover segmentation. The system integrates user-defined climate scenarios, physics-informed neural networks, and multi-source satellite data, offering a dynamic platform for adaptive land management and policy planning. By filling a critical gap in current Earth System DTs, this project enhances resilience and decision-making capacity in the face of climate and socio-environmental changes.

Challenge or Problem Addressed

In the context of land cover changes, Ukraine faces widespread environmental disruption due to armed actions, while Switzerland contends with climate-driven degradation of Alpine ecosystems and water resources. Both countries lack of unified digital infrastructure for consistent, high-resolution, and transferable land use modeling. Existing solutions are limited by fragmented data standards, low scalability, and minimal stakeholder engagement. The project responds to these gaps by developing a scalable digital twin framework that merges AI with Earth observation, enabling detailed, real-time analysis of land transformation. The practice improves evidence-based planning for post-war recovery, climate adaptation, and sustainable land management by empowering stakeholders with intuitive tools for scenario-based analysis and decision-making.

DT4LC STRENGTHENS CLIMATE RESILIENCE BY INTEGRATING AI, SATELLITE DATA, AND SOCIO-ECONOMIC INDICATORS INTO ONE SCALABLE MONITORING SYSTEM.

SRI NASU-SSAU | DT4LC | DIGITAL TWIN FOR LAND COVER CHANGE MONITORING

Technical Approach and Methods

- The DT4LC project builds a modular Digital Twin architecture for monitoring rapid and gradual land cover and land use changes in Ukraine and Switzerland. The system integrates data from Sentinel-1/2 imagery (SAR and optical), climate models (e.g., DestinE), and in-situ/user-provided data into a cohesive GeoAI pipeline.
- Central to this approach are Foundation Model Encoders, trained on multi-source Earth observation and climate datasets, which extract dense embeddings from satellite images and climate data. These are used to initialize Land Cover Segmentation Decoders, producing detailed LC/LU maps through semi-supervised learning.
- Two primary modeling pathways form the dual-timescale DT framework:
- Rapid change detection is enabled by Vegetation Index Prediction Models and Physics-Informed Models, which simulate the short-term dynamics of vegetation response to weather anomalies, droughts, or anthropogenic activities. These models incorporate satellite data, physical priors, and learned insights to estimate vegetation state (e.g., NDVI, NDWI, GCI) in near real-time.
- Gradual change detection is conducted via the Land Use Change component, which uses long-term trends in vegetation state and LC/LU maps to identify and forecast transformations such as crop rotation, land abandonment, and urban expansion.
- Insight Translation Components contextualize LC/LU changes into narratives or summaries adapted to stakeholders, supported by Generative Foundation Models for interpretability and relevance.
- Outputs are exposed through a UI Layer (Web Map Service), including an Interactive Dashboard for scenario simulation and decision-making. These interfaces present multi-temporal visualizations, text summaries, and user-specific insights.
- The entire DT system is designed around Digital Twin Instances — modular, reusable components focusing on specific processes (e.g., VI state estimation, LC segmentation) — ensuring scalability and transferability across regions and environmental contexts.

THIS MODULAR DIGITAL TWIN SYSTEM TURNS COMPLEX SATELLITE AND CLIMATE DATA INTO ACTIONABLE INSIGHTS FOR **SUSTAINABLE LAND MANAGEMENT** IN UKRAINE AND SWITZERLAND.

SRI NASU-SSAU | DT4LC | DIGITAL TWIN FOR LAND COVER CHANGE MONITORING

Impact and Outcomes

- The **DT4LC** project is anticipated to significantly enhance the capacity for land use monitoring and environmental decision-making in both Ukraine and Switzerland. By integrating near real-time satellite data with advanced AI models, the digital twin enables early detection of abrupt land cover changes—such as flood damage, wildfires, or conflict-induced landscape degradation—supporting faster disaster response and recovery planning. The system also improves long-term forecasting of urbanization, agricultural shifts, and climate-related land transformations, **informing strategic policy and sustainability initiatives.** Through its user interface, stakeholders can simulate future scenarios, enhancing engagement and scenario-based planning.
- Expected results include the generation of new LUC change datasets and the development of novel harmonized data representations, which will provide a more comprehensive and standardized understanding of land use dynamics. Furthermore, the project aims for advancements in machine learning techniques to improve the accuracy and efficiency of land cover change detection and prediction. The development of pilot digital twin simulations will offer practical demonstrations of the system's capabilities and inform future applications. This collaborative effort is also expected to yield joint publications, contributing to the scientific community's knowledge base, and establish training programs to build local capacity in Earth Intelligence and digital twin technologies.
- Early demonstrations of the system have already shown its potential to provide scientific interpretation, analyse environmental indicators, and detect challenges for specific areas with further explanation and problem breakdown for different domains.

Alignment with SDGs

SRI NASU-SSAU | DT4LC | DIGITAL TWIN FOR LAND COVER CHANGE MONITORING

Lessons Learned and Recommendations

- The evolving landscape of Earth System Digital Twins has demonstrated significant promise for environmental monitoring, climate adaptation, and disaster response. Large-scale initiatives like DestinE and NASA's ESDT show how multi-source satellite data, AI-driven analytics, and predictive modeling can be integrated to simulate Earth's processes in near real-time. These platforms excel in assimilating continuous data streams—from remote sensing and in-situ measurements—thus maintaining up-to-date simulations that improve forecasting accuracy and support proactive decision-making in the face of extreme weather and climate events.

- However, the analysis and practical experience within the DT4LC project reveal that current digital twins still struggle to address key challenges — particularly in the domain of land use change. Most operational ESDTs are primarily oriented toward modeling climate and environmental variables and offer only limited support for fine-grained land use classification or tracking human-driven transitions such as urbanization, agricultural expansion, or post-conflict land restoration. High-resolution, near-real-time monitoring of such changes is computationally demanding, requiring access to massive volumes of satellite data and robust infrastructure that can support scalable processing. In addition, a lack of standardized pipelines and interoperable data structures continues to hinder the fusion of satellite, socio-economic, and in-situ datasets into actionable, context-aware insights.

- From given technical explorations, one of the more complex challenges lies in experimenting with foundation models for land cover segmentation. These models—trained on large, generic datasets—perform well in familiar contexts but often struggle when applied to novel, localized data. Although they offer versatility and can serve as general-purpose encoders for broad-scale inference, they are not yet robust enough for specialized tasks without significant fine-tuning. Their development is ongoing, and it takes time to fully understand, adapt, and validate them in practical settings. For now, task-specific machine learning or deep learning architectures often remain more reliable for producing consistent results. Nevertheless, foundation models may prove useful as a fallback mechanism in digital twins when ingesting generic or less-structured data, as they tend to be less sensitive to input variation.

- Another limitation of existing DTs is the lack of meaningful user feedback loops. Without the ability to explore alternative scenarios, challenge model assumptions, or refine parameters based on stakeholder knowledge, these systems risk being perceived as non-transparent or disconnected from real-world planning needs. We experimented with large language models to support scientificreasoning and interpret complex results. In theory, LLMs could help bridge the communication gap between technical outputs and end-user understanding. However, challenges persist around model accuracy, particularly hallucinations, and model

SRI NASU-SSAU | DT4LC | DIGITAL TWIN FOR LAND COVER CHANGE MONITORING

accessibility due to licensing limitations and cost concerns. In addition, LLMs are vulnerable to misleading input data, which can lead to incorrect interpretations if not properly verified. As a result, their integration into digital twin workflows should be handled cautiously, with appropriate safeguards such as human-in-the-loop validation, transparent licensing for research, and mechanisms for verifying user input quality.

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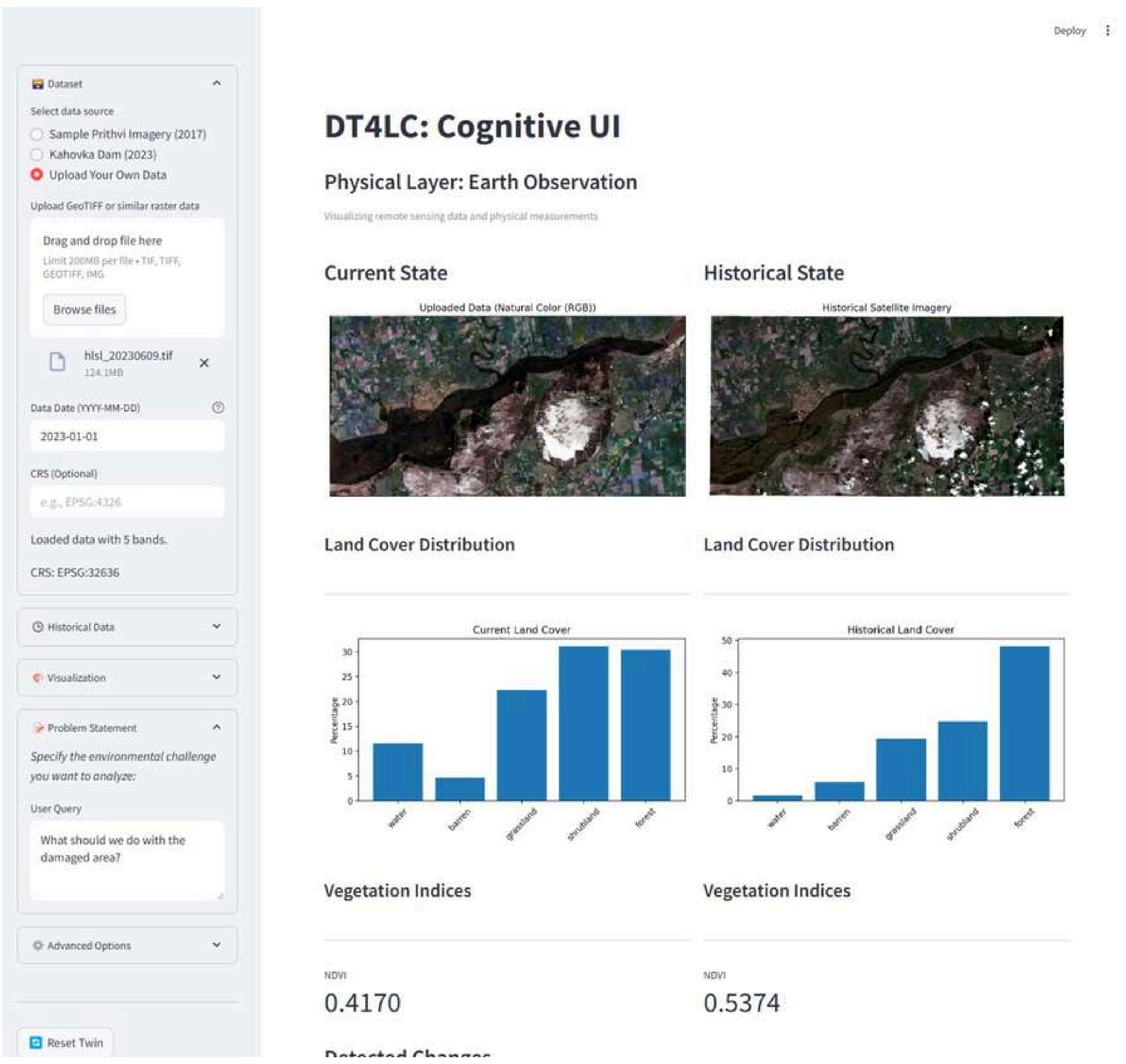


Figure: Interactive Dashboard

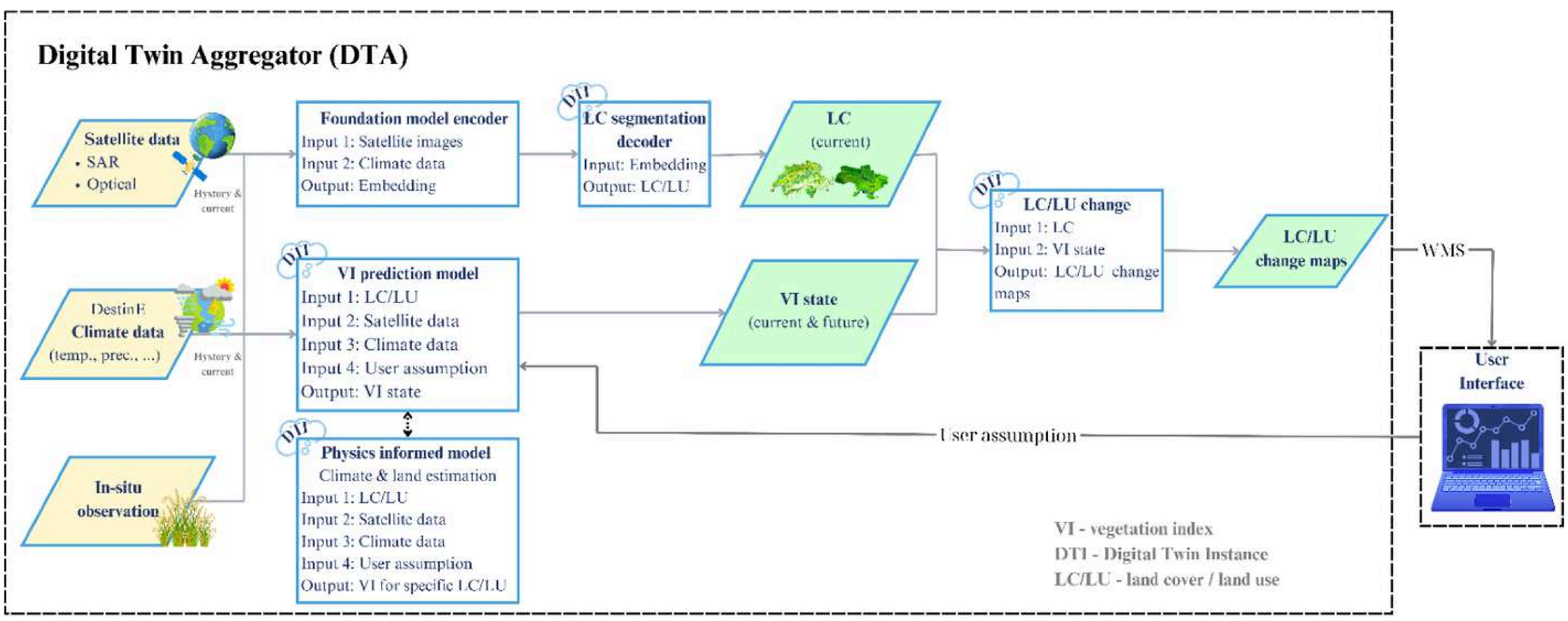


Figure: Architecture of the proposed DT for monitoring land cover changes in Ukraine and Switzerland

SUPARCO | FOREST TREE MAPPING USING HYPERSPECTRAL DATA

Title of GeoAI Practice

GeoAI Integrated Hyperspectral Satellite Data Approach for Forest Tree Species Mapping to Improve Above Ground Biomass Estimation in Northern Pakistan

Brief Description

This practice utilizes a GeoAI framework integrating hyperspectral satellite data with advanced machine learning (ML) and deep learning (DL) techniques for forest tree species classification in the northern region of Pakistan. The goal is to produce highly accurate forest type maps that feed into improved above-ground biomass (AGB) estimation models. By applying 2D and 3D Convolutional Neural Networks (CNNs), Random Forest (RF), and XGBoost classifiers, this initiative exploits the rich spectral and spatial resolution of hyperspectral imagery. The use of Deep Spectral-Spatial Networks (DSSNs), developed using frameworks like Keras, TensorFlow, and PyTorch, ensures that both spectral signatures and spatial patterns are effectively captured. This approach addresses limitations in traditional AGB estimation models that rely on lower-resolution or multispectral data.

Challenge or Problem Addressed

This practice addresses the challenge of low-accuracy forest mapping by leveraging hyperspectral remote sensing and GeoAI techniques to provide species-level classification and enhance the accuracy of AGB estimates.

Impact and Outcomes

- Improved species-level mapping accuracy
- Enhanced AGB/Carbon Stock estimation models
- Scalable monitoring framework
- Open AI Models and Data Products

Technical Approach and Methods

- **Satellite Data: Hyperspectral imagery from sources like EO-1 Hyperion, EnMAP**
- **AI/ML Techniques:**
  - Random Forest (RF), XGBoost
  - 2D CNNs for spectral-spatial feature extraction
  - 3D CNNs for volumetric spectral-spatial data analysis
  - Deep Spectral-Spatial Networks
- **Frameworks/Tools: TensorFlow, Keras, PyTorch, Scikit-learn, Rasterio, GDAL, QGIS/ArcGIS.**

SUPARCO | FOREST TREE MAPPING USING HYPERSPECTRAL DATA

Alignment with SDGs

Lessons Learned and Recommendations

- Demonstrates how AI and hyperspectral remote sensing can redefine forest inventory and climate models.
- Highlights the need for harmonized data standards and ground-truth networks.

HYPERSPECTRAL SATELLITE DATA ENABLES **PRECISE** FOREST SPECIES MAPPING TO IMPROVE ABOVE-GROUND BIOMASS ESTIMATION AND ADDRESSING LIMITATIONS OF TRADITIONAL LOW-RESOLUTION METHODS.

Section F: Common Elements of Success and Lessons Learned

Overview

GeoAI adoption is strengthened by common success factors across RSOs, including strong data governance, integrated technical workflows, and institutional collaboration. Validated ground truth and open data standards are essential for model reliability. Capacity-building efforts and localized training support long-term sustainability. Policy alignment and user engagement ensure that tools are actionable and context-specific. These elements help scale effective GeoAI practices across regions.

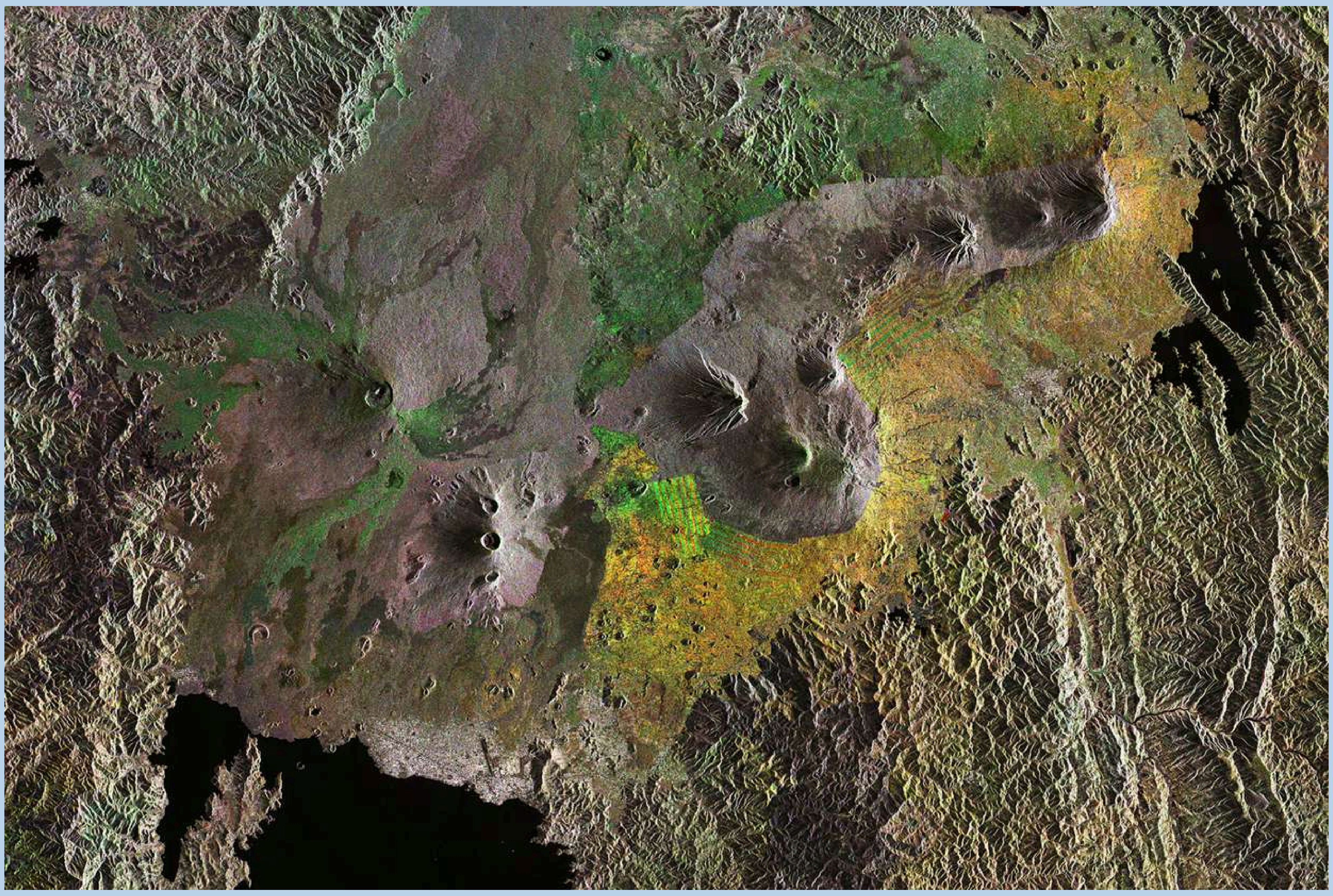


Figure: Earth observation to evaluate natural risk to human settlements and agriculture in the east of the Democratic Republic of the Congo
(c) UN Earth observation and imagery

AIT

IMPORTANCE OF USING SLOPE UNITS AND SPATIAL VALIDATION FOR LANDSLIDE MODELS

- Aggregating data at the slope-unit level using the r.slopeunits tool ensures that landslide modeling reflects hydrologically and geomorphologically consistent terrain units which more accurately represent natural landscape processes, improving prediction accuracy and making results more actionable for planners and disaster managers identifying high-risk areas.

- Slope units support realistic hazard mapping, which has informed local hazard zoning updates and strengthened trust and usability of the model in Nepal's capacity-building efforts.

- Applying spatially aware techniques like regional cross-validation tested the model's ability to generalize beyond the data area, ensuring its reliable use in other high-risk, data-limited regions for landslide risk assessment.

- Without spatial validation, spatial clustering would distort performance estimates and reduce accuracy. Using spatial validation ensures trustworthy and robust predictions, enhancing the model's impact on disaster risk reduction and hazard mitigation planning.

BRIN

NEED FOR CAPACITY-BUILDING AND LOCAL KNOWLEDGE IN URBAN APPLICATIONS

- Local knowledge from field observations in Bandung City was essential for classifying slum settlements, revealing that they are typically near rivers, roads, and railways. This insight informed a decision tree model that determined whether a settlement fell within designated buffer zones.

- Capacity-building was supported through training sessions and workshops in which the Department of Housing and Settlements of West Java Province, the Office of Communication and Informatics of West Java Province, and the Bandung Institute of Technology were introduced to the Google Earth Engine (GEE)-based slum mapping platform.

- UNESCAP supported capacity-building by helping local government staff integrate spatial and statistical data for slum mapping using GeoAI, strengthening planning and decision-making capacity.

- The project recommended more practical training for stakeholders, as processing satellite imagery and GeoAI on the GEE platform requires high and complex capacity, posing challenges for long-term sustainability without continued support.

ECoE

EMPHASIS ON DATA INTEGRATION AND GROUND-TRUTH VALIDATION ACROSS MULTIPLE CASES

- ECoE integrates satellite, environmental, and in-situ data, (Sentinel-1/2 imagery, DEMs, GPM IMERG precipitation, CORINE and USGS land cover, 90 rain stations, geology, drainage, and infrastructure maps) into harmonized GeoAI pipelines for landslides, floods, wildfires, earthquakes, coastal erosion, and oil spills. This supports spatially explicit, locally tailored, and scalable early warning and resilience tools.

- Ground-truth validation is central to all ECoE cases, using hazard-specific methods. Landslide models were validated with geological inventories and GNSS-informed precipitation, flood models with rain station data (2011–2023) and known flood zones, wildfire risk with MODIS indices and ERA5 interpolation, coastal erosion with GNSS surveys and historical orthophotos, and oil spill detection with 50 confirmed cases (2014–2019) to validate deep learning outputs.

- This focus on data integration and validation enabled high-resolution GeoAI tools, including a 500m wildfire risk model, a nationwide probabilistic flood map, an earthquake vulnerability index with structural imagery and OpenQuake scenarios, and coastal monitoring using UAV, satellite, and GNSS data, supporting infrastructure protection, emergency response, and national planning.

- Validated GeoAI tools are used by Cypriot disaster management related authorities, i.e., the Civil Defence, water development agencies, insurers, and municipalities, informing flood plans, fire prevention, landslide mitigation, and infrastructure assessments like Paphos General Hospital, demonstrating scalability and global relevance for multi-hazard risk reduction and sustainable development.

IWMI

NECESSITY OF LOCAL CO-DESIGN AND LANGUAGE MODELS FOR RURAL APPLICATIONS

- Local co-design with farmers and extension agents ensured adoption and relevance of the AI system. Co-design workshops were conducted to align use cases with local needs, and field validation was carried out in collaboration with Krishi Vigyan Kendras (KVKs) and disaster management cells helped tailor the system's functionality. These local extension agencies also integrated the chatbot into workflows during pilots in Maharashtra, Odisha, and Tamil Nadu.

- The chatbot supports multilingual interaction using AI4Bharat language models, ensuring inclusive access for rural and linguistically diverse populations in India, a necessity given that local stakeholders in these regions typically lack real-time decision support tools. By delivering localized advisories in regional languages based on real-time satellite data, drought indices (SPI, VHI, SMAI, TCI), and district contingency plans, the system effectively addresses the fragmentation in data dissemination and bridges the last-mile delivery gap that disproportionately affects smallholder farmers.

- The AI system was fine-tuned through LoRA and instruction tuning of DeepSeek-V3 and required continuous tuning of language models to maintain effectiveness in rural contexts. A Retrieval-Augmented Generation (RAG) setup was used to extract information from government contingency plans, enabling the chatbot to generate context-aware recommendations across crops, livestock, and water resources. The need for ongoing tuning highlights the importance of adapting language models to evolving user needs, local dialects, and region-specific planning data to ensure sustained usability and impact in rural drought management.

SRI NASU-SSAU

ON LIMITATIONS OF FOUNDATION MODELS AND NEED FOR STAKEHOLDER ENGAGEMENT IN DIGITAL TWINS

- Foundation models for land cover segmentation, though versatile and trained on large, generic datasets, often struggle with novel, localized data. DT4LC found that while these models work for broad-scale inference, they are not yet robust for specialized tasks like urban expansion, post-conflict land restoration, or agricultural shifts without substantial fine-tuning. Their development is ongoing and requires time for adaptation and validation. In practice, task-specific machine learning or deep learning models remain more reliable, though foundation models can serve as fallback tools for generic or less-structured data due to their lower sensitivity to input variation.

- High-resolution, near-real-time monitoring of human-driven land use change remains demanding for digital twin systems like DT4LC. While Earth System Digital Twins (ESDTs) like DestinE and NASA's ESDT excel at modeling environmental variables using constant satellite and on-the-ground data, they provide limited support for fine-grained land use classification or tracking changes like urban growth or land abandonment. DT4LC tackled these issues by combining Sentinel-1/2 SAR and optical imagery, Open Data Cube infrastructure, physics-informed neural networks, and semi-supervised segmentation models, but doing so required major infrastructure, standardized data pipelines, and solutions to fix inconsistent data formats.

- A key limitation identified by DT4LC is the lack of meaningful user feedback loops in current digital twin systems, which limits transparency, trust, and stakeholder relevance. Most platforms do not let users simulate scenarios, challenge assumptions, or refine outputs with domain knowledge. DT4LC addressed this by integrating Generative Foundation Models and an Interactive Dashboard with scenario simulation and text-based insight translation. While this improved stakeholder engagement compared to earlier models, the project found that true participation also requires tools for users to adjust core parameters, validate results, incorporate local data or experiential insights into the modeling pipeline.

- DT4LC's experiments with large language models (LLMs) showed promise in translating technical outputs for users but also revealed risks with accuracy, cost, and interpretability. While LLMs helped explain environmental indicators, issues like hallucinations, misleading inputs, and limited access due to licensing emerged. Safe use requires human-in-the-loop validation, transparent licensing, and input verification. Without these safeguards, LLMs risk causing misinterpretation rather than enhancing stakeholder engagement.

SUPARCO

INSIGHTS INTO TEMPORAL MODELING, GROUND TRUTH VALIDATION, AND MULTIMODAL AI FUSION ACROSS MULTIPLE PRACTICES

- Temporal modeling enabled differentiation of dynamic risk patterns and phenological stages, improving on static hazard models. SUPARCO's use of ConvLSTM and hybrid CNN-LSTM in fire risk, landslide susceptibility, and crop mapping captured seasonal changes more effectively and avoiding complexity of spectral differentiation in mixed land uses. Forest fire vulnerability mapping used multi-temporal composites to detect pre-ignition hotspots, while field-scale crop mapping tracked phenological shifts to distinguish spectrally similar crops. Challenges remain, including limited temporal resolution for forest fires and gaps in historical landslide inventories, highlighting the need for better data continuity.

- Comprehensive ground truth validation improved classification accuracy and resilience to data imbalance. SUPARCO shifted from coarse or survey-only data to high-resolution, field-verified datasets, such as LULC samples, Open Buildings footprints, and expert-driven AHP comparisons, boosting AI performance across practices. LULC and crop classification models benefited from data augmentation and focal loss functions, enhancing robustness in complex urban areas. A key lesson was the importance of pre-processing and ground-truth quality for building reliable national-scale datasets.

- SUPARCO improved high-accuracy mapping by combining different types of satellite data with expert knowledge. Instead of relying on a single data source, SUPARCO shifted to a mix of optical (RGB+NIR), SAR, thermal, DEMs, and hyperspectral imagery. In the building typology model, a dual-branch CNN combined spectral and elevation data to better classify urban structures. For forest species mapping, 2D/3D CNNs and Deep Spectral-Spatial Networks were used to improve biomass estimation. These methods gave a better understanding of land features and composition, though there is still a need for consistent data standards.

- The move to AI-supported platforms allowed for wider use of decision tools with real impact on national policies. By sharing GeoAI results through OGC-compliant WMS/WFS services like the NatCat Risk Calculator, SUPARCO shifted from testing models to using them in real planning. Crop-type maps, land cover data, and fire risk maps can now be used directly by disaster managers, planners, and insurers. This made early warnings, risk assessments, and insurance planning more efficient by combining AI insights with delivery formats. Still, SUPARCO found that AI models need more improvement in unplanned urban areas and rural regions where classification is still uncertain.

WHU

IMPORTANCE OF COMBINING UAVS AND SAR FOR RAPID POST-DISASTER MAPPING

- A key lesson from this approach is the importance of real-time data accessibility and reliable acquisition of high-resolution remote sensing (HRRS) imagery for assessing disaster damage. While satellites like Jilin-1 and UAVs enable rapid post-disaster data collection, challenges persist. Cloud cover, particularly during floods, obstructs optical imagery, necessitating reliance on lower-resolution SAR data. It is necessary to combine near-real-time SAR for all-weather monitoring, UAVs for local details, and open-access platforms like the Gaofen series for wide-area coverage.

- The combined use of UAVs and SAR effectively addresses data acquisition challenges like satellite revisit delays and limited field access. UAVs capture high-resolution imagery of localized damage such as roof collapses and foundation cracks, while SAR ensures broad-area coverage in poor weather. Together, these technologies enable faster, more comprehensive, and weather-independent assessments that improve situational awareness in both urban and rural settings.

- A major success of this method is reducing disaster assessment cycles from weeks to days. By replacing manual surveys with an automated deep learning–integrated object-oriented framework using multi-source inputs (Jilin-1, GF-2, UAVs), it rapidly delivers standardized geospatial damage maps and summaries to emergency responders. This shift from fragmented assessments to agile, data-driven governance relies on UAVs for detailed segmentation. A key lesson is the value of timely high-resolution imagery and combining satellite data with UAVs to overcome cloud cover and access limits. This hybrid model accelerates emergency response and minimizes human error and improves resilience across diverse terrains.

VI. RECOMMENDATIONS AND WAY FORWARD

GeoAI has transitioned from a proof-of-concept to an operational reality across the UN-SPIDER Regional Support Office network. Yet the case studies collected in this Compendium also reveal uneven access to compute resources, skills, and sustained financing.

The following recommendations translate those lessons into an actionable roadmap for the next triennium (2025-2028).

STRENGTHENING MULTI-STAKEHOLDER COLLABORATION

GeoAI projects that achieved the fastest operational uptake coupled RSO geospatial expertise with local domain knowledge and private-sector technology stacks. To institutionalise this model:

- UN-SPIDER should establish a "GeoAI Partnership Portal." Host a living inventory of open models, cloud credits, and support contacts on the UN-SPIDER knowledge portal.
- UN-SPIDER and RSOs should leverage global accelerator programmes. Align RSO pilots with initiatives such as Digital Earth Africa, the CEOS Open Data Cube, and commercial "disaster-response credits" so that hardware and archive costs are absorbed by the provider rather than the host agency.

SCALING GEOAI SOLUTIONS

The step from pilot to national roll-out hinges on replicable workflows, permissive licensing, and cloud-native architecture. Recommended actions include:

- Publishing containerised reference pipelines. A catalogue of Docker or Singularity images—tested on AWS, GEE, and CREODIAS—will let any RSO spin up flood or landslide mapping in minutes.
- Adopting model cards and data sheets. Standardised metadata describing training data, performance bounds, and known limitations allows regulators and emergency operations centres to decide when a model is "fit for purpose."
- Bridging the digital divide with "compute-as-a-service." Negotiate a pooled GPU quota (e.g., 100,000 GPU-hours per year) shared via federated identity. Least-connected RSOs can queue batch inference jobs without requiring hardware provisioning.

FROM NATIONAL SILOS TO FEDERATED ANALYTICS

Cross-border hazards (drought, cyclone, transboundary flood) demand models trained on diverse geographies, yet raw imagery often cannot cross sovereign clouds due to security statutes or data-residency laws. Privacy-preserving federated learning is emerging as a compliance-ready alternative: model weights—not raw pixels—move between jurisdictions, improving with each iteration.

LOCALISING GEOAI WORKFLOWS

Global models underperform when local land-cover classes, architectural styles, or climate regimes diverge significantly from the training corpus. UN-SPIDER should therefore:

- Support local fine-tuning of models by ensuring that each operational deployment must include a 10 % "local hold-out" validation set and at least one transfer-learning iteration using indigenous samples or crowd-sourced labels.
- Support multilingual data pipelines by investing in optical character recognition and natural language processing layers that translate local disaster bulletins and citizen science inputs into model-ready features.
- Promote community labelling campaigns by pairing secondary school STEM curricula with micro-grant schemes so that students generate verified training tiles for national hazards maps.

ADVANCING INNOVATION AND RESEARCH

Next-generation sensors and algorithms are poised to lift both spatial and semantic resolution. UN-SPIDER and RSOs should prioritize following research directions:

- Constellation fusion and on-board AI. Pilot edge-inference on low-orbit SAR/optical cubesats to deliver "first look" hazard masks within a single downlink pass.
- 4-D foundation models. Collaborate with academic labs to pre-train time-aware transformers that treat space-time cubes as native input, improving drought or urban-growth forecasting.
- Quantum-assisted optimisation. Explore hybrid quantum-classical solvers for rapid evacuation-route optimisation in megacities once commercial gate counts exceed 500 qubits.

BUILDING SUSTAINABLE CAPACITY AND FINANCING

Skills and budgets must match the rising technical ceiling. Recommended mechanisms to achieve this include:

- Integration into national budget lines by advocating for recurring line items—e.g., "GeoAI Analytics Services"—within DRM and climate-adaptation programmes rather than ad-hoc project grants.
- Results-based blended finance as structured pilot extensions so that private insurers or catastrophe-bond issuers co-fund model maintenance once accuracy benchmarks reduce underwriting uncertainty.

GOVERNANCE, ETHICS, AND TRUST

Operational credibility depends on transparent algorithms and responsible data use. Actions include:

- UN-SPIDER should develop "AI for Disaster Ethics" guidelines that address issues like bias audits, privacy-impact assessments, and opt-out clauses when high-resolution imagery intersects with personally identifiable information.
- Implement model provenance tracking. Every inference layer published must store hash-signed references to code commits, dataset versions, and parameter files.
- Strengthen cyber-defences. Integrate adversarial-input detection and routine penetration testing into the DevSecOps pipeline for all mission-critical GeoAI services.

FUTURE OUTLOOK

The next five-year policy window—book-ended by COP 30 in Belém (10-21 Nov 2025), the Sendai Framework's 2030 stock-take, and the final SDG Summit in 2027—will determine whether GeoAI matures from an early-adopter toolset into standard operating infrastructure for disaster-risk governance. Three mutually reinforcing trajectories are already visible.

FROM MAPPING TO PROBABILISTIC FORESIGHT

GeoAI workflows are shifting focus from retrospective damage delineation to sub-seasonal impact forecasting. Ensemble learning pipelines that fuse NWP outputs, Earth-observation time-series and socio-economic exposure layers now deliver probabilistic flood-depth and crop-yield scenarios two to four weeks ahead of peak hazard windows. RSOs piloting such workflows report F1-scores above 0.82 for three-day lead flood masks and ±10 per cent error bands for district-level yield forecasts.

FROM PIXELS TO POLICY DASHBOARDS

Real-time GeoAI outputs are moving up the value chain—from GIS desktops to cloud dashboards wired into budget, insurance and loss-and-damage accounting platforms. Brazil's COP 30 presidency has already signalled interest in climate-budget tagging modules that link satellite-derived forest-loss alerts to fiscal transfer rules at the state level. Similar pipelines can automate Article 8 reporting under the Paris Agreement by streaming exposure metrics—e.g., critical infrastructure within 100-year flood plains—directly into national climate registries. For UN-SPIDER, this means packaging reference pipelines not just as geospatial layers but as API-ready micro-services that ministries of finance and planning can consume without geospatial expertise.

VII. CONCLUSION

COLLABORATION BEYOND THE UN SYSTEM

GeoAI's success also rests on partnerships that transcend institutional boundaries. Private-sector imagery providers have activated disaster-response licences that waived fees for 14 major emergencies in 2024 alone. Academic labs have contributed foundation-model checkpoints trained on petabyte-scale archives, accelerating RSO experiments by orders of magnitude. Philanthropic foundations have financed skill-building bootcamps and open-source sprints, ensuring that knowledge dissemination keeps pace with algorithmic innovation. These alliances validate a core premise of the Sendai Framework—risk reduction is a shared responsibility—and demonstrate how multilateral bodies can amplify their impact by orchestrating, rather than owning, every link in the value chain.

STRATEGIC IMPERATIVES FOR 2025-2030

Building on these insights, three imperatives should guide programme planning through the Sendai Framework's closing horizon:

- Institutionalise GeoAI pipelines. RSOs and national governments should embed GeoAI services—e.g., "satellite-based flood now-casting"—as permanent budget items within disaster-management agencies, ensuring continuity beyond project cycles.
- Operationalise federated analytics. UN-SPIDER should finalise governance protocols that allow gradient-only exchanges among sovereign clouds and deploy a secure aggregation server by Q4 2026.
- Mainstream ethics-by-design. All production workflows must publish model cards, data-sheets, and bias-audit summaries; compliance should become a prerequisite for platform hosting on the UN-SPIDER Knowledge Portal.

LESSONS LEARNT

Several cross-cutting lessons emerge from the Compendium's evidence base:

- Automation is necessary, not sufficient. High-throughput inference must be complemented by rigorous validation and clearly communicated uncertainty metrics; otherwise, decision-makers remain sceptical.
- Local fine-tuning is non-negotiable. Even state-of-the-art global models suffer performance drops of up to 25 per cent in data-poor or ecologically unique regions unless retrained with indigenous samples.
- Ethics and provenance cannot be retrofitted. Bias audits, privacy-impact assessments, and cryptographically signed model registries need to be embedded from the first code commit, not bolted on post-deployment.
- Capacity outlives hardware. GPU quotas and cloud vouchers accelerate adoption, but institutional ownership—budget lines, job descriptions, and career tracks—keeps workflows alive once pilot funding lapses.

THE ROAD AHEAD

The future outlook chapter outlined three technology vectors—probabilistic foresight, policy-ready dashboards, and privacy-preserving federated learning—that will shape the next generation of GeoAI services. Achieving those milestones will require sustained investment in people, platforms, and governance. RSOs must cultivate talent pipelines that combine geospatial expertise with machine-learning fluency. UN-SPIDER must broker long-term compute agreements that insulate critical operations from market volatility in cloud-service pricing. And the global partner community must align research roadmaps with operational needs, avoiding the temptation to chase novelty at the expense of reliability.

CLOSING REFLECTION

GeoAI's ascent is not merely a technological evolution; it is a strategic reconfiguration of disaster-risk governance. By transforming satellite pixels into anticipatory intelligence, GeoAI compresses the temporal gap between sensing and action—a gap that has historically cost lives and livelihoods. The Compendium demonstrates that this transformation is already under way, but its full potential will only be realised if UN-SPIDER, RSOs, and their partners remain disciplined stewards of open science, inclusive capacity-building, and ethical innovation.

If we succeed, GeoAI will become to disaster management what GPS is to navigation: an indispensable, largely invisible utility that quietly empowers billions. The pages that follow will serve as both a snapshot of progress to date and a living scaffold for the discoveries yet to come—updated annually, peer-reviewed rigorously, and always tethered to the tangible goal of safeguarding communities in an era of accelerating hazard and change.

VIII. ANNEXES

VIII. ANNEXES

This publication aims to assess the current state of Geospatial Artificial Intelligence (GeoAI) applications in disaster risk reduction and to identify operational challenges and best practices from across the UN-SPIDER Regional Support Office (RSO) network. To complement background research and internal analysis, a structured questionnaire was circulated to all twenty-seven RSOs under the UN-SPIDER programme. This process aimed to document field-tested applications of GeoAI, spanning various hazard types and use cases across the disaster management cycle.

Best Practice Submission Template
(as used by all RSOs)

Each GeoAI practice in this compendium was submitted using the standardized form below. It ensures clarity, consistency, and comparability across all Regional Support Offices.

Section	Details Required
Title of the GeoAI Practice	A clear, descriptive title that reflects the essence of the project.
Brief Description	100–200 word summary including purpose and context.
Challenge or Problem Addressed	The specific problem this practice aims to resolve (e.g., early warning, hazard mapping).
Implementation and Collaborations	Partnerships with agencies, academia, or private sector.
Impact and Outcomes	Measurable benefits (e.g., faster response, better planning, policy use).
Alignment with UN-SPIDER Goals or SDGs	How it supports UN-SPIDER's mandate or aligns with SDG targets. 8. Lessons Learned and Recommendations
Lessons Learned and Recommendations	Key insights, implementation tips, and challenges encountered.
Additional References or Resources	Links to publications, data, visuals, or external tools.

LIST OF ABBREVIATIONS

Abbreviation	Definition
ACTRIS	Aerosol, Clouds and Trace gases Research Infrastructure
AIT	Asian Institute of Technology
AI	Artificial Intelligence
API	Application Programming Interface
BMBF	German Federal Ministry of Education and Research
CECP	China-ESCAP Cooperation Programme
CGIAR	Consultative Group on International Agricultural Research
CHIRPS	Climate Hazards Group InfraRed Precipitation with Station data
CIGIDEN	Research Center for Integrated Disaster Risk Management
CORINE	Coordination of Information on the Environment
DEM	Digital Elevation Model
DLR	German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt)
EARLINET	European Aerosol Research Lidar Network

LIST OF ABBREVIATIONS

Abbreviation	Definition
EARSeL	European Association of Remote Sensing Laboratories
ECoE	ERATOSTHENES Centre of Excellence
ESCAP	Economic and Social Commission for Asia and the Pacific
ESA	European Space Agency
ESRI	Environmental Systems Research Institute
EW4All	Early Warnings for All
GEE	Google Earth Engine
GEO	Group on Earth Observations
GeoAI	Geospatial Artificial Intelligence
GIC	Geoinformatics Center
GIS	Geographic Information System
GNSS	Global Navigation Satellite System
GPU	Graphics Processing Unit

LIST OF ABBREVIATIONS

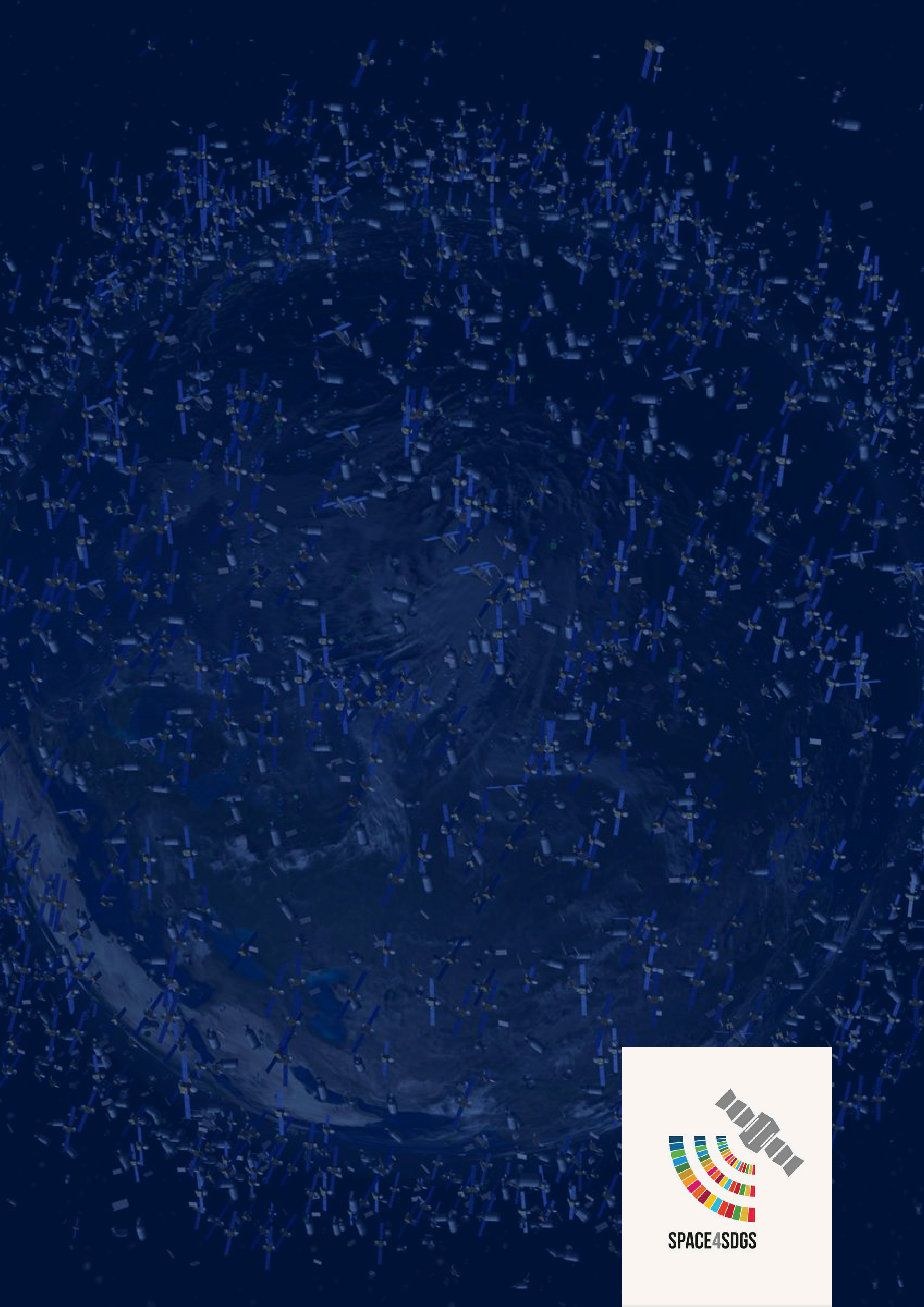
Abbreviation	Definition
HPC	High-Performance Computing
IMERG	Integrated Multi-satellite Retrievals for GPM
InSAR	Interferometric Synthetic Aperture Radar
ISPRS	International Society for Photogrammetry and Remote Sensing
IWMI	International Water Management Institute
LC/LU	Land Cover / Land Use
LSTM	Long Short-Term Memory
MCDA	Multi-Criteria Decision Analysis
ML	Machine Learning
MODIS	Moderate Resolution Imaging Spectroradiometer
NASA	National Aeronautics and Space Administration
NDMA	National Disaster Management Authority
NDRCC	National Disaster Reduction Center of China

LIST OF ABBREVIATIONS

Abbreviation	Definition
NDRMF	National Disaster Risk Management Fund
NEREUS	Network of European Regions Using Space Technologies
PDMA	Provincial Disaster Management Authority
RIESGOS	Riesgo Sistémico en el Cono Sur (Systemic Risk in the Southern Cone)
RSO	Regional Support Office
SAR	Synthetic Aperture Radar
SDG	Sustainable Development Goal
SHAP	SHapley Additive exPlanations
SMILE	Statistical Machine Intelligence and Learning Engine
SNSF	Swiss National Science Foundation
SRTM	Shuttle Radar Topography Mission
SUPARCO	Space and Upper Atmosphere Research Commission
UAV	Unmanned Aerial Vehicle

LIST OF ABBREVIATIONS

Abbreviation	Definition
UC Lan	University of Central Lancashire
UNESCAP	United Nations Economic and Social Commission for Asia and the Pacific
UN-SPIDER	United Nations Platform for Space-based Information for Disaster Management and Emergency Response
UNOOSA	United Nations Office for Outer Space Affairs
USGS	United States Geological Survey
USJRP	Ukrainian–Swiss Joint Research Programme
WHU	Wuhan University
ZFL	Center for Remote Sensing of Land Surfaces (University of Bonn)



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