Accelerating landscape recovery from artisanal and small-scale gold mining in Indonesia using Nature-based Solutions

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Project Highlights:

- **Novel integration of satellite data and numerical modelling**: Combines multi-temporal remote sensing with high-resolution DEMs and landscape evolution modelling to quantify geomorphological change and hydrological alterations in ASGM-affected landscapes.
- **Scenario-based testing of Nature-based Solutions**: Long-term simulations will evaluate the effectiveness of restoration interventions in accelerating landscape recovery.
- **Scalable restoration protocols for tropical mining regions**: Develop evidence-based frameworks applicable across Indonesia's 2,000+ ASGM sites and transferable to other tropical mining contexts globally.

Overview:

This project addresses the urgent environmental challenge of landscape degradation caused by artisanal and small-scale gold mining (ASGM) in Central Kalimantan, Indonesia. ASGM operates at over 2,000 locations across 30 provinces in Indonesia, providing livelihoods for more than 2 million people, yet generates severe and persistent environmental legacies that can endure for decades to centuries without intervention.

ASGM operations fundamentally alter landscape structure and function, leaving behind degraded land with modified topography, disrupted hydrological pathways, and contaminated soils. Abandoned areas typically receive no restoration measures, resulting in a constantly expanding footprint of disturbed terrain characterised by excavated pits, waste material accumulation, vegetation clearance, and modified drainage patterns. These alterations fundamentally change erosion rates, sediment transport dynamics, and hydrological connectivity, creating cascading environmental impacts that extend beyond mine sites to affect downstream river systems and floodplains across entire catchments.

Despite the scale of degradation, there is a critical knowledge gap regarding effective post-mining restoration strategies for tropical ASGM environments. This project develops scalable, cost-effective restoration strategies using Nature-based Solutions (NbS) that harness natural processes to restore landscape functionality while providing co-benefits including improved water quality, enhanced biodiversity, and carbon sequestration.

The project comprises four integrated components: (1) mapping the spatiotemporal evolution of ASGM sites using multi-temporal satellite data to quantify landscape changes and mining patterns; (2) generating high-resolution digital elevation models (DEMs) to characterise topographic alterations and flow path modifications; (3) applying landscape evolution modelling to simulate geomorphological and hydrological processes over 1-250 year timescales, establishing both pre-mining and post-mining baseline conditions; and (4) designing and testing Nature-based Solutions scenarios that accelerate recovery toward pre-mining erosion rates and hydrological function.

Findings will provide actionable guidance for environmental restoration practitioners, mining communities, and policymakers in Indonesia and other tropical mining regions. Results will inform the development of standardised restoration protocols that can be scaled across Southeast Asian mining landscapes and adapted for similar contexts globally (estimated 10-15 million people engaged in ASGM worldwide). Restoration analyses will enable evidence-based decision-making, ultimately contributing to improved environmental outcomes and more sustainable practices in ASGM-affected areas.

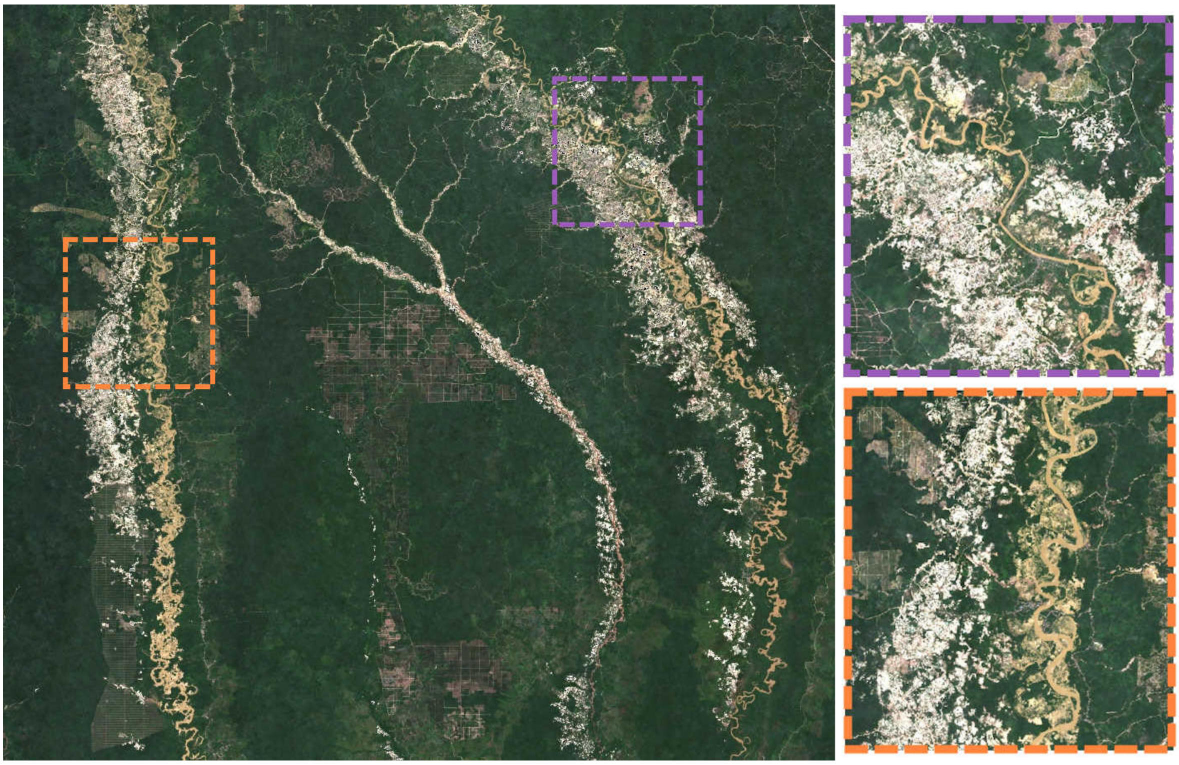

Figure 1: Landscape degradation by ASGM operations along the Kapuas (purple) and Kahayan Rivers (orange) in Central Kalimantan, Indonesia (Sentinel-2 imagery acquired in 2025). A rapid increase in ASGM activity is observable since 2003.

Methodology:

The project comprises four integrated components using remote sensing and numerical modelling:

1. Multi-temporal satellite imagery (Landsat, Sentinel-2, Planet Labs) and satellite embeddings (AlphaEarth Foundations) analysed in Google Earth Engine will map ASGM evolution.
2. High-resolution DEMs generated from stereoscopic satellite imagery (WorldView, Pleiades) will characterise topography, quantify geomorphic change, and evaluate hydrological modifications in mine-affected catchments. DEMs will capture current degraded conditions and pre-mining topography from historical archives for direct comparison.
3. CAESAR-Lisflood landscape evolution model will simulate erosion, sediment transport, flow routing, and vegetation succession over 1-250 year timescales, calibrated using published

data from comparable tropical environments. Baseline simulations will characterise pre-mining (historic/reconstructed DEMs) and post-mining conditions (current degraded DEMs) as reference scenarios for evaluating restoration effectiveness.

4. Nature-based Solutions scenarios (vegetation planting, drainage modifications, bioengineering) will be simulated over decadal to centennial timescales and evaluated against multiple criteria: pre-mining erosion convergence, sediment yield reduction, vegetation establishment, and hydrological recovery. Comparative analysis will rank interventions by effectiveness, informing evidence-based restoration protocols for tropical ASGM regions.

Possible Timeline:

Year 1:

- Comprehensive literature review of ASGM, landscape restoration, and Nature-based Solutions in tropical environments.
- Spatiotemporal analysis of mine site evolution using satellite imagery and satellite embeddings.
- Acquisition of stereoscopic satellite imagery and generation of high-resolution DEMs for initial site.
- Setup and initial parameterisation of the CAESAR-Lisflood landscape evolution model.
- Drafting of Manuscript 1: *'Mapping the multi-decadal spatiotemporal evolution of artisanal mining in Central Kalimantan'*.

Year 2:

- Completion of DEM generation for all selected mine-affected catchments.
- Calibration of the CAESAR-Lisflood model using DEMs and published data from comparable tropical environments.
- Running baseline model simulations (1-250 year timescales) to project future landscape trajectories without intervention and establish pre-mining reference conditions.
- Begin designing and implementing Nature-based Solutions (NbS) scenarios within the model framework.
- Drafting of Manuscript 2: *'Modelling the geomorphological and hydrological impacts of ASGM on tropical landscapes'*.

Year 3:

- Completion of NbS scenario simulations to evaluate the effectiveness of different restoration strategies over decadal to centennial timescales.
- Comparative analysis ranking interventions by effectiveness, implementation costs, and feasibility.
- Final data analysis, synthesis of results, and development of evidence-based restoration protocols.
- Dissemination of findings to project partners, environmental practitioners, and policymakers.
- Drafting of Manuscript 3: *'Evaluating Nature-based Solutions for accelerating recovery of ASGM-degraded landscapes'*.

Year 3.5:

- Thesis synthesis, integration of chapters, and final writing.
- Preparation and submission of any remaining manuscripts for publication.
- Thesis submission and preparation for viva voce examination.

Training and skills:

TARGET researchers will participate in a minimum of 40 days training over the 3.5 years of study composed of:

- an annual one-week workshop dedicated to their year group, and tailored to that cohort's needs in terms of skills development – *for the first three years of their study*;
- an annual all-TARGET workshop with cross-year interactions, advanced training and opportunities to specialise in particular areas – *all years of study*;
- a number of one-day workshops;
- additional online events and in-person workshops attached to relevant conferences.

The student will receive specialist training from the supervisory team in remote sensing (Google Earth Engine, JavaScript/Python), stereoscopic satellite imagery, and numerical modelling using CAESAR-Lisflood. They will develop skills in scientific computing, data analysis, and visualisation of large environmental datasets. Additional training will include GIS, hydrological modelling, and scenario-based restoration planning. The student will gain experience in interdisciplinary research and policy-relevant communication. They will develop professional research skills including presenting at major international conferences (e.g., EGU, AGU), writing scientific publications for high-impact journals, and peer review processes. These skills are highly transferable across academia, consultancy, environmental NGOs, and Earth observation sectors.

Partners and collaboration (including CASE):

Dr Boothroyd (University of Liverpool) brings expertise in fluvial geomorphology and applied remote sensing, including the application of emerging geospatial technologies to environmental challenges in tropical environments. Dr Bennett (University of Exeter) has extensive experience of modelling earth surface processes and hazards using a combination of fieldwork, remote sensing, wireless sensor networks and numerical modelling. Dr Panici (University of Exeter) adds complementary expertise on the monitoring and modelling of Nature-based Solutions, working at the interface of hydraulics, geomorphology, hydrology. The supervisory team are in discussions with relevant project partners; further information will be provided soon.

Further reading:

Boothroyd, R.J., Williams, R.D., Hoey, T.B., Barrett, B. and Prasojo, O.A., (2021). Applications of Google Earth Engine in fluvial geomorphology for detecting river channel change. *Wiley Interdisciplinary Reviews: Water*, *8*(1), p.e21496. https://doi.org/10.1002/wat2.1496

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Hancock, G.R., Duque, J.M. and Willgoose, G.R., (2020). Mining rehabilitation–Using geomorphology to engineer ecologically sustainable landscapes for highly disturbed lands. *Ecological Engineering*, *155*, p.105836. https://doi.org/10.1016/j.ecoleng.2020.105836

Joann, M. and Allan, J., 2021. Geomorphic perspectives on mining landscapes, hazards, and sustainability. *Treatise Geomorphology*, *9*, pp.106-43. https://doi.org/10.1016/B978-0-12-818234-5.00159-0

Panici, D., Bennett, G.L., Boothroyd, R.J., Abancó, C., Williams, R.D., Tan, F. and Matera, M. (2024). Observations and computational multi-phase modelling in tropical river settings show complex channel changes downstream from rainfall-triggered landslides. *Earth Surface Processes and Landforms*, *49*(8), pp.2498-2516. https://doi.org/10.1002/esp.5841

Further details:

Please visit https://target.le.ac.uk/ for additional details on how to apply.

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