Democratising Deforestation Intelligence for Sovereign Finance: A Replicable EO Framework for Sustainability-Linked Bonds in Developing Economies

A cloud-resilient Sentinel-1 SAR deforestation tracker generating near-real time performance indicators to generate satellite-verified deforestation Key Performance Indicator (KPI) to increase confidence and enable sustainability-linked bonds, debt-for-nature swaps, and conservation finance in emerging economies.

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Problem

Forests underpin sovereign debt sustainability — yet monitoring lags behind finance needs

-65%
Uganda forest cover 2000–2020
From 24% → <9% of land area

-1.5B
Ecuador Amazon debt-for-nature swap 2023–24
4.6M ha conserved

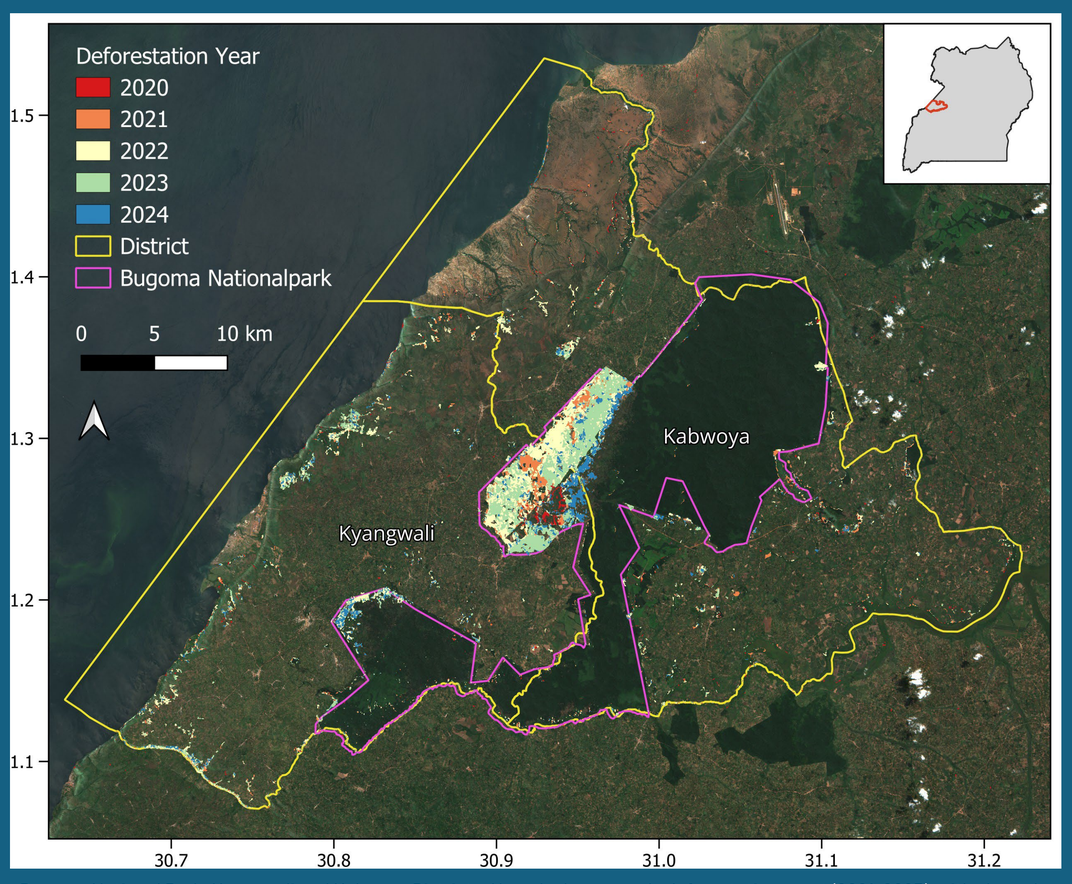
5 yr
Uganda forest monitoring cycle
Too coarse for annual finance KPIs

Sovereign sustainability-linked bonds (**SSLBs**) and debt-for-nature swaps tie **debt costs** directly to **verifiable, annual nature outcomes** — but existing forest monitoring is too infrequent, cloud-affected, and unautomated. Emerging economies need credible, independent, low-cost EO systems that can be embedded into national MRV frameworks and international financial instruments.

Earth Observation KPI Annual forest loss (ha) → **SSLB/Swap** Coupon adjustment → **Conservation $** Fiscal savings reinvested

Results

Conservative, finance-safe detection — outperforming deforestation references



Bugoma National Park, Kyangwali and Kabwoya Districts, Uganda. Large-scale deforestation event (2021–2025), with cleared areas converted to sugarcane plantations. Basemap: Sentinel-2 RGB (07/2024).

Assessment

- Performance differs by reference dataset, largely reflecting the known biases of the comparison products rather than instability in the S1 tracker.
- Tracker alerts are generally reliable: when deforestation is flagged, it is usually correct, indicating strong precision.
- The tracker tends to under-detect rather than over-detect forest loss, which is preferable for SSLBs, where false alarms could reduce trust.
- Visual assessment highlights limitations in the reference datasets: Hansen appears to over-detect loss, while JRC appears to under-detect it.
- The S1 tracker provides a less noisy signal than Hansen and captures some deforestation events missed by both Hansen and JRC.

Note: an independent test dataset is required for rigorous quantitative validation.

Method

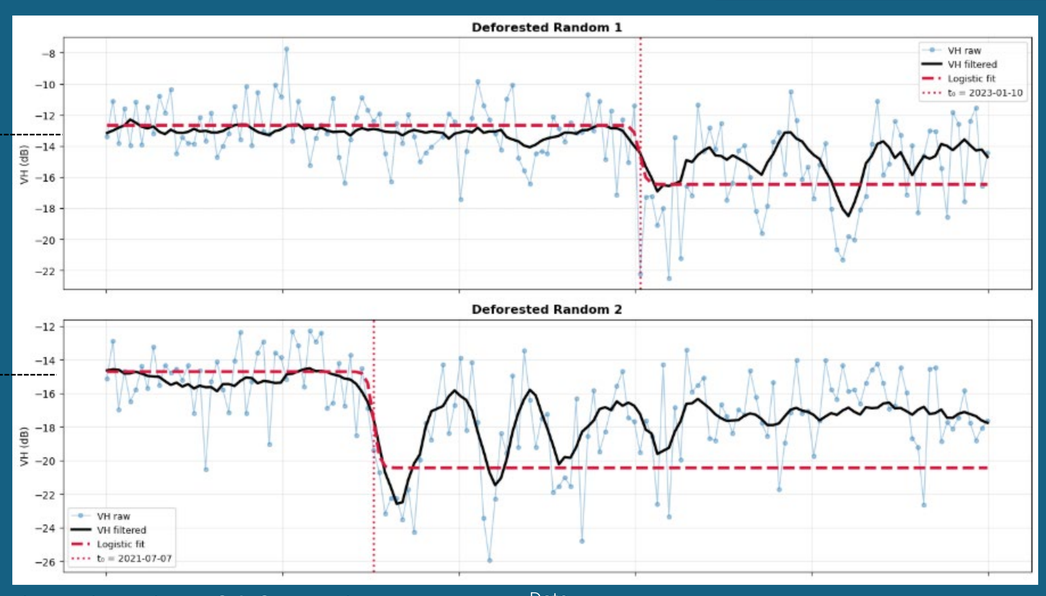
Create forest baseline for 2020
Land Cover (ESRI) + Copernicus tree density (CLMS) + Natural forest mask (Neumann et al. 2025)

S1 SAR Deforestation Tracker adapted after Dascalu et al. 2023
Time series GRD 2020–2025 (VH polarisation, 30 m) → Multi-temporal speckle filtering → temporal variability filter → logistic curve analysis per pixel → detect deforestation events

Knowledge Progress Indicator (KPI) generation
Per-district forest loss (ha), forest → crop conversion (%) (Dynamic World) → analytics-ready CSV for sovereign finance reporting

Logistic analysis

$$\gamma_i(x,y) = k / (1 + e^{-a(ti - t0)}) + LowLim$$



From EO to KPIs

Key Performance Indicators

KPI 2020-25	Kabwoya	Kyangwali
Forest Baseline 2020	31159	13032
Total Forest loss (ha)	3210	4486
Forest to Crop conversion %	84	85

A simple, scalable EO-linked framework for sovereign nature finance based on national forest baselines.

SSLBs & debt swaps
Verifiable annual forest KPIs could be embedded directly into Uganda's sovereign bond framework → coupon tied to measurable conservation performance

S1 SAR Deforestation Tracker
Open access Sentinel data + reproducible, scalable workflow → replicable in any country; only the forest baseline needs updating.

Other integrations
Designed to complement Uganda's existing optical forest monitoring systems, providing cloud-resilient, near-real-time detection. It is adaptable to other KPI frameworks.

Next Steps

1. Test transferability in other forest types: different open forest structure, seasonality, environmental conditions and land management
2. Independent ground truth validation dataset
3. Improved 2020 forest baseline through land cover mapping
4. Expand KPIs: agroforestry, planted and restored forest