EARTH OBSERVATION FOR SDG TARGETS AND INDICATORS, LOT-1

SDG 15.2.1 EO PATHFINDER: EO FOR SUSTAINABLE FOREST MANAGEMENT

D5.1 Results of National Demonstrations

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EO4SDG-Forest
SUSTAINABLE FOREST MANAGEMENT

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Version	Date	Organisation(s) Author(s)
1.0	2024/11/10	Dzhaner Emin (IABG) Andrés Andrade (IABG) Jose Cortes (IABG) Dr. Maximilian Schwarz (RSS) Henri Giraud (SERTIT)

Document change directory

Version	Date	Description	Section/ page

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Applicable Documents

Ref.	Title	Ver-sion	Date
[AD01]	Hansen, et al. (2013). High-Resolution Global Maps of 21st-Century Forest Cover Change. Science (New York, N.Y.). 342. 850-853. 10.1126/science.1244693.		2013
[AD02]	Lang, N., Jetz, W., Schindler, K. et al. A high-resolution canopy height model of the Earth. Nat Ecol Evol 7, 1778–1789 (2023). https://doi.org/10.1038/s41559-023-02206-6		2023
[AD03]	Friis, Ib & Demissew, Sebsebe & Breugel, Paulo. (2010). Atlas of the Potential Vegetation of Ethiopia. 58. 307.		2010
[AD04]	Jucker, et al. (2022). Tallo: A global tree allometry and crown architecture database. Global change biology. 28. 10.1111/gcb.16302.		2022

Web References

Ref.	URL	Description	Last access
[URL01]	https://land.copernicus.eu/en/products/global-dynamic-land-cover/copernicus-global-land-service-land-cover-100m-collection-3-epoch-2015-globe	Land Cover 2015 (raster 100 m), global, yearly – version 3	28.08.2024
[URL02]	https://archive.ipcc.ch/ipccreports/sres/land_use/index.php?idp=46	Types of Forest Definitions	28.08.2024
[URL03]	https://r-spatialecology.github.io/landscapemetrics/index.html	Description of landscape metrics	17.09.2024

1 Scope

This document compiles the results of all national demonstrations conducted for Ethiopia and Vietnam. Each section provides an overview of the respective product, along with standardized descriptions of the associated datasets, including details such as geographical and temporal coverage, resolution, publication date, DOI link, and more. Additionally, supplementary information is provided for the key variables used within the products. All output datasets are hosted on Zenodo.

2 Forest Mask (FM)

2.1 Overview

The product is a raster of a forest/non-forest classification showing the extent of forest stands in ha (Table 1). Forest will be classified based on the forest definition, where forest stands have to cover more than 0.5 ha in area, a height above 5m and a canopy cover of at least 10%. Areas that are pre-dominantly under agricultural and urban use will be excluded.

Accurate forest inventory data is needed for Ethiopia due to varying existing figures. The Global Forest Change (GFC) map from the University of Maryland [AD01], requiring specific calibration, was used alongside high-resolution RapidEye maps to create a calibrated forest map for Ethiopia. Tree cover thresholds were determined based on the potential vegetation types in Ethiopia (Moist/transitional evergreen forest, Dry evergreen forest, and Woodland). Accuracy was assessed using random points and the optimal thresholds were selected to minimize errors. The result was a calibrated forest classification for Ethiopia for 2017, corrected for forest changes up to 2017.

An updated forest mask for 2020 was developed using the 2017 mask and additional datasets for forest gain and loss. Canopy height data, Sentinel-2 NDVI trends, and specific thresholds were used to identify forest gain and loss (Table 2). This updated the forest mask, considering inaccuracies in canopy height data and NDVI influenced by clouds, resulting in a new forest classification for Ethiopia for 2020 (Figure 1, Figure 2).

Table 1. Forest Mask output dataset description

Dataset Description	
Data type	Raster
Projection	EPSG:32637 - WGS 84 / UTM zone 37N
Horizontal Coverage	Longitude of right side: 47.9788° (bottom-right), 48.2730° (top-right) Longitude of left side: 32.9919° (bottom-left), 32.7932° (top-left)
Horizontal Resolution	30
Temporal Coverage	2020
Temporal resolution	N/A
File format	TIF
Update frequency	N/A
DOI	10.5281/zenodo.14004524
Publication date	2024/10/28
Licence	GPL3

Table 2. Main variables used to compute the Forest Mask product

Main Variables		
Name	Unit	Description
Sentinel-2 data time series	m	Used as base imagery for NDVI-max calculation, which is needed for vitality status definition
GFC Map Products: From the University of Maryland [AD01]	Dimensionless	Used as base forest map for further calibrations
High-Resolution RapidEye-Based Forest Benchmark Maps	m	Used to create a calibration based on high resolution imagery to adjust Hansen Forest mask
Global canopy height dataset [AD02]	m	Used as base height information for forest stands in AOI

2.2 Results

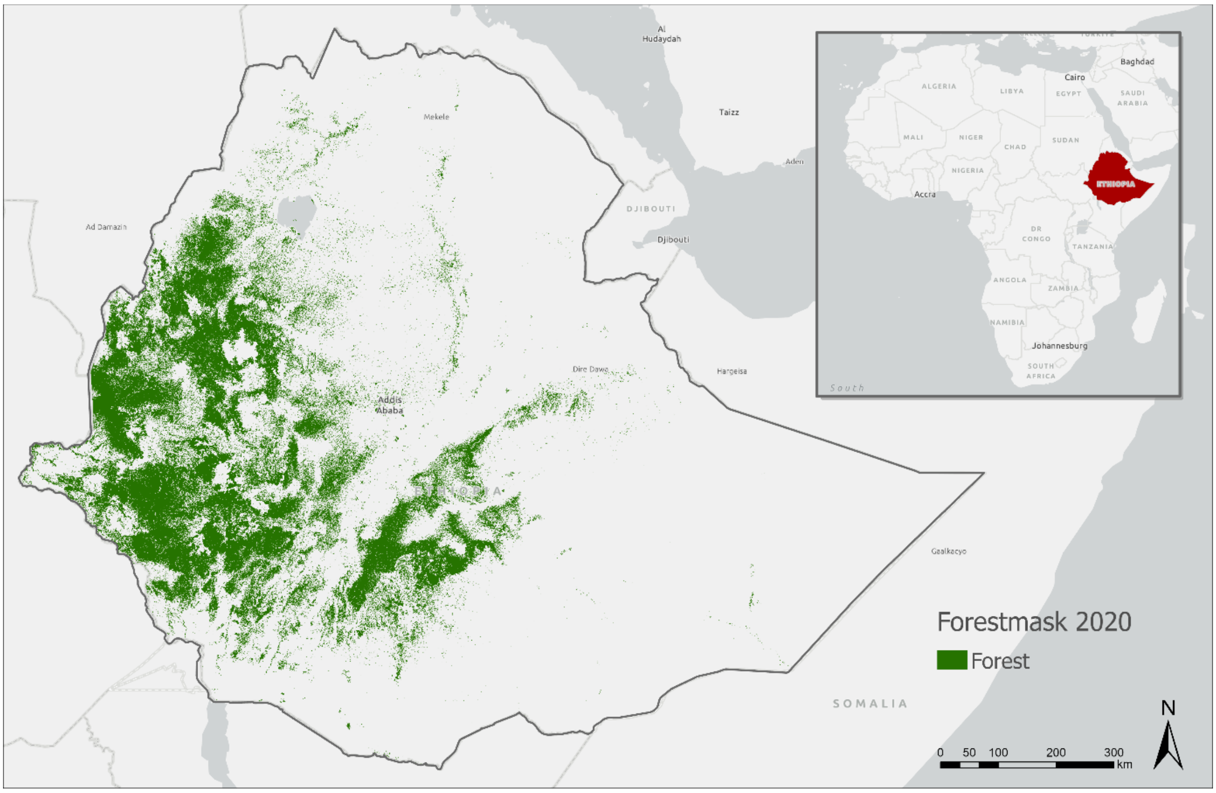


Figure 1. Final Forest mask product Ethiopia 2020

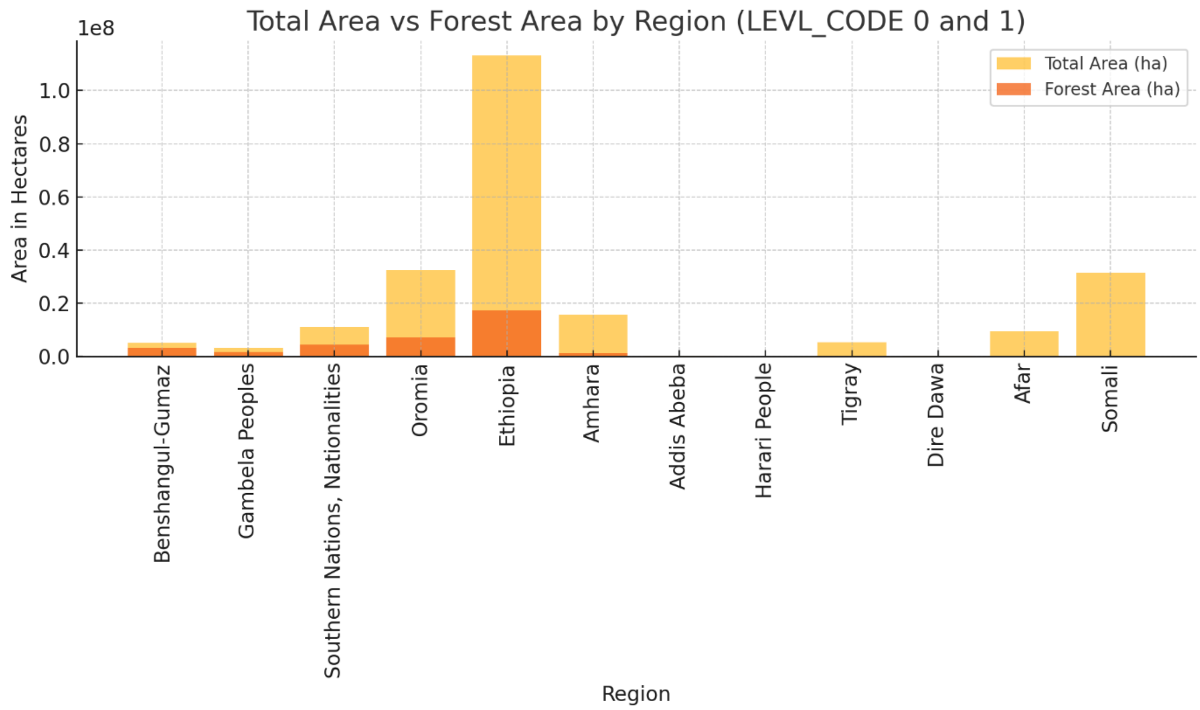


Figure 2. Forest area statistics due to the Forest Mask

3 Forest Area Net Change Rate (FNC)

3.1 Overview

This product is a raster dataset that captures forest area changes, distinguishing between afforestation (forest gain) and deforestation (forest loss) (Table 3). The analysis is based on a comparison of forest masks from two-time steps, along with forest management practices.

For forest gain, the product integrates three datasets (Table 4):

- Canopy Height: Based on Lang et al. (2023) [AD02], tree heights above 5m in non-forest areas from 2017 are considered as forest gain.
- NDVI Trend: The Normalized Difference Vegetation Index (NDVI) was calculated using Sentinel-2 data from 2017 to 2020. If the positive NDVI change exceeded a threshold of 0.3, the pixel was classified as forest gain.
- NDVI from 2020: Pixels with a yearly maximum NDVI value greater than 0.6 were also classified as forest gain.

Only when all three criteria were met did the pixel get mapped as forest gain. The result was further refined using the 2017 forest mask to capture net gain. For forest loss, a negative NDVI trend below -0.15 was used to classify pixels as forest loss, with calculations confined to pixels that were forested in 2017 (Figure 3). The product combines both forest gain and loss data to represent Forest Area Net Change, accounting for potential errors due to inaccuracies in canopy height data and the influence of clouds on NDVI readings.

Table 3. Forest Area Net Change output dataset description

Dataset Description	
Data type	Raster
Projection	EPSG:32637 - WGS 84 / UTM zone 37N
Horizontal Coverage	Longitude of right side: 47.9788° (bottom-right), 48.2730° (top-right) Longitude of left side: 32.9919° (bottom-left), 32.7932° (top-left)
Horizontal Resolution	30
Temporal Coverage	2020
Temporal resolution	N/A
File format	TIF / SHP
Update frequency	N/A
DOI	10.5281/zenodo.14004524
Publication date	2024/10/28
Licence	GPL3

Table 4. Main variables used to compute the Forest Area Net Change product

Main Variables		
Name	Unit	Description
Forest Mask	m	Existing forest mask of AOI; input by user
Sentinel-2 data time series	m	Used as base imagery for NDVI-max calculation, which is needed for vitality status definition
Global canopy height dataset [AD02]	m	Used as base height information for forest stands in AOI

3.2 Results

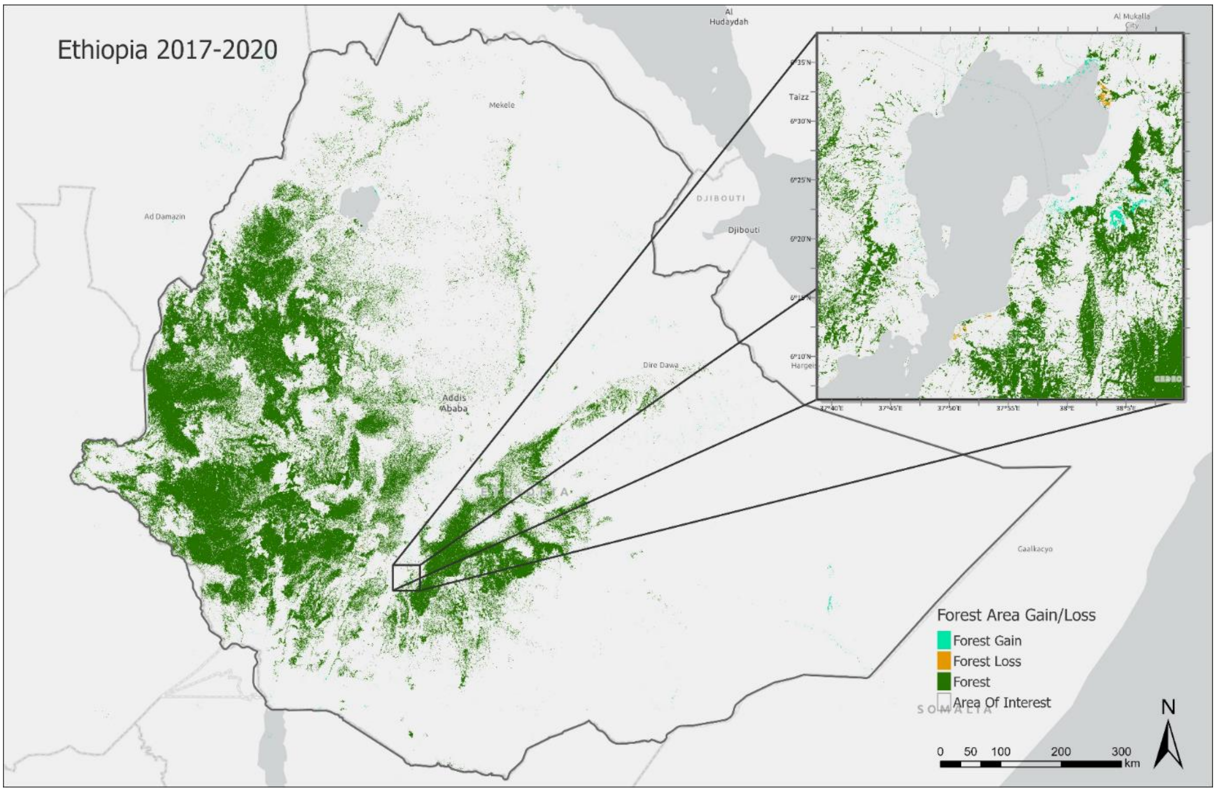


Figure 3. Forest Area Net Change Rate classification

4 Above-Ground Biomass Stock (AGB)

4.1 Overview

This product is a raster dataset that estimates above-ground biomass (AGB) of forest stands in tons per hectare (t/ha) (Table 5). It primarily relies on Earth Observation (EO) data such as Sentinel-2, along with canopy height information. Additional user data, such as forest maps, inventories, and tree-specific allometries, can be integrated to enhance the accuracy of the biomass estimation.

A new methodology for biomass estimation in Ethiopia was developed using the land cover classification by Friis et al. (2010) [AD03], which identifies four main forest biomes:

- Moist Afromontane Forest
- Acacia-Commiphora bushland
- Dry Afromontane Forest
- Combretum-Terminalia woodland

For each biome, relevant tree species were identified, and literature was used to determine forest density and suitable allometric equations for biomass calculation.

The tree species were validated through the Tallo database [AD04], which provides detailed tree measurements such as trunk diameter, height, and crown radius. Regression analyses were performed using this data to establish relationships between tree height and diameter at breast height (DBH) for each biome, enabling more precise biomass estimates.

The biomass estimation process used the ETH Zurich canopy height model (CHM) [AD02] in combination with the land cover classification. Regression models based on allometry were applied, and the initial biomass was calculated in kilograms per tree at a resolution of 10x10 meters. These values were then converted to tons per hectare, factoring in forest density (Table 6). The final biomass calculation differentiates forest from non-forest areas using an updated forest mask (Figure 4).

Table 5. Above-Ground Biomass Stock output dataset description

Dataset Description	
Data type	Raster
Projection	EPSG:32637 - WGS 84 / UTM zone 37N
Horizontal Coverage	Longitude of right side: 47.9788° (bottom-right), 48.2730° (top-right) Longitude of left side: 32.9919° (bottom-left), 32.7932° (top-left)
Horizontal Resolution	30
Temporal Coverage	2020
Temporal resolution	N/A
File format	TIF
Update frequency	N/A
DOI	10.5281/zenodo.14004524
Publication date	2024/10/28
Licence	GPL3

Table 6. Main variables used to compute the Above Ground Biomass Stock product

Main Variables		
Name	Unit	Description
Forest Mask	m	Existing forest mask of AOI; input by user
Tallo database [AD04]	Dimensionless	Base database for calculating regression based allometries for dbh/H relations
Global canopy height dataset [AD02]	m	Used as base height information for forest stands in AOI

4.2 Results

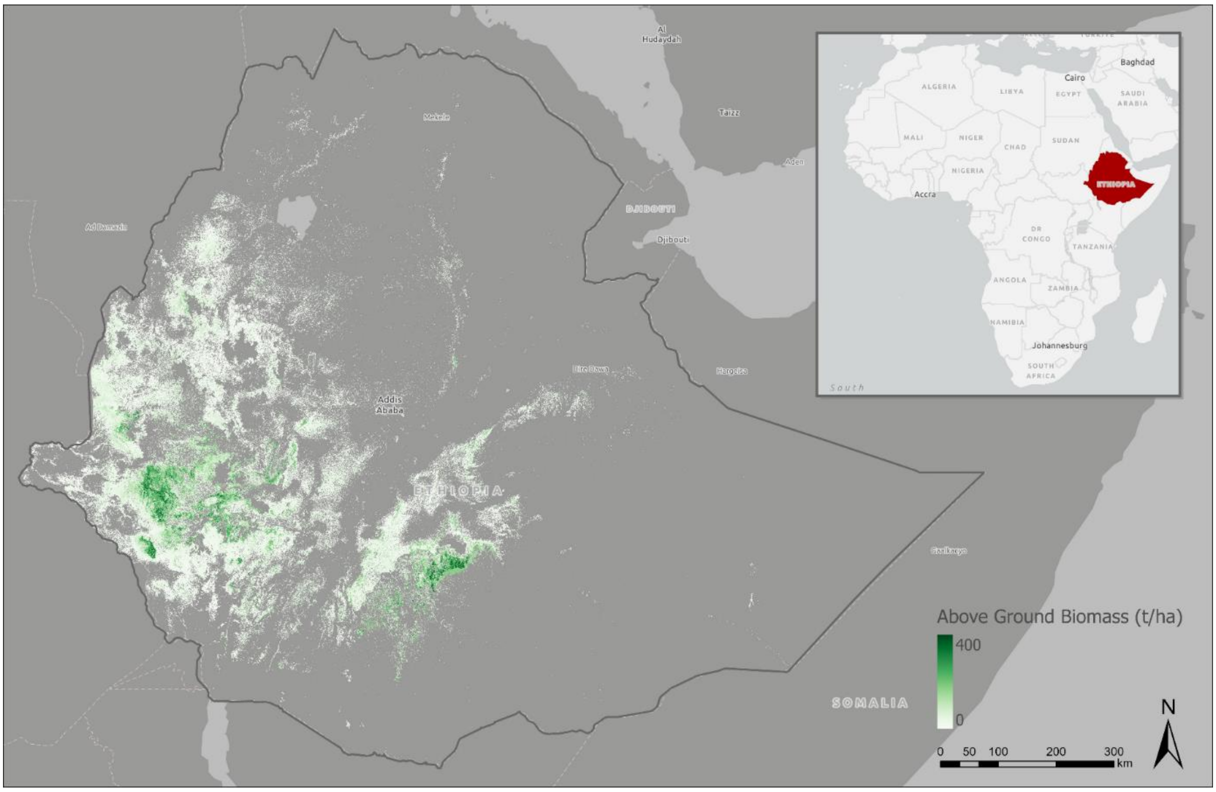


Figure 4. Final AGB estimation for Ethiopia

5 Forest Condition Monitoring (FCM)

5.1 Overview

5.1.1 Vitality

The product is a raster indicating forest condition changes (Table 7). Changes in forest condition are derived from Sentinel-2 time series at regular intervals, e.g. on an annual basis. A mean vitality benchmark is used as a basis for comparison in order to determine whether the vitality of the forests is increasing, decreasing or remaining constant (Table 8).

The forest condition layer provides vitality trends for all forest types. It is a pixel-based approach using all Sentinel-2 data between 2017 and 2023, which were aggregated monthly and yearly via a best-pixel approach to gather mostly cloud free composites. To identify changes in forest vitality, the NDVI was calculated for each monthly composite, on which basis yearly NDVI maximum values were calculated in the next step. These maximum NDVI composites were then compared between years to identify forest disturbances and timber harvesting as well as forest areas without change or areas with regrowth. A time-series analysis of the monthly maximum NDVI composites reflects the NDVI-based vitality trend that shows vitality gain and loss (Figure 5).

Table 7. FCM Vitality output dataset description

Dataset Description	
Data type	Raster
Projection	EPSG:32637 - WGS 84 / UTM zone 37N
Horizontal Coverage	Longitude of right side: 47.9788° (bottom-right), 48.2730° (top-right) Longitude of left side: 32.9919° (bottom-left), 32.7932° (top-left)
Horizontal Resolution	30
Temporal Coverage	2020
Temporal resolution	N/A
File format	TIF
Update frequency	N/A
DOI	10.5281/zenodo.14004524
Publication date	2024/10/28
Licence	GPL3

Table 8. Main variables used to compute the FCM Vitality product

Main Variables		
Name	Unit	Description
Forest Mask	m	Existing forest mask of AOI; input by user
Sentinel-2 data time series	m	Used as base imagery for NDVI-max calculation, which is needed for vitality status definition

5.1.2 Disturbance

Disturbances are an integral part in forest ecosystems, influencing their stand, structure, and re-generation. Although there is no single definition for a disturbance that satisfies all scientific and societal questions, it can be described as a negative deviation from the long-term phenology and thus a decrease in vitality. Plants are regularly exposed to stress, as these site-bound organisms are dependent on a variety of environmental influences and stressors. Next to abiotic stressors such as air pollution, droughts, fires, floods and storms, biotic stressors like pathogens, insects and invasive species and anthropogenic causes such as pollution and deforestation place strain on the vegetation and can cause a decrease of vitality. In most cases, stressors do not act individually, but several at the same time, whereby the interactions can be synergic, antagonistic, or overlapping.

Large-scale condition monitoring is particularly important to understand changes in the condition of forest ecosystems. To detect vitality disturbances with remote sensing sensors, the stress symptoms must result in a sufficiently large change in reflection for a sensor to measure them. Moreover, the spectral, spatial, and temporal characteristics of the disturbance and the object of interest (from single tree level up to forest level) highly influence the detectability of vitality disturbances.

The method selected in this analysis is Sustained Change, a breakpoint or change detection algorithm implemented in open-source software. The results in the next section are shown for a selection of AOIs where change detection (i.e. vegetation decrease) in a pixel is considered as disturbance. We consider a pixel that has at least 2 events in a year (compared to the previous year) flagged as disturbance to be a "true" disturbance. In this way we eliminate potential false positives. The resulting datasets and their main variables are summarised in Table 9 and Table 10.

Table 9. Dataset description of FCM Disturbance results in Vietnam

Dataset Description	
Data type	Raster, vector
Projection	EPSG:4326
Horizontal Coverage	Extent coordinates (lat/long): • Top: 23°22'55,9596" N • Bottom: 8°24'43,4592" N • Left: 102°8'34,7712" E • Right: 111°55'19,7544" E
Horizontal Resolution	10 m
Temporal Coverage	2023
Temporal resolution	Yearly
File format	.tif, .gpkg
DOI	10.5281/zenodo.14004524
Publication date	2024/10/28
Licence	GPL3

Table 10. Main variables in output datasets FCM Disturbance

Main Variables		
Name	Unit	Description
dist_2020	Hectares [ha]	Total detected forest disturbance in hectares for 2020 for all administrative units (NUTS-1, -2, -3)
dist_2021	Hectares [ha]	Total detected forest disturbance in hectares for 2021 for all administrative units (NUTS-1, -2, -3)
dist_2022	Hectares [ha]	Total detected forest disturbance in hectares for 2022 for all administrative units (NUTS-1, -2, -3)
dist_2023	Hectares [ha]	Total detected forest disturbance in hectares for 2023 for all administrative units (NUTS-1, -2, -3)
dist_2024	Hectares [ha]	Total detected forest disturbance in hectares for 2024 for all administrative units (NUTS-1, -2, -3)
None	Hectares [ha]	No detected disturbance

5.2 Results

5.2.1 Vitality

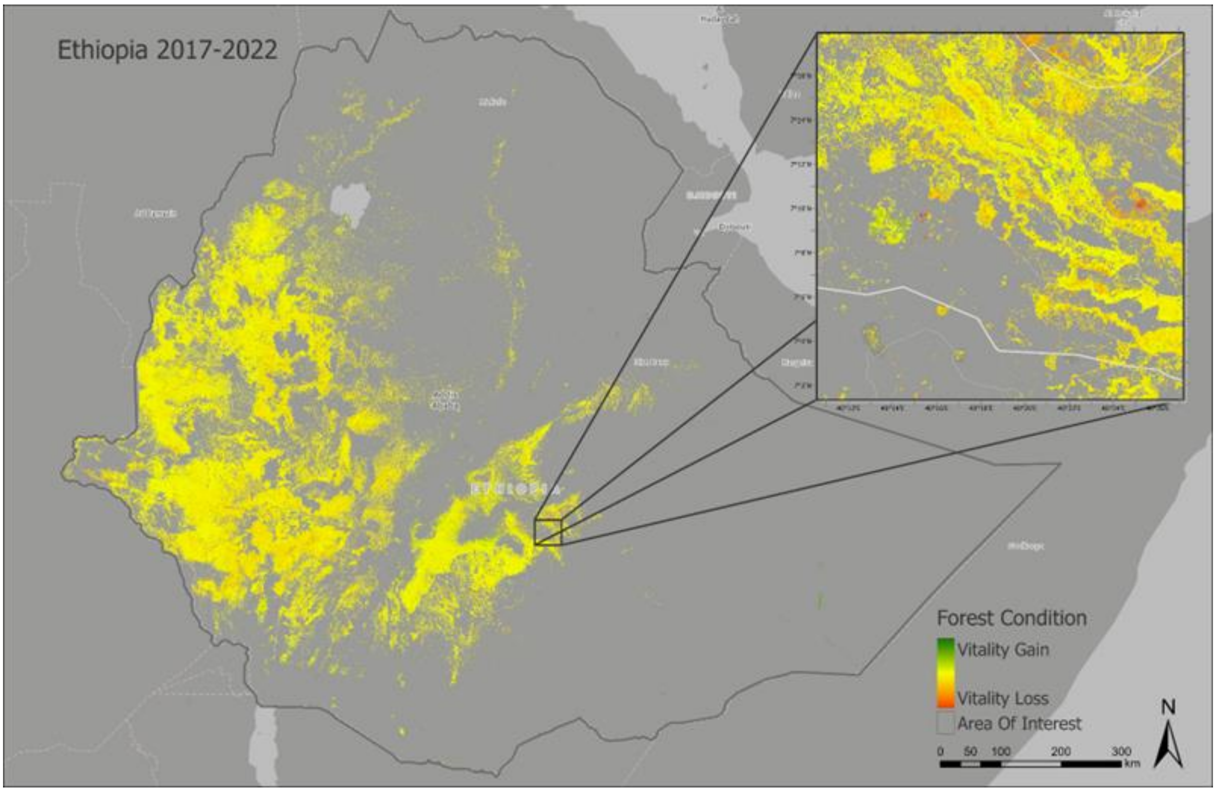


Figure 5. Final forest cover vitality classification Ethiopia

5.2.2 Disturbance

The first two figures in this section (Figure 6, Figure 7) present the results for forest disturbance at the national level. Results in raster format are not included at this level, but we have aggregated them to the smallest possible administrative unit (NUTS-3). This makes it easier to compare results for the same municipalities in different years. With the possible exception of central Vietnam, there is no visible continuity between years in the detected disturbance in most of the municipalities. Each year seems to display a different region where most of the disturbance (by area in hectares) takes place. At least visually, there does not seem to be a trend.

Other figures in this section present a variety of results in raster format from northern, central, and southern Vietnam (Figure 8, Figure 9, Figure 10, Figure 11). All results presented in this section can be reproduced for any region of Vietnam. These results are presented in at a regional level (NUTS-1), with subdivisions shown at a lower hierarchical level (NUTS-2) in order to better identify where disturbances are or are not occurring.

All forested areas in the 2019 dataset that have not changed over the years are displayed in green, which also visualises the total extent of forest for a given region. The disturbance analysis for 2024 could only be conducted until the month of June, which partly explains the lack of corresponding pixels across regions.

The last four figures in this section show a general picture at the regional level. However, zooming in on individual areas can provide more detailed information.

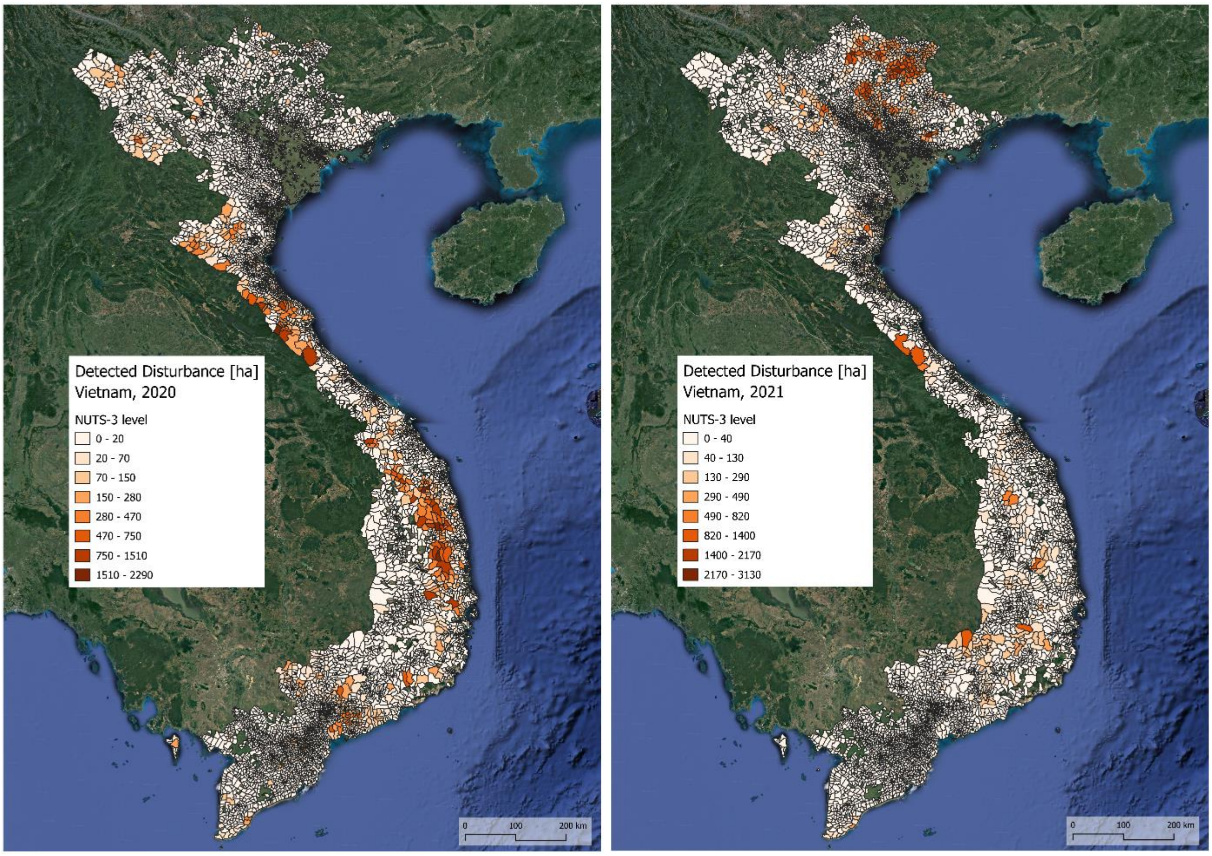


Figure 6. Detected disturbance for the years 2020 and 2021 aggregated at NUTS-3 administrative level.

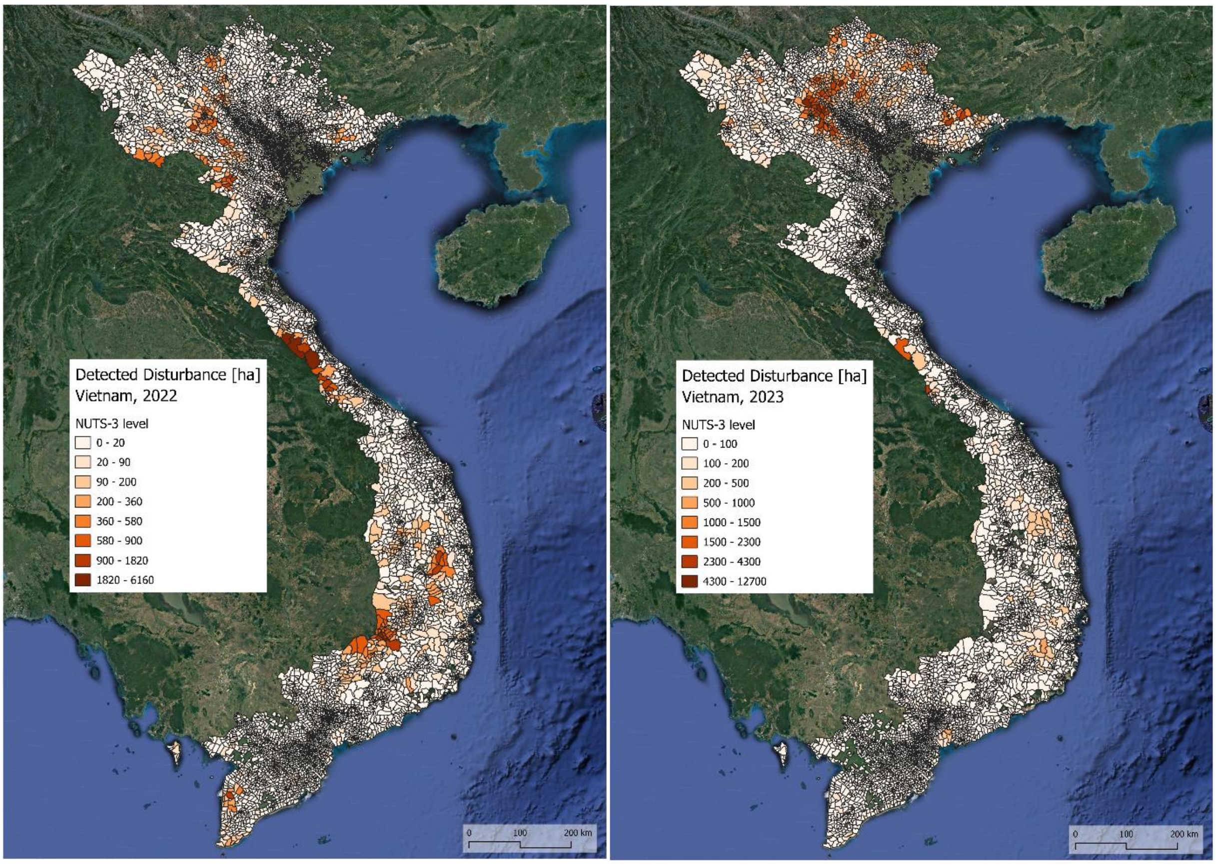


Figure 7. Detected disturbance for the years 2022 and 2023 aggregated at NUTS-3 administrative level.

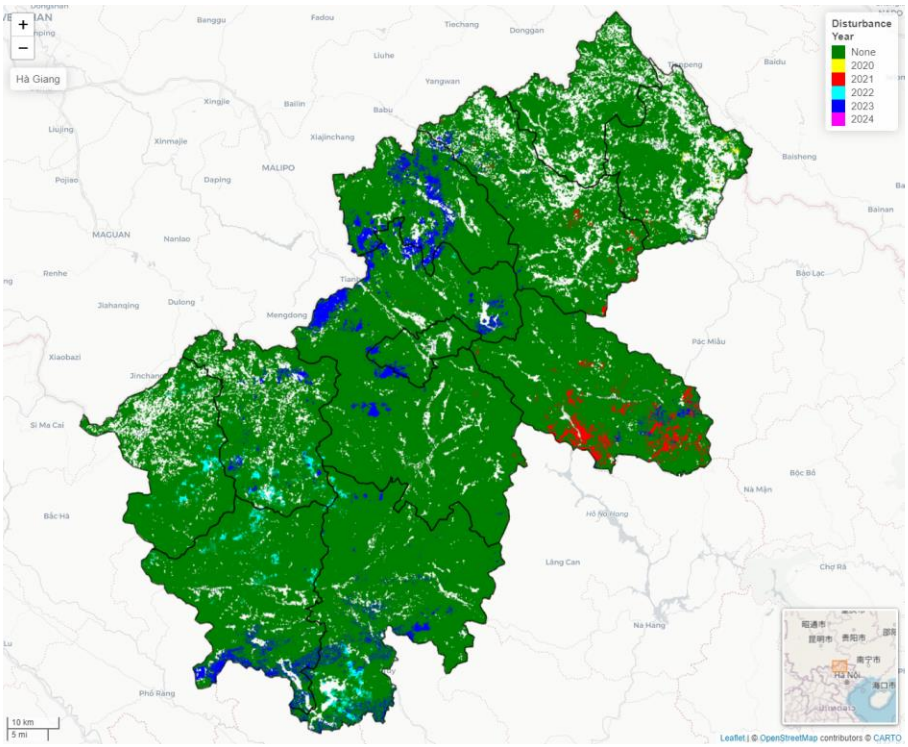


Figure 8. Forest disturbance per year (2020-2024) for the Ha Giang region, northern Vietnam.

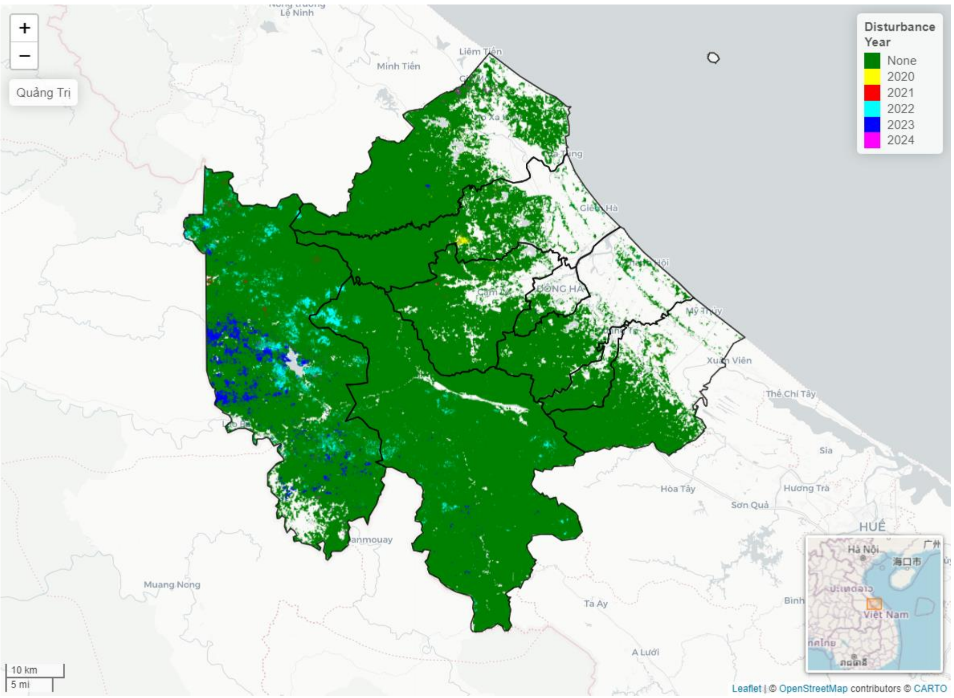


Figure 9. Forest disturbance per year (2020-2024) for the Quang Tri region, central Vietnam.

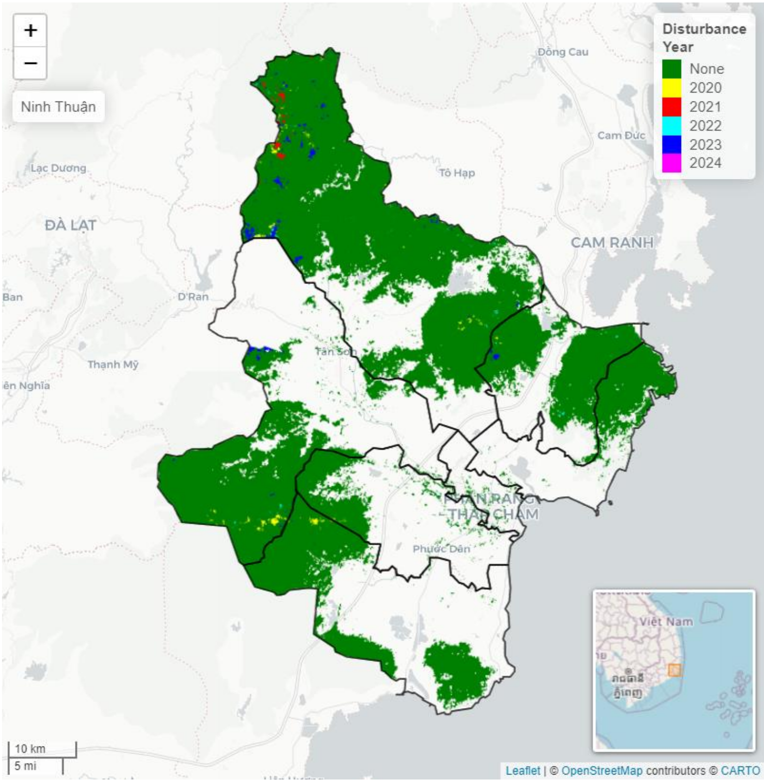


Figure 10. Forest disturbance per year (2020-2024) for the Ninh Thuan region, southern Vietnam.

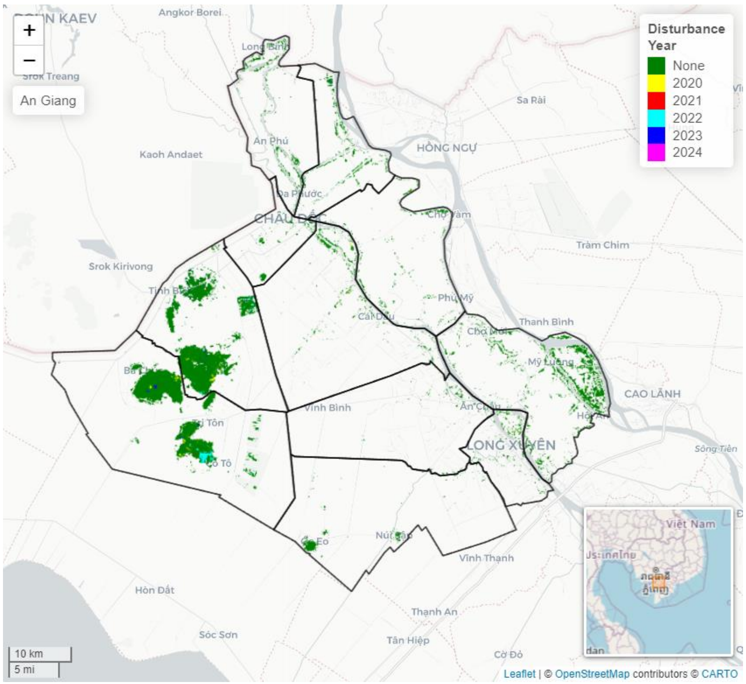


Figure 11. Forest disturbance per year (2020-2024) for the An Giang region, southern Vietnam.

6 Change in Erosion Risk / Landslide Risk (FER)

6.1 Overview

For the FER product (including the Erosion Risk and the Landslide Risk components) it has been chosen to generate the National Demonstrator over Vietnam.

6.1.1 Erosion Risk

The Erosion Risk product is based on the Revised Universal Soil Loss Equation (RUSLE) soil erodibility model, a well-known, universally accepted and implemented empirical soil erosion estimation model. The model output is then reclassified according to the soil erosion susceptibility values in order to group them in soil erosion risk classes ranging from very low (or tolerable) to severe.

Therefore, the output consists in two raster layers (10m spatial resolution, .tif format):

- Soil erosion susceptibility (mean annual soil loss, in ton/ha/year),
- Soil erosion risk classification (5 classes: 1 (Very Low), 2 (Low), 3 (Moderate), 4 (High), 5 (Severe)).

For visualization and analytics purposes, the product also includes some statistics calculated using Vietnam administrative units. The average of the soil erosion susceptibility has been computed over various administrative levels (country, province and district levels) and compiled into a vector file (.shp format).

Table 11 below provides a summary of the Erosion Risk dataset main characteristics.

Table 11. Erosion Risk output dataset description

Dataset Description	
Data type	Raster / Vector
Projection	UTM 48 North
Horizontal Coverage	Extent coordinates (lat/long): • Top: 23°22'55,9596" N • Bottom: 8°24'43,4592" N • Left: 102°8'34,7712" E • Right: 111°55'19,7544" E
Horizontal Resolution	10m
Temporal Coverage	2022-2024 (product based on several Sentinel-2 images acquired between 2022 and 2024; the complete list of Sentinel-2 acquisitions is provided below)
Temporal resolution	N/A
File format	TIF (raster files) / SHP (vector file)
Update frequency	N/A
DOI	10.5281/zenodo.14004524
Publication date	2024/10/28
Licence	GPL3

Vietnam having a monsoon-influenced climate, finding cloud free satellite acquisitions is not an easy task. Selecting Sentinel-2 imagery form multiple observation dates has been necessary to avoid using images with too many clouds and to be able to cover the whole country. This is why the selected Sentinel-2 acquisitions range from December 2022 to January 2024, with most of them acquired outside of the rainy season (between late April/early May and October).

The inventory of all the Sentinel-2 acquisitions used is provided in Table 12. For each acquisition date, the selected Sentinel-2 tiles with their corresponding projection, as well as the location is also indicated.

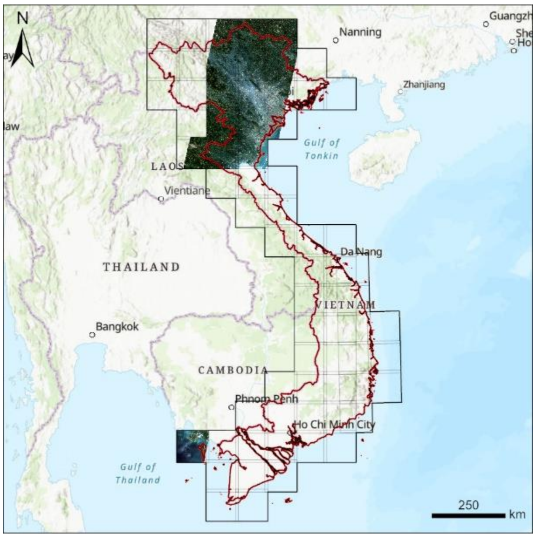
Table 12. Inventory of Sentinel-2 acquisition dates and tiles used to compute the FER-ER product

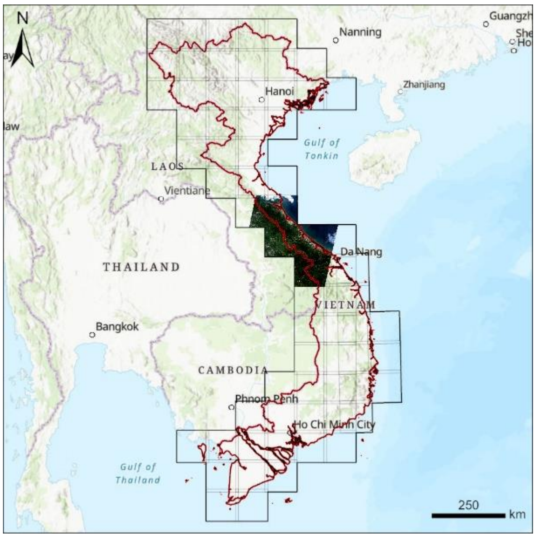
Input Sentinel-2 Imagery			
Acquisition Date	Projection	Location	Sentinel-2 tiles
19/12/2022	UTM 48 North	North, Southwest	48QVL, 48QWL, 48QXL, 48QVK, 48QWK, 48QXK, 48QVJ, 48QWJ, 48QXJ, 48QVH, 48QWH, 48QXH, 48QUG, 48QVG, 48QWG, 48PUS
15/01/2023	UTM 48 North	Center	48QWE, 48QXE, 48QXD, 48QYD, 48QZD, 48PYC, 48PZC
30/01/2023	UTM 48 North	Northeast	48QXK, 48QYK, 48QXJ, 48QYJ, 48QZJ, 48QXH
08/03/2023	UTM 48 North UTM 49 North	South	48PYB, 48PZB, 48PYA, 48PZA, 48PYV, 48PZV, 48PXU, 48PYU, 48PZU, 48PXT, 48PYT, 48PZT, 48PXS, 48PYS, 48PZS, 48PXR, 49PBP, 49PBN
05/05/2023	UTM 48 North	Center	48QWF, 48QXF, 48QWE, 48QXE
18/05/2023	UTM 48 North	North	48QVG, 48QWG
22/05/2023	UTM 48 North UTM 49 North	Southwest	48QZD, 48PZC, 48PZB, 48PZA, 48PZV, 49PBT, 49PBS, 49PBR, 49PCR, 49PBQ, 49PCQ, 49PBP, 49PCP, 49PBN
09/12/2023	UTM 48 North	North	48QVG, 48QWG, 48QVF, 48QWF

Input Sentinel-2 Imagery			
30/01/2024	UTM 48 North	Southwest	48PXU, 48PYU, 48PWT, 48PXT, 48PYT, 48PUS, 48PVS, 48PWS, 48PXS, 48PVR, 48PWR, 48PXR, 48PVQ, 48PWQ
06/03/2024	UTM 48 North	Northwest	48QTL, 48QUL, 48QVL, 48QTK, 48QUK, 48QVK, 48QTJ, 48QUJ, 48QVJ, 48QUH

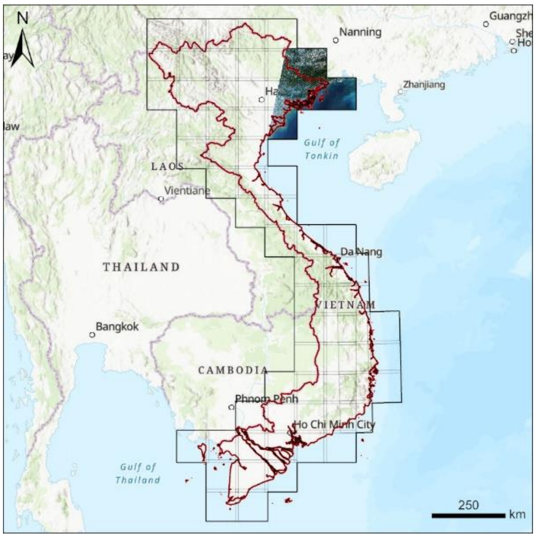
In addition to these characteristics, Figure 12 shows an overview of each Sentinel-2 acquisition location and coverage.

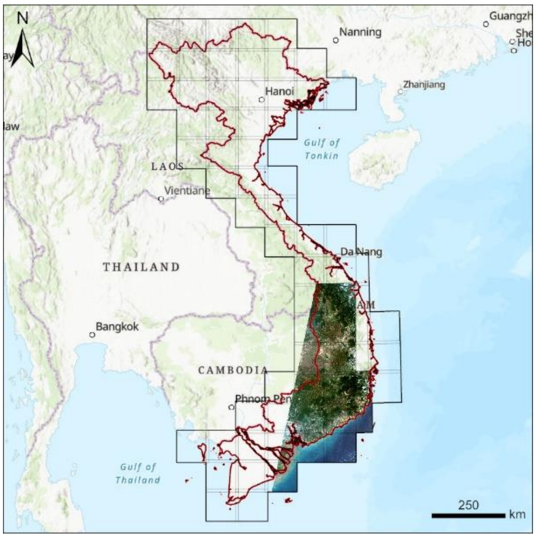
19/12/2022 | 15/01/2023



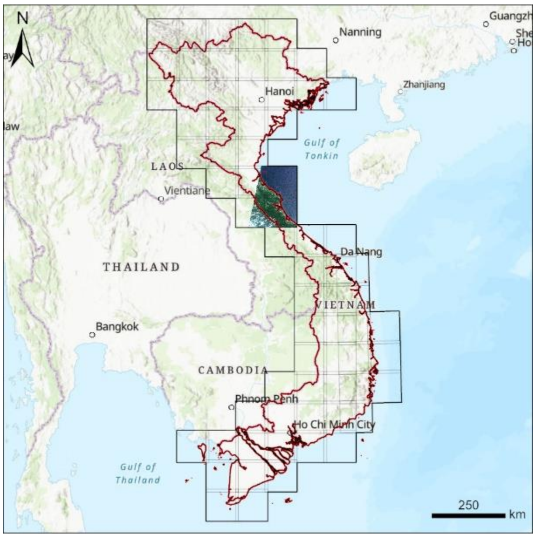


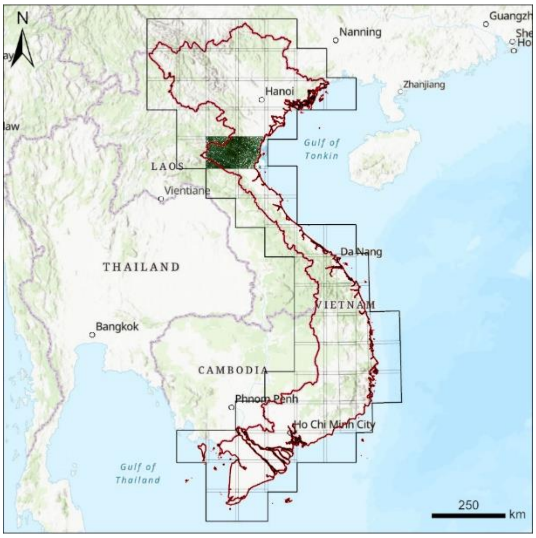
30/01/2023 | 08/03/2023



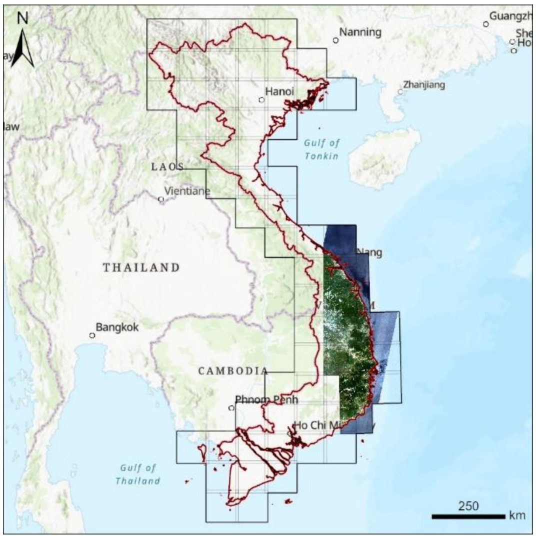


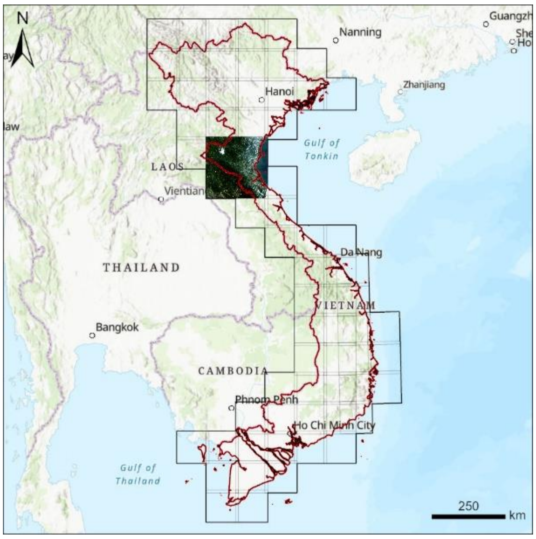
05/05/2023 | 18/05/2023



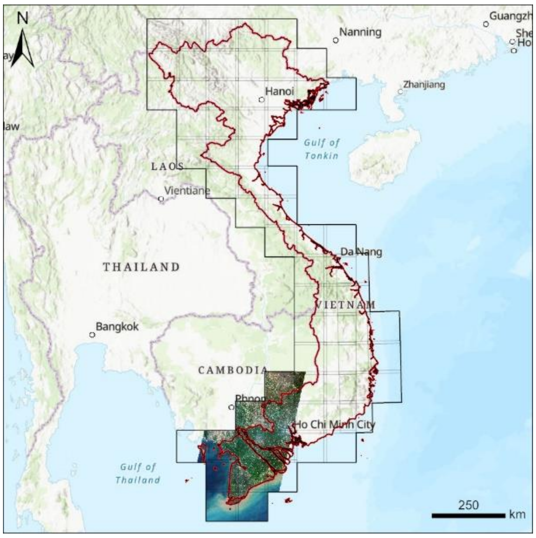


22/05/2023 | 09/12/2023





30/01/2024 | 06/03/2024



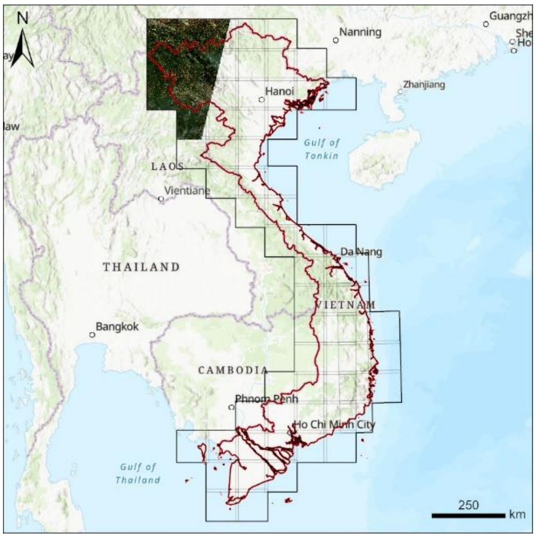


Figure 12. Location and coverage of each Sentinel-2 acquisition used to generate the FER-ER product

Along with the Sentinel-2 imagery, several other variables are needed to compute the Erosion Risk product. The layers used to represent these variables are listed in Table 13.

Table 13. Main variables used to compute the Erosion Risk product

Main Variables		
Name	Unit	Description
Global rainfall erosivity dataset	$ha.h.ha^{-1}.MJ^{-1}.mm^{-1}$	Corresponds to the R factor, used as input parameter of the RUSLE model
Global soil erodibility dataset	$MJ.mm.ha^{-1}.h^{-1}.year^{-1}$	Corresponds to the K factor, used as input parameter of the RUSLE model
Copernicus DEM - Global Digital Elevation Model	Dimensionless	Used to compute the slope length and steepness (LS) factor, which is an input of the RUSLE model
ESA WorldCover	Dimensionless	Used to compute the cover management (C) factor, which is an input of the RUSLE model

6.1.2 Landslide Risk

The FER Landslide Risk product is based on the Landslide Susceptibility Index (LSI), calculated using the European Landslide Susceptibility (ELSUS) or the Analytical Hierarchical Process (AHP) multi-criteria approaches according to the territory considered. The output is then reclassified in order to group them in landslide risk classes ranging from very low (or tolerable) to severe.

Therefore, the output consists in two raster layers (30m spatial resolution, .tif format):

- Landslide susceptibility (dimensionless),
- Landslide risk classification (5 classes: 1 (Very Low), 2 (Low), 3 (Moderate), 4 (High), 5 (Severe)).

Like the Erosion Risk product, some statistics are calculated using administrative units. The average of the landslide susceptibility has been computed over various administrative levels (country, province and district levels) and compiled into a vector file (.shp format).

Table 14 below provides a summary of the Landslide Risk dataset main characteristics.

Table 14 . Landslide Risk output dataset description

Dataset Description	
Data type	Raster / Vector
Projection	UTM 48 North
Horizontal Coverage	Extent coordinates (lat/long): • Top: 23°22'55,9596" N • Bottom: 8°24'43,4592" N • Left: 102°8'34,7712" E • Right: 111°55'19,7544" E
Horizontal Resolution	30m
Temporal Coverage	2021 (product based on the ESA WorldCover 2021)
Temporal resolution	N/A
File format	TIF (raster files) / SHP (vector file)
Update frequency	N/A
DOI	10.5281/zenodo.14004524
Publication date	2024/10/28

Dataset Description	
Licence	GPL3

The temporal coverage is driven by the Landuse / Landcover layer (LULC) used (product only based on external layers, no satellite imagery used)

Unlike the Erosion Risk, no satellite imagery is used to generate the Landslide Risk product, but relies on six main variables: elevation, slope, aspect, hydrological network, landcover, lithology. Four of these parameters are topography characteristics, and are derived from a digital elevation model. The layers corresponding to these main variables are listed in Table 15.

Table 15. Main variables used to compute the Landslide Risk product

Main Variables		
Name	Unit	Description
Global Lithological Map database	Dimensionless	Used to compute the geology conditioning factor
Copernicus DEM - Global Digital Elevation Model	Dimensionless	Used to compute the topography conditioning factors (elevation, slope, aspect, hydrological network)
ESA WorldCover	Dimensionless	Used to compute the landuse / landcover conditioning factor

6.2 Results

6.2.1 Erosion Risk

Figure 13 displays an overview of the soil erosion risk classification over Vietnam.

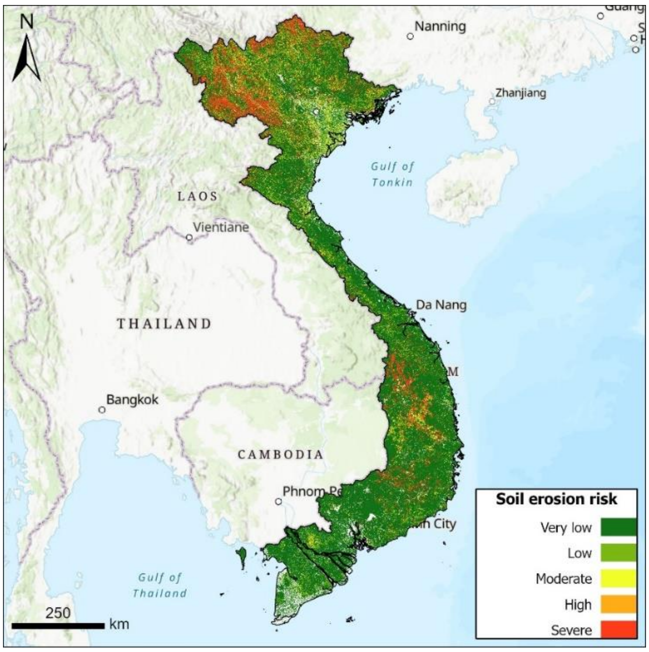


Figure 13. Soil erosion risk classification over Vietnam

At this scale, the soil erosion risk seems to be relatively low, except in some places corresponding to the mountainous areas, but this first assessment can be completed thanks to the statistical analysis. The Figure 14, Figure 15, and Figure 16 display soil erosion risk classifications calculated over the various Vietnam administrative levels (country, provinces and districts), each unit classified according to its associated average value of the mean annual soil loss. At the country scale, the average value of the mean annual soil loss is classified as severe, which can be surprising in comparison with the map of the soil erosion risk presented earlier. In addition, the soil erosion risk classifications based on the provinces and the districts levels are consistent, confirming the higher risk is located in the northern and the central part of Vietnam.

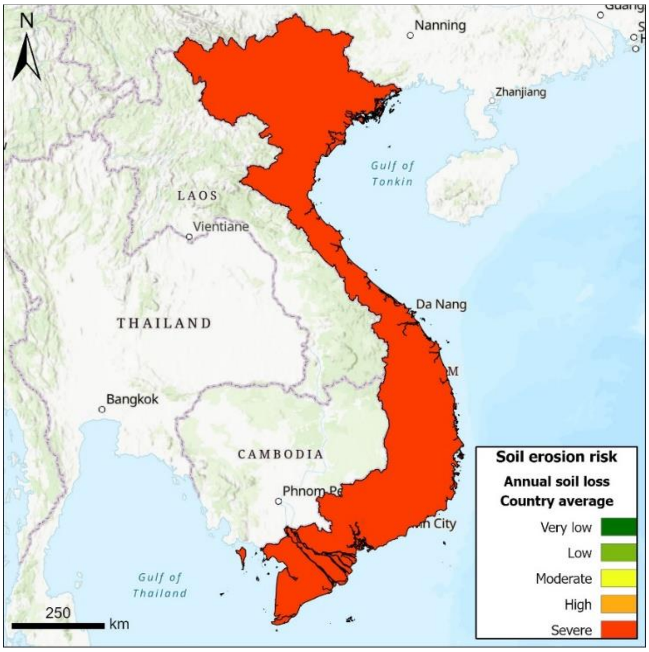


Figure 14. Soil erosion risk classification calculated using the average value of the mean annual soil loss over Vietnam

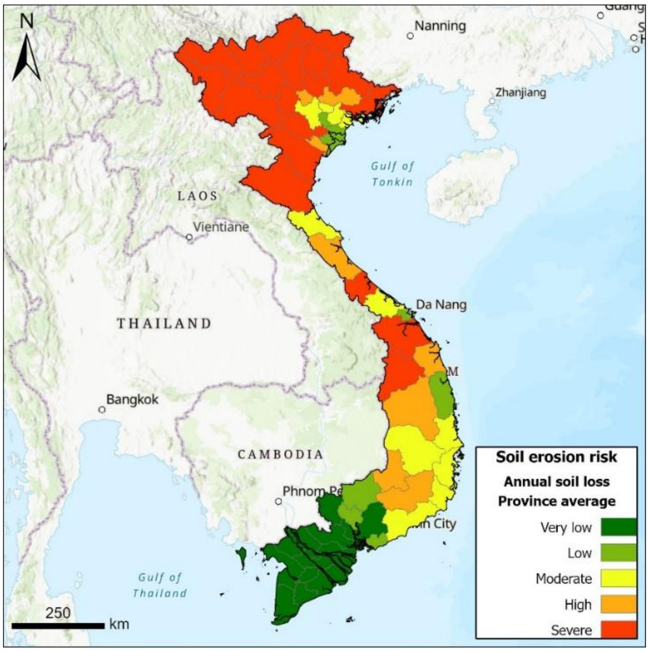


Figure 15. Soil erosion risk classification calculated using the average value of the mean annual soil loss over the Vietnam provinces

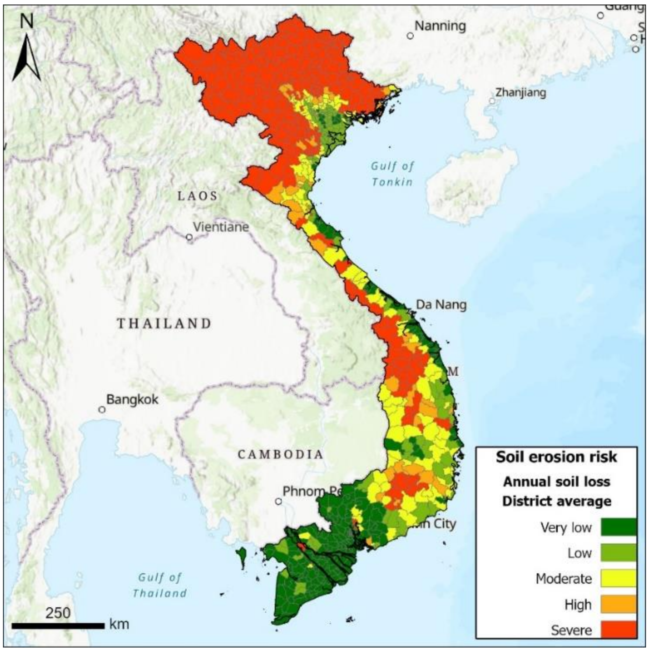


Figure 16. Soil erosion risk classification calculated using the average value of the mean annual soil loss over the Vietnam districts

It is also possible to compare, for instance through a boxplot diagram, the distribution of the mean annual soil loss average values, according to the unit types, to analyse to what extent it is similar between Vietnam provinces and districts (Figure 17).

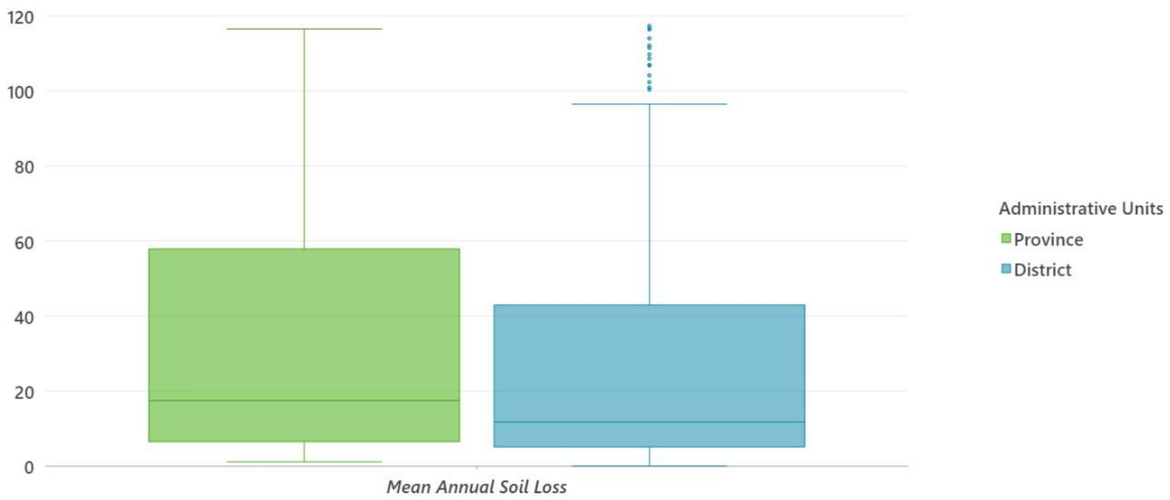


Figure 17. Boxplot distribution of the mean annual soil loss average values calculated over the administrative units, and classified by unit types (province and district)

Finally, Figure 18 and Figure 19 present the soil erosion risk distribution of each administrative unit type (province and district), based on their mean annual soil loss average value. Both figures show that the distribution is relatively similar for both unit types.

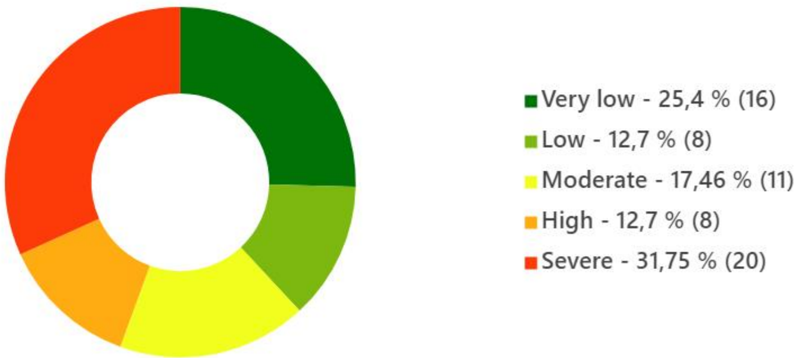


Figure 18. Soil erosion risk distribution of the Vietnam provinces

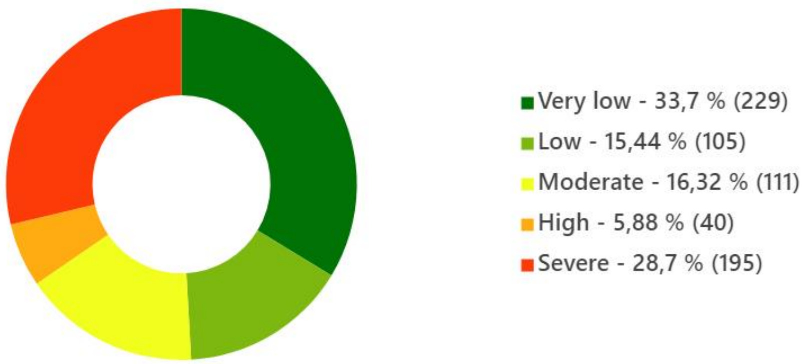


Figure 19. Soil erosion risk distribution of the Vietnam districts

6.2.2 Landslide Risk

Figure 20 presents an overview of the landslide risk classification over Vietnam. This map is consistent with the soil erosion risk, but tends to indicate that the landslide risk affects a larger part of the country.

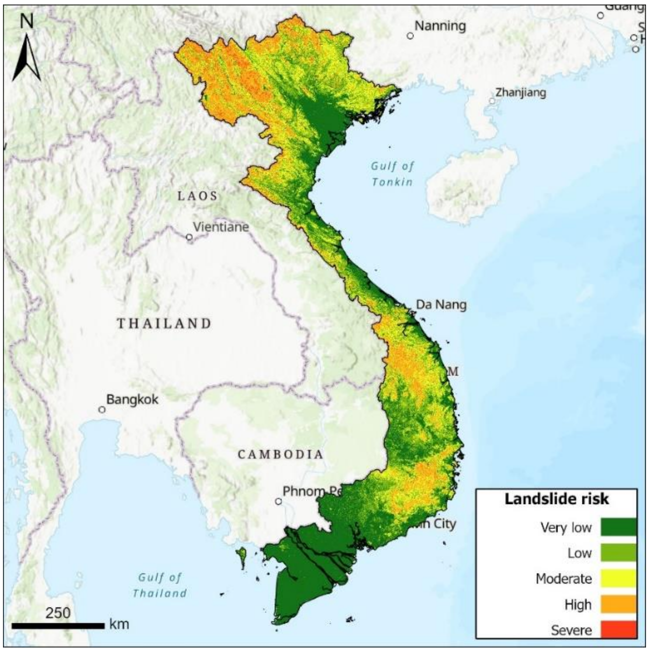


Figure 20. Landslide risk classification over Vietnam

Figure 21, Figure 22, and Figure 23 display landslide risk classifications calculated again over the Vietnam administrative levels (country, provinces and districts). Each unit is classified according to its associated average value of the landslide susceptibility index. At the country scale, the average value of the landslide susceptibility index is classified as moderate. It can be also surprising in comparison with the soil erosion risk results, but also widely depends on the threshold values used. The classifications based on the provinces and the districts levels are consistent, but fewer areas are classified as severe in comparison with soil erosion.

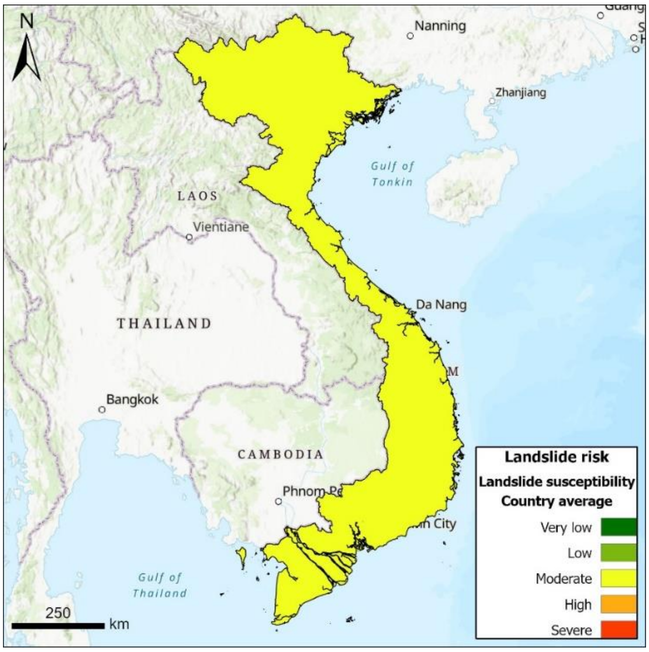


Figure 21. Landslide risk classification calculated the average value of the landslide susceptibility over Vietnam

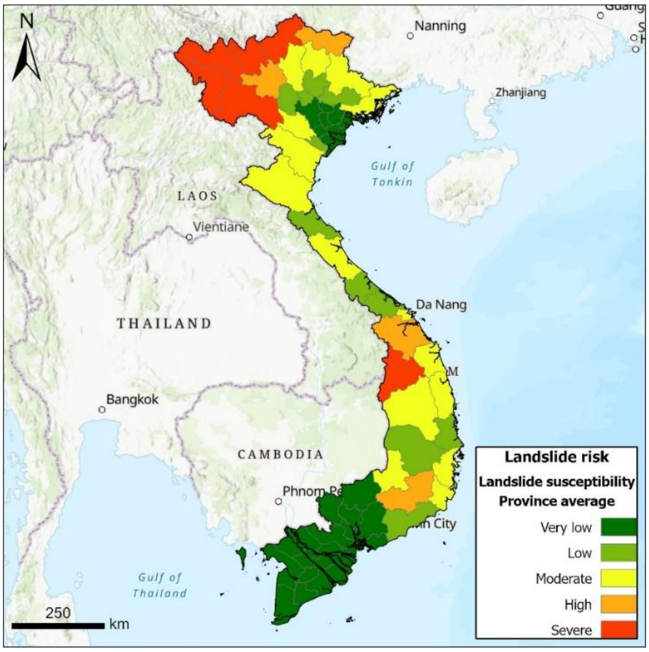


Figure 22. Landslide risk classification calculated using the average value of the landslide susceptibility over the Vietnam provinces

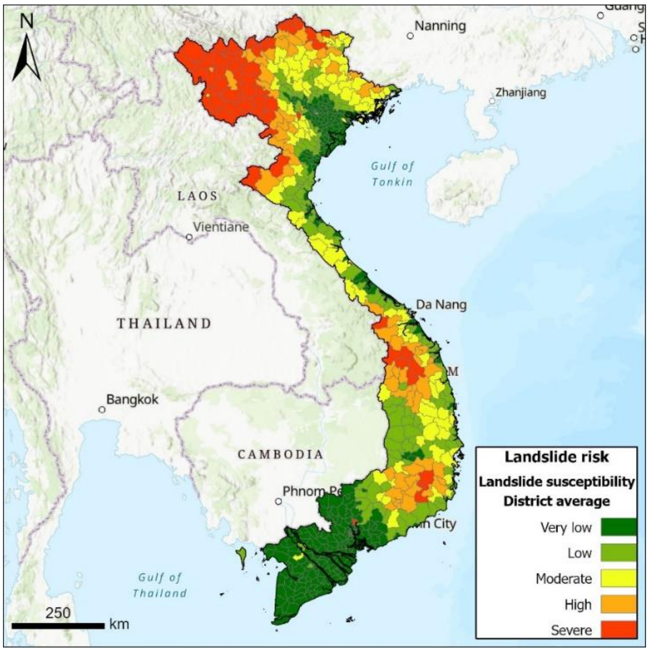


Figure 23. Landslide risk classification calculated using the average value of the landslide susceptibility over the Vietnam districts

Figure 24 shows a boxplot distribution of the landslide susceptibility index average values, according to the unit types, to analyse to what extent it is similar between Vietnam provinces and districts

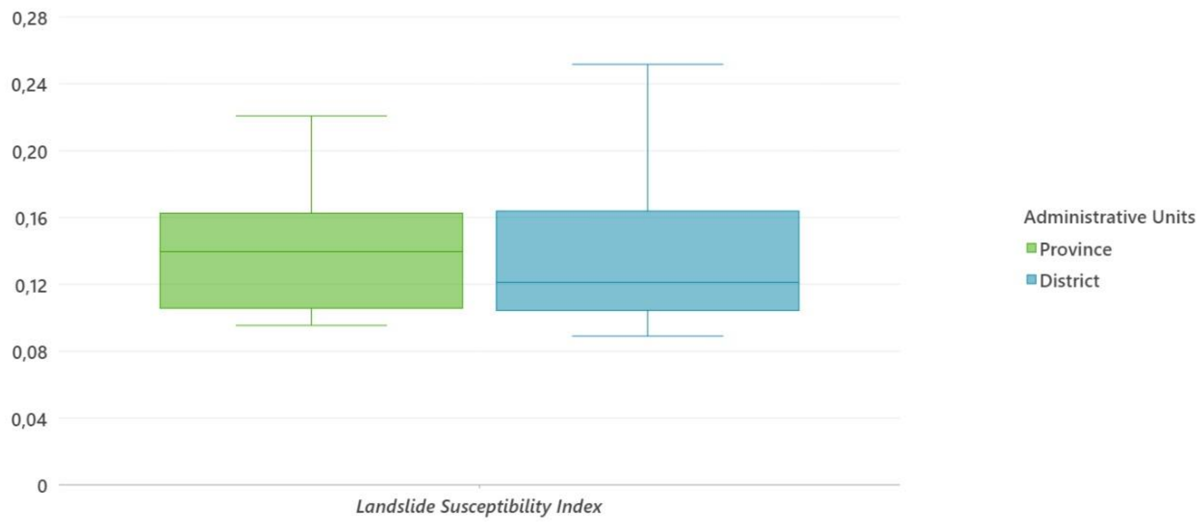


Figure 24. Boxplot distribution of the landslide susceptibility index average values calculated over the administrative units, and classified by unit types (province and district)

Finally, Figure 25 and Figure 26present the landslide risk distribution of each administrative unit type (province and district), based on their landslide susceptibility index average value. Again, both diagrams indicate there is no major difference between provinces and districts.

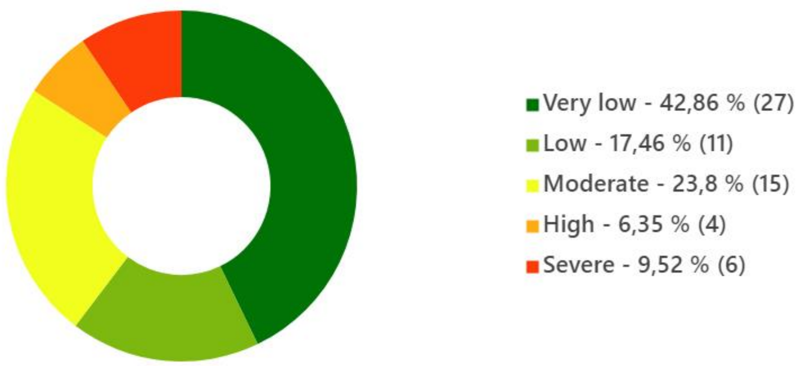


Figure 25. Landslide risk distribution of the Vietnam provinces

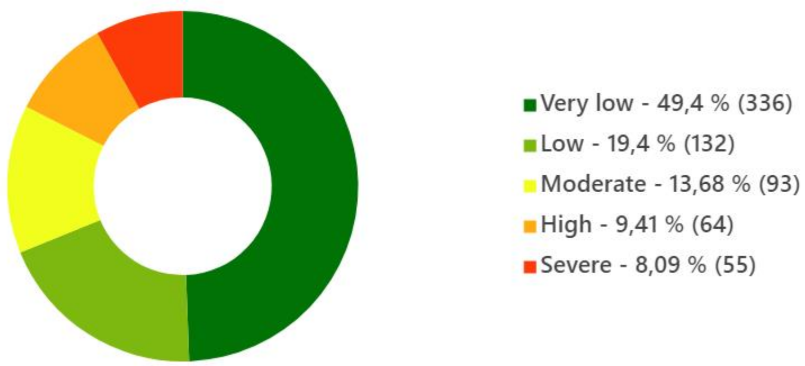


Figure 26. Landslide risk distribution of the Vietnam districts

7 Landscape Metrics (FLM)

7.1 Overview

Growing concerns over the loss of biodiversity have spurred land managers to seek better ways of managing landscapes at a variety of spatial and temporal scales. The developing field of landscape ecology has provided a strong conceptual and theoretical basis for understanding landscape structure, function, and change. Landscape ecology involves the study of landscape patterns, the interactions among patches within a landscape mosaic, and how these patterns and interactions change over time. Landscape ecology makes use of several methods, among which we find the use of landscape metrics. These are metrics that offer a numeric way of assessing all the processes stated above and are a great tool to understand and manage landscapes more sustainably. The metrics calculated here relate to area, shape, edge, core (patch level) isolation (class level), and diversity (landscape level). In the next section, we focus on a selection of these, namely the area, shape, and diversity metrics.

The aim of this product is to create meaningful landscape metrics and scale them for the country of Vietnam. These are summarised in Table 16 and Table 17, and exemplified by several selected AOIs in the next subsection. However, the metrics used here could be calculated for any place in the world. Moreover, this section aims to present visually appealing maps, graphs and tables summarising our main findings. Finally, we include important supporting information with our results for easier interpretation by users.

Table 16. Dataset description of results of FLM in Vietnam

Dataset Description	
Data type	Gridded (raster), vector
Projection	EPSG:4326
Horizontal Coverage	Extent coordinates (lat/long): • Top: 23°22'55,9596" N • Bottom: 8°24'43,4592" N • Left: 102°8'34,7712" E • Right: 111°55'19,7544" E
Horizontal Resolution	100 m
Temporal Coverage	2015
Temporal resolution	Yearly
File format	.tif, .gpkg/.shp
DOI	10.5281/zenodo.14004524
Publication date	2024/10/28
Licence	GPL3

Table 17. Main variables in output dataset for the FLM product

Main Variables [URL]		
Name	Unit	Description
Area	Hectares [ha]	Area of each patch in hectares. The lowest value is limited by the resolution of the input raster. One of the most basic yet most important metrics. Range of values: AREA >0
Core [Core area]	Hectares [ha]	Equals the absolute area within a patch that is not on the edge of it. Range of values: Core ≥ 0
Perim [Perimeter]	Meters [m]	Equals the perimeter of the patch including the edge to the landscape boundary. Range of values: Perim > 0
Cai [Core area index]	Percentage	Equals the percentage of a patch that is core area (as opposed to edge area). A cell is defined as core area if the cell has no neighbour with a different value than itself. Range of values: 0 ≤CAI ≤ 100
Circle	Dimensionless	Shape metric that represents the ratio between patch area and the smallest circumscribing circle of the patch. The metric characterises the compactness of a patch. Range of values: 0 ≤ Circle ≤ 1 (Circle = 0 for a circular patch and approaches Circle = 1 for a linear patch)
Contig [Contiguity index]	Dimensionless	Shape metric that assesses the spatial connectedness (contiguity) of cells in patches. Range of values: 0 ≤ Contig ≤ 1 (Contig = 0 for one-pixel patches and increases to a limit of 1 for fully connected patch).
Enn [Euclidean nearest neighbor distance]	Meters [m]	Aggregation metric that measures the distance to the nearest neighbouring patch of the same class i. The distance is measures from edge to edge. It is a simple way to describe patch isolation. Range of values: ENN > 0
Frac [Fractal dimension index]	Dimensionless	Shape metric that describes patch complexity. It is based on patch perimeter and area, and it is standardised. Range of values: 1 ≤ Frac ≤ 2 (values approach 1 for a squared patch shape for and 2 for an irregular shape).
Ncore [Number of core areas]	Hectares [ha]	It counts the disjunct core areas. A compact shape (e.g. a square) will contain less disjunct core areas than a more irregular patch. Range of values: Ncore ≥ 0
Para [Perimeter-area ratio]	Dimensionless	Shape metric that describes patch complexity. It is not standardised and not scale independent, so that increasing patch size while not changing the patch form will change the ratio. Range of values: Para > 0
Shape	Dimensionless	Simple measure of patch complexity. Ratio between patch perimeter and the square root of the area. Range of values: Shape ≥ 1 (equals 1 for a squared patch and increases without limit as the patch shape becomes more complex).
Prd [Patch richness density]	Dimensionless	One of the simplest diversity and composition metrics. Ratio between number of classes and total landscape

Main Variables [URL]		
		area. Range of values: Prd > 0 (value approaches 1 when only one patch is present, and the landscape is rather large. Increases without limit as the number of classes increases and the total landscape area decreases)
Shdi (Shannon's diverstiy index)	Dimensionless	Widely used diversity metric in ecology. Takes both the number of classes and abundance of each class into account. Range of values: Shdi ≥ 0 (equals 0 when only one patch is present, and increases without limit as the number of classes increases while the proportions are equally distributed).
Shei (Shannon's evenness index)	Dimensionless	Diversity metric. It is the ratio between the Shannon's diversity index and the theoretical maximum of the same index. It can be understood as a measure of dominance. Range of values: 0 ≤ Shei ≤ 1 (Equals 0 when only one patch present and equals 1 when the proportion of classes is completely equally distributed).

7.2 Results

This section begins with a map of Vietnam showing the area covered by different types of forest across the country (Figure 28). Approximately 16 million hectares of forest are covered by closed forest evergreen broadleaf, representing the majority of the country's forest cover [URL01]. This approximation might be slightly higher than other estimations, but the discrepancy can be explained by the fact that, given the spatial resolution of 100m of our reference dataset, a pixel is not always completely covered by forest when it is classified as such. Therefore, an overestimation of about 5% can occur. The distinction between open and closed forests is evaluated based on the percentage of crown cover [URL02]. Typically, open forests are defined as having a crown cover ranging between 50-80%, while closed forests have a crown cover exceeding 80%. The objective of this map is to provide a broader overview of the distribution of forests at the national level and to offer insights into the potential characteristics of forest patches in different regions of Vietnam.

There are several landscape metrics that can be calculated for this service. Because of the valuable information they provide and their relative ease of interpretation, we selected two metrics at the patch level (mean patch area, shape) and one metric at the landscape level (diversity) to be shown in this section. For the national level, the raster outputs were aggregated to NUTS-3 (in the case of area and shape metrics) and NUTS-2 (in the case of diversity), which facilitates an easier comparison between administrative units and provide a good overview of these metrics at a larger scale (Figure 28). For the regional examples, the aim was to select one area close to urban centres and one area where human intervention appears to be minimal, and forests can spread naturally. Therefore, the regions chosen were Quang Nam (close to urban centres, central Vietnam) and Son La (close to dense forest areas, northern Vietnam).

The results of the patch-level metrics are presented as a pair of maps. The firs map shows results in an aggregated version by the lowest administrative level of the "Nomenclature of Territorial Units for Statistics" or NUTS3 in this case. This map was derived from a second one, depicted to the right side in most figure pairs, which presents disaggregated results at pixel level (Figure 30, Figure 31, Figure 31,

Figure 33). In the case of the Shape Index metric (Figure 31, Figure 33) results on the pixel level can take a range of values ≥1. A patch with a value of 1 represents a square patch, and the value can increase, without limit, as the patch shape becomes more complex. Results on the aggregated version provide an average shape value for the entire municipality at the NUTS3 level and can be used to compare values across municipalities and regions.

It is only possible to calculate aggregated values for metrics at landscape level, and therefore it is not possible to present the same map pairs as at the patch level. However, the results on diversity are coupled with a land cover image showing the different forest types present in the region. The aim here is to provide the user with more context to better interpret the diversity values (Figure 34). In the case of landscape-level metrics, the data aggregations take place at the NUTS2 level instead of at NUTS3. The reasoning behind is that it is generally less probable to find a variety of forest classes at the smallest administrative units. It follows that diversity estimations in such areas would not be very meaningful. Therefore, we decided to aggregate values by NUTS2 and display results by NUTS1, so that diversity values between regions can be compared.

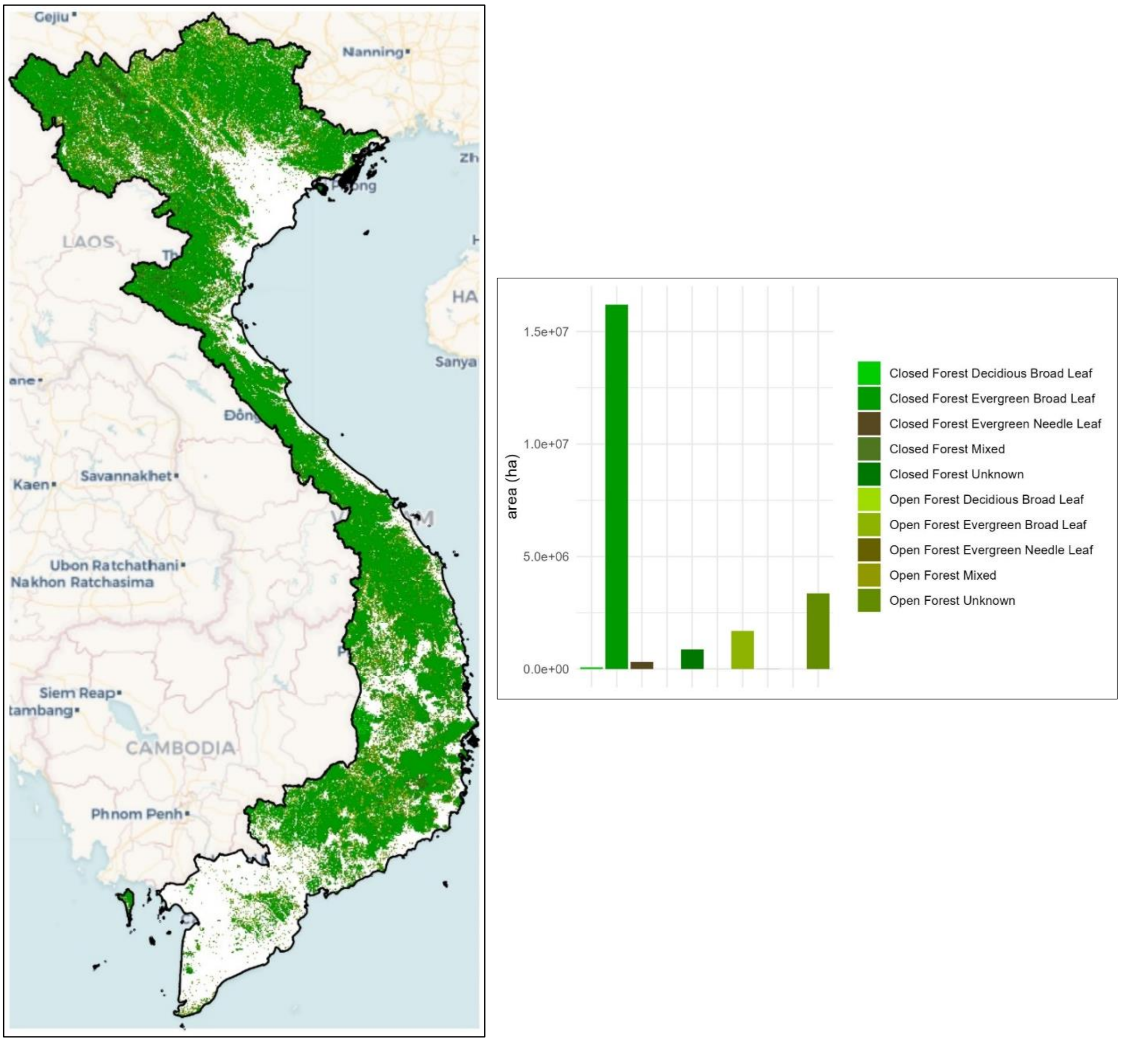


Figure 27. Area covered by forest in Vietnam as of 2015.

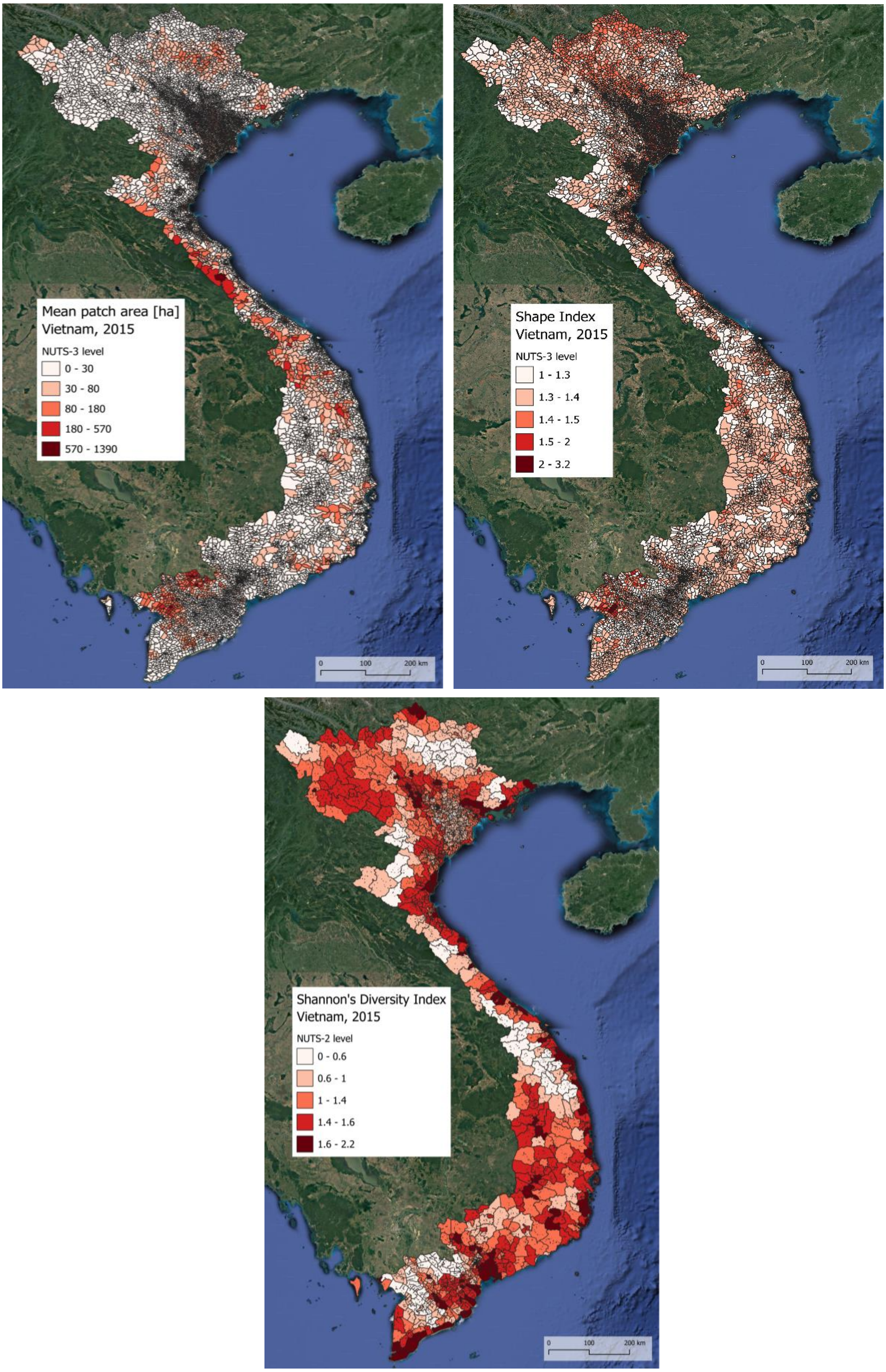


Figure 28. FLM results at national level for patch area, shape index and Shannon's diversity index.

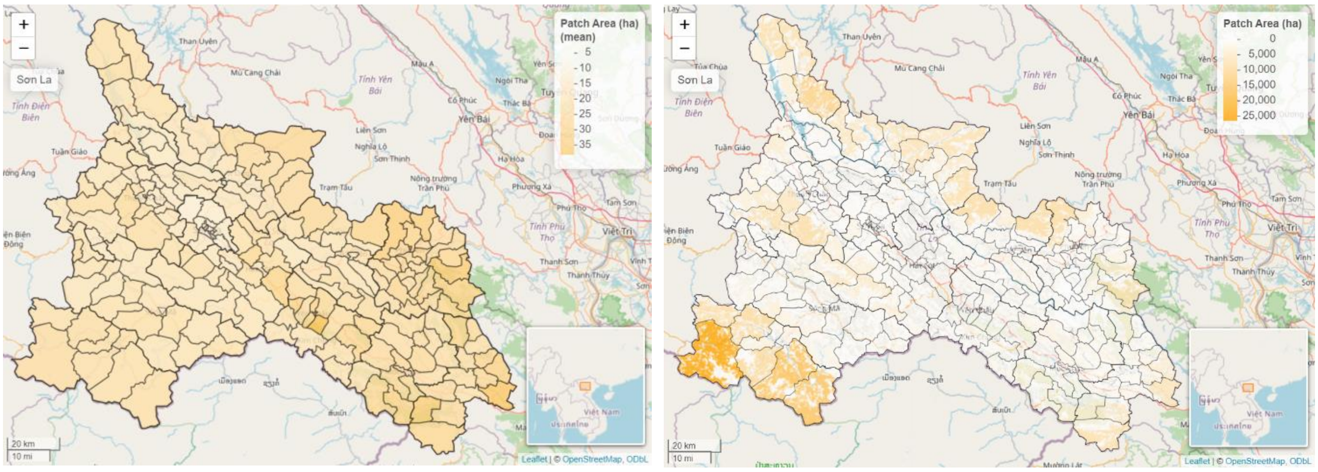


Figure 29. Mean patch area (aggregated values on the left, values per pixel on the right) for the Son La region in northern Vietnam.

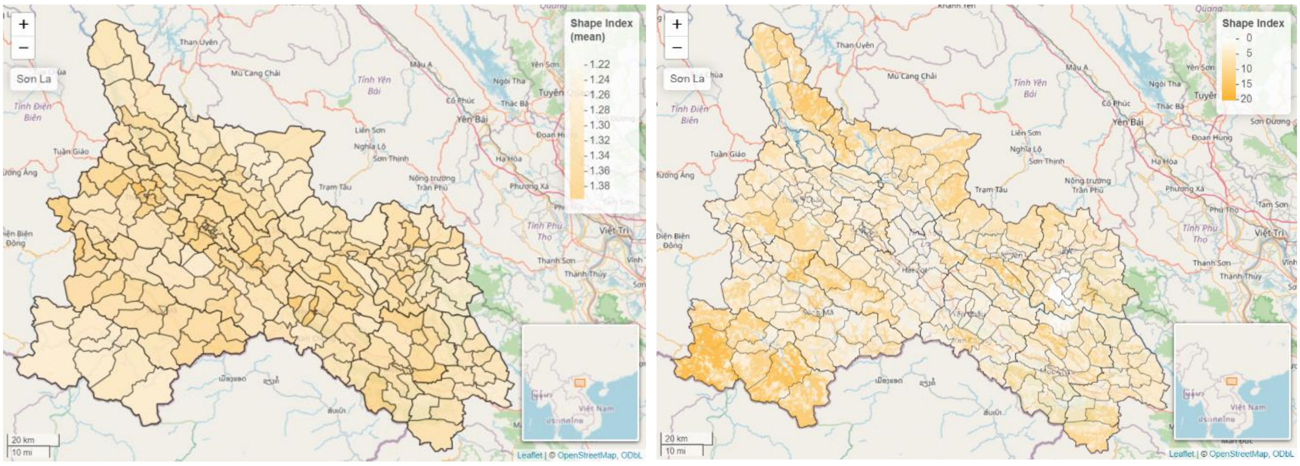


Figure 30. Shape index on patch level (aggregated values on the left, values per pixel on the right) for the Son La region in northern Vietnam.

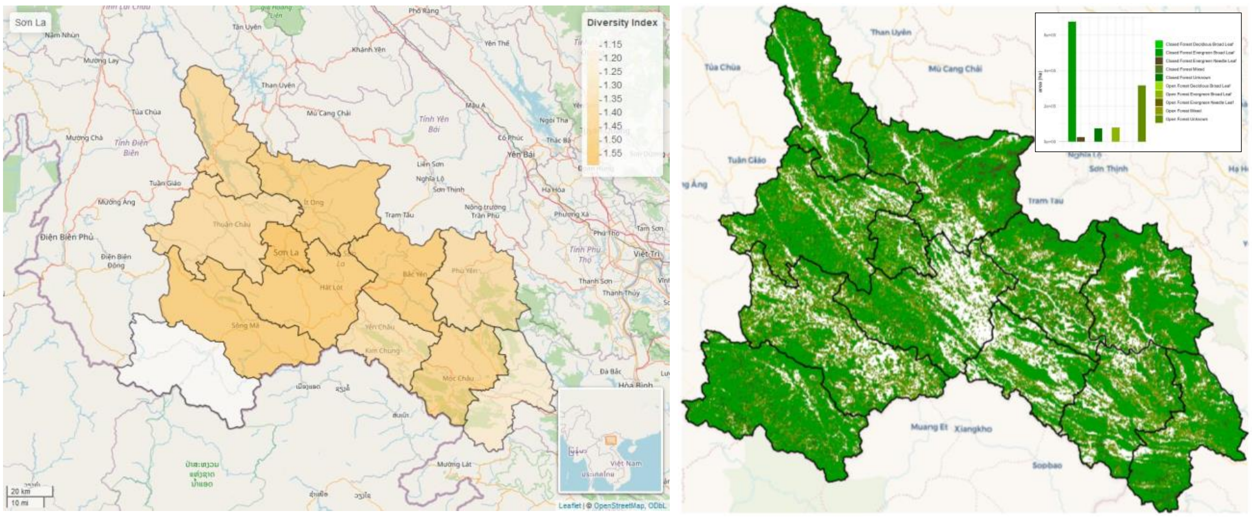


Figure 31. Aggregated diversity index on landscape level (left), forest cover with classes as legend (right) for the Son La region in northern Vietnam.

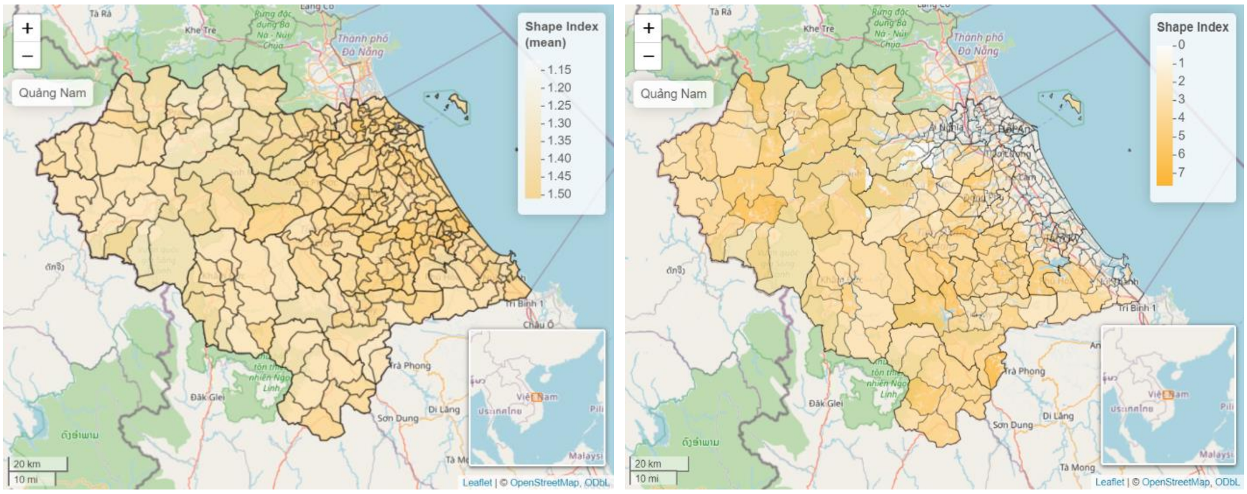


Figure 32. Shape index on patch level (aggregated values on the left, values per pixel on the right) for the Quang Nam region in central Vietnam.

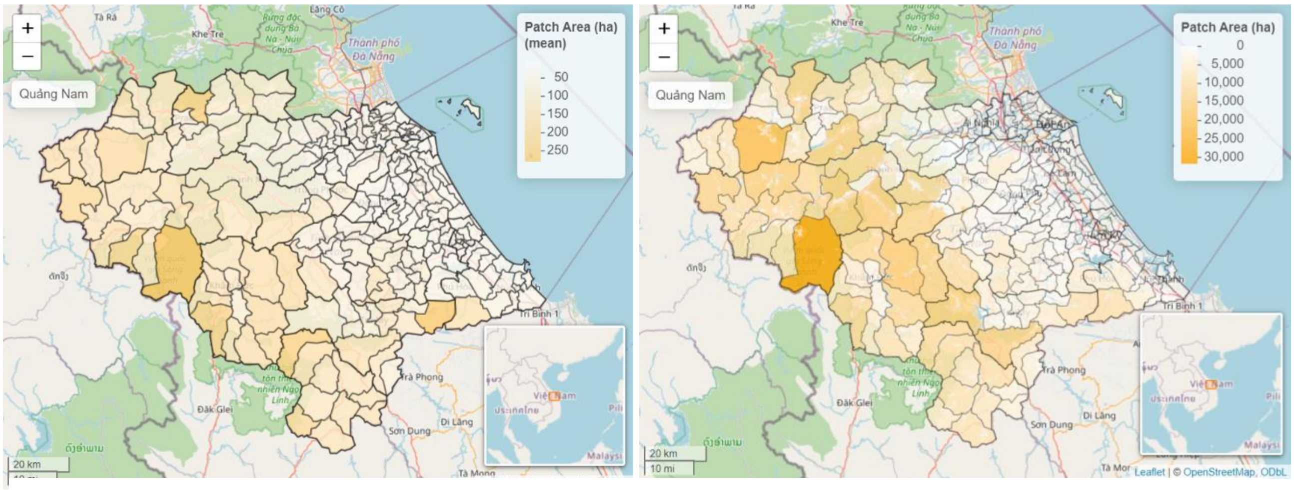


Figure 33. Mean patch area (aggregated values on the left, values per pixel on the right) for the Quang Nam region in central Vietnam.

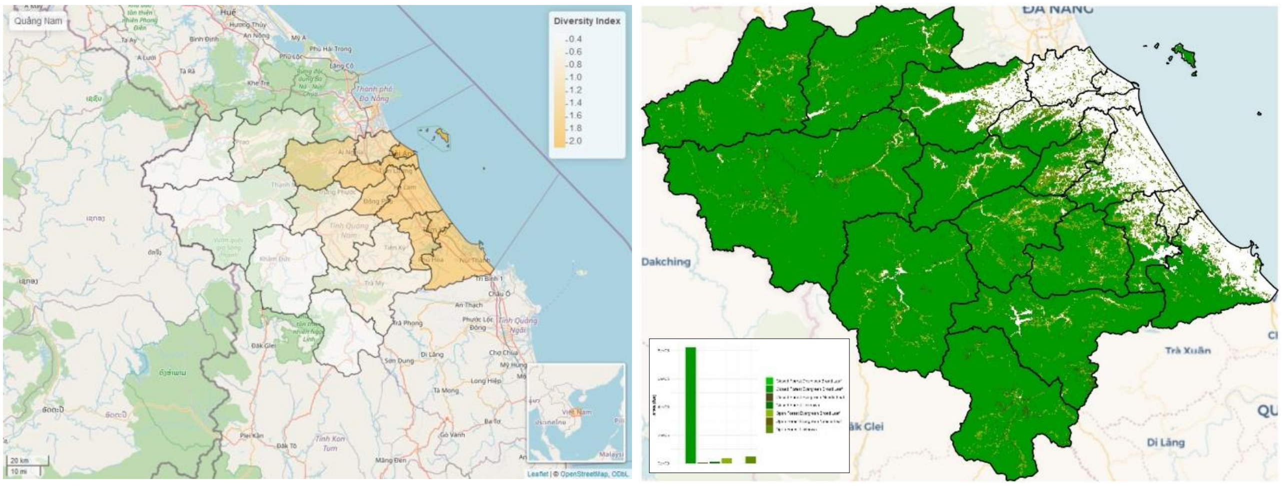


Figure 34. Aggregated diversity index on landscape level (left), forest cover with classes as legend (right) for the Quang Nam region in northern Vietnam.

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