Characterization of Dilijan National Park Forest Ecosystems, Armenia

Work Order Report

Support requested by:

United Nations Development Programme (UNDP)

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[RD-1]	ESA Request for Proposal: EOC0004_RFP_v02
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ABOUT THIS DOCUMENT

This document is the final Work Order Report of the ESA (European Space Agency) EO Clinic project EOC0004 Characterization of Dilijan National Park Forest Ecosystems, in Armenia. This publication was prepared in the framework of the EO Clinic (Earth Observation Clinic, see below), in partnership between ESA, the United Nations Development Programme (UNDP) Armenian Office, and a team of service providers contracted by ESA: GeoVille GmbH (Austria) and SIRS (France).

This Work Order Report (WOR) is structured as in the following:

- **Section 1** describes the context of the UNDP activities on the Characterization of Dilijan National Park Forest Ecosystems, in Armenia, the project objectives and requested EO products and services.
- **Section 2** highlights the applied work logic and responsibilities among the EO Clinic service providers.
- **Section 3** describes the services, their specifications, methods and outcomes.
- **Section 4** presents an evaluation of the data availability and suitability in support of the EO products and services under the perspective of a potential roll-out.

ABOUT THE EO CLINIC

The EO Clinic (Earth Observation Clinic) is an ESA initiative to create a rapid-response mechanism for small-scale and exploratory uses of satellite EO information in support of a wide range of International Development projects and activities. The EO Clinic consists of "on-call" technically pre-qualified teams of EO service suppliers and satellite remote sensing experts in ESA member states. These teams are ready to demonstrate the utility of satellite data for the development sector, using their wide range of geospatial data skills and experience with a large variety of satellite data types.

The support teams are ready to meet the short delivery timescales often required by the development sector, targeting a maximum of 3 months from request to solution.

The EO Clinic is also an opportunity to explore more innovative EO products related to developing or improving methodologies for deriving socio-economic and environmental parameters and indicators.

The EO Clinic was launched in March 2019 and is open to support requests by key development banks and agencies during the 2 years project duration.

AUTHORS

The present document was prepared and coordinated by Nathalie Morin (Production lead, SIRS) with support from the following contributors: Antoine Masse (Project lead, SIRS), Martin Siklar (Production Lead, GeoVille), Christian Treml (Framework Coordinator, GeoVille).

ACKNOWLEDGEMENTS

The following colleagues provided valuable inputs, insights and evaluation feedback on the work performed: Hovik Sayadyan (Technical lead, United Nations Development Programme Armenia)and Zoltan Bartalis (ESA Coordinator and Technical Officer).

For further information	Please contact Christian Treml, Framework Coordinator, GeoVille (treml@geoville.com), with copy to Zoltan.Bartalis@esa.int if you have questions or comments with respect to content or if you wish to obtain permission for using the material in this report. Visit the ESA EO Clinic: https://eo4society.esa.int/eo_clinic.

1. DEVELOPMENT CONTEXT AND BACKGROUND

1.1. Forest ecosystems in Dilijan National Park

Armenian forests are among the most threatened ecosystems, with degradation accelerating, largely attributable to deforestation and overexploitation. This results in high rates of erosion, increasing soil salinity, lowered soil fertility, and loss of biodiversity. Thus, *"expansion of forests is one of the main goals for Armenia, not only for the forests' protective role, but also to develop forest-related businesses and to ensure fuelwood supply to the population"*, said Ekrem Yazici, Deputy Chief of the Joint UNECE/FAO Forestry and Timber Section. However, due to a dense population living within the protected forest areas, developed infrastructures, uncontrolled tourism, illegal logging, poaching and non-sustainable use of natural resources, environmental degradation threatens this unique biodiversity, rich natural-historical and cultural landscapes. In order to become more resilient to external and internal shocks, there is a necessity for integration of new approaches and policy instruments to rehabilitate degraded forests and increase forest cover significantly, while formulating the country's development agenda. In this context, UNDP Armenia is focusing its efforts to better understand the past forest ecosystems transformations, the land use and land cover changes, and in general, all the socio-environmental processes in the past and today that affect the sustainable management of forest resources.

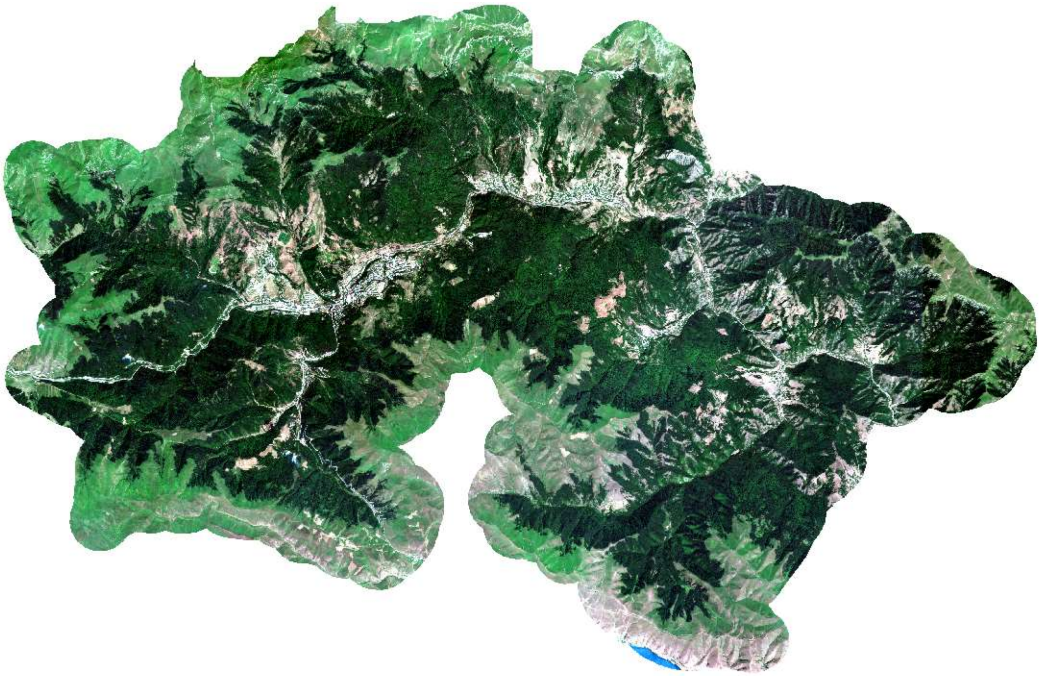

Figure 1: Sentinel-2 image of Dilijan National Park on 31st July 2019 (Source: European Space Agency).

1.2. Objectives

The objective of the present report is to assess and report on the state of Armenia's forests with a focus on the Dilijan National Park. Dilijan National Park is one of the four National Parks in Armenia, located in the Northern part of Armenia on the slopes of Pambak, Miapor and Aregani mountain chains and on the basin of Aghstev and Getik rivers. Although the area became a specially protected area in 1958 in order to protect the park's flora and fauna, the National Park was only established in the year 2002. Today, Dilijan National Park is known for its forest landscapes, rich biodiversity, medicinal mineral water springs, natural and cultural monuments, and extensive network of hiking trails. The mapping shall demonstrate the suitability of validated EO products for an independent forest monitoring and support land use planning for sustainable forest management.

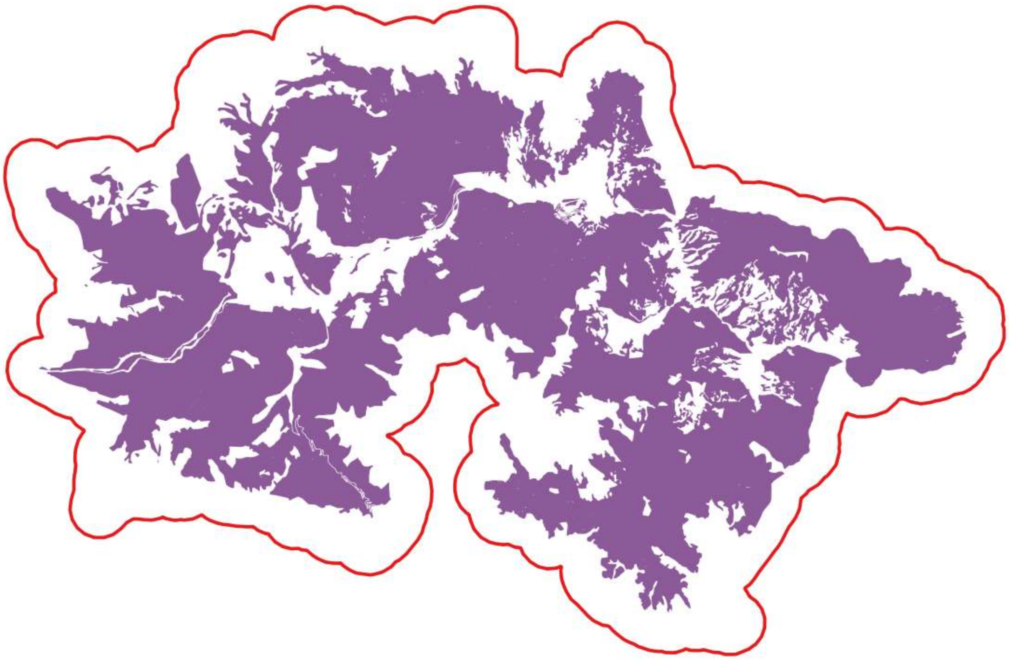

Figure 2: Area of Interest (red outline) and Dilijan National Park limits (purple)

The following information services have been requested:

- ***Service 1: Land Cover and Land Use Classification and Associated Changes*** - providing detailed land use and land cover classification maps for the epochs 1991-2019 a basic planning support tool for characterizing forest ecosystems and main evolution trends in Dilijan National Park, in Armenia.
- ***Service 2: Forest Mapping*** - delivering an in depth examination of the forest classes of the previous service, subdividing forested areas into different forest density and type classes. The service shall focus on assessing and locating areas where deforestation or forest degradation is taking place.

2. WORK LOGIC

The overall work logic and organization between GeoVille (coordinator of EO-Clinic framework contract, interface towards ESA and UNDP, and service provider) and SIRS (service provider) is presented in Figure 3 below. GeoVille has acted as focal point towards ESA as the contracting authority and UNDP Armenia.

During the implementation phase the following stakeholder representatives were involved:

- Hovik Sayadyan (Technical lead, United Nations Development Programme, Armenia)

This work was planned over a tight period of 10 weeks and requires that all input data are available in time for the work to get started in a timely manner and avoid any delays. The acquisition of EO and other required data sources is a pre-requisite for the implementation of all the services. In addition, Service 1 is used as an input to Service 2 by allowing the establishment of a deeper analysis of the forest classes. Note that each Service provides outputs of direct interest and use for the local stakeholder. The overall work logic and organization between SIRS and GeoVille is presented in the figure below.
The consortium is managed by GeoVille who will undertake the initial communication with ESA and UNDP to set the activities. The technical work will be coordinated by SIRS and structured around the 2 Services. SIRS will first oversee the pre-processing and ancillary data preparation and will work on a first forest/non-forest classification mask. Then, go deeper in the analysis of the forest areas for the Service 2 and GeoVille will complete the classification on all other non-forest areas (Service 1).

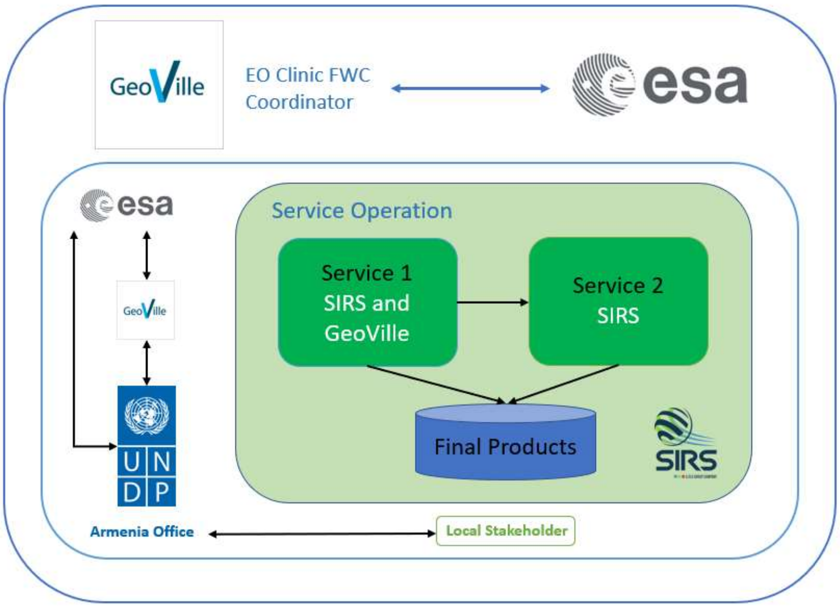

Figure 3: Overall Work Logic and interaction between organisations and services

3. DELIVERED EO-BASED PRODUCTS AND SERVICES

3.1. Service 1 – Land Cover and Land Use Classification and Associated Changes

The requested thematic information requirements for Service 1 were a standardized LU/LC (Land Use and Land Cover) classification and associated changes in the Dilijan National Park to support the land use planning. This included information on land cover for the following epochs:

- Epoch 1: 2019 - most recent situation
- Epoch 2: 2015
- Epoch 3: 2010
- Epoch 4: 2005
- Epoch 5: around May 2002 (status change from state reserve to national park)
- Epoch 6: 2000
- Epoch 7: 1995
- Epoch 8: 1991 (Armenian independence)

Based on previous experience on LU/LC projects over Europe, a stepped approach was performed to best assess the information on land use patterns and forest mapping. As a first step the work focused on the most recent epoch (2019) and subsequently focused on the detection of changes in the previous epochs. The following chapters provide details on the technical specifications, the method and the quality of the generated products (chapter 3.1.2), as well as the provided outputs (chapter 3.1.2) and their usage, limitations and constraints (chapter 3.1.3)

3.1.1. Specifications

The technical specifications of the products adhere to the proposed properties in the technical proposal. This includes 9 Land Cover (LC) Products: 8 historical products in 30m resolution for each epoch based on Landsat 8 and one additional product for 2019 based on Sentinel-2 in 10m resolution. It was decided to provide two versions for the 2019 epoch to facilitate the historic change assessment by using Landsat data for consistency reasons and at the same time enable a future monitoring on the best available data source, which is currently the Sentinel-2 satellite constellation.

LC Product List:

Product	Category	Reference year	File name
Land Cover	Status layer	1991	LC_Armenia_Dilijan_1991.tif
Land Cover	Status layer	1995	LC_Armenia_Dilijan_1995.tif
Land Cover	Status layer	2000	LC_Armenia_Dilijan_2000.tif
Land Cover	Status layer	2002	LC_Armenia_Dilijan_2002.tif
Land Cover	Status layer	2005	LC_Armenia_Dilijan_2005.tif
Land Cover	Status layer	2010	LC_Armenia_Dilijan_2010.tif
Land Cover	Status layer	2015	LC_Armenia_Dilijan_2015.tif
Land Cover	Status layer	2019 (Sentinel)	LC_Armenia_Dilijan_2019_10m.tif
Land Cover	Status layer	2019 (Landsat)	LC_Armenia_Dilijan_2019_30m.tif

Table 1: Land Cover Product List

Furthermore, the following Land Cover Change (LCC) products were derived: For each subsequent epoch the changes in land cover were computed and stored in two separate layers. For the changes between the years 1991-1995 this exemplary constitutes a "LCC_Armenia_Dilijan_1991_1995.tif" product which contains the initial class (from class) of the changed areas in the year 1991 and one "LCC_Armenia_Dilijan_1995_1991.tif" which contains the target transition class (to class). Additionally, the same change products are available for the period of 1991-2019. An exhaustive list of all LCC products is provided below.

LCC Product List:

Product	Category	Reference years	File name
Land Cover Change Source Class	Change layer	1991-1995	LCC_Armenia_Dilijan_1991_1995.tif
Land Cover Change Target Class	Change layer	1991-1995	LCC_Armenia_Dilijan_1995_1991.tif
Land Cover Change Source Class	Change layer	1995-2000	LCC_Armenia_Dilijan_1995_2000.tif
Land Cover Change Target Class	Change layer	1995-2000	LCC_Armenia_Dilijan_2000_1995.tif
Land Cover Change Source Class	Change layer	2000-2002	LCC_Armenia_Dilijan_2000_2002.tif
Land Cover Change Target Class	Change layer	2000-2002	LCC_Armenia_Dilijan_2002_2000.tif
Land Cover Change Source Class	Change layer	2002-2005	LCC_Armenia_Dilijan_2002_2005.tif
Land Cover Change Target Class	Change layer	2002-2005	LCC_Armenia_Dilijan_2005_2002.tif
Land Cover Change Source Class	Change layer	2005-2010	LCC_Armenia_Dilijan_2005_2010.tif
Land Cover Change Target Class	Change layer	2005-2010	LCC_Armenia_Dilijan_2010_2005.tif
Land Cover Change Source Class	Change layer	2010-2015	LCC_Armenia_Dilijan_2010_2015.tif
Land Cover Change Target Class	Change layer	2010-2015	LCC_Armenia_Dilijan_2015_2010.tif
Land Cover Change Source Class	Change layer	2015-2019	LCC_Armenia_Dilijan_2015_2019.tif
Land Cover Change Target Class	Change layer	2015-2019	LCC_Armenia_Dilijan_2019_2015.tif
Land Cover Change Source Class	Change layer	1991-2019	LCC_Armenia_Dilijan_1991_2019.tif
Land Cover Change Target Class	Change layer	1991-2019	LCC_Armenia_Dilijan_2019_1991.tif

Table 2: Land Cover Changes Product List

A detailed overview on the used satellite-based input data, the data specifications, thematic information, and target ac Table 3 below. A visual example of the 2019 LC products (Sentinel and Landsat) can be seen in Figure 4.

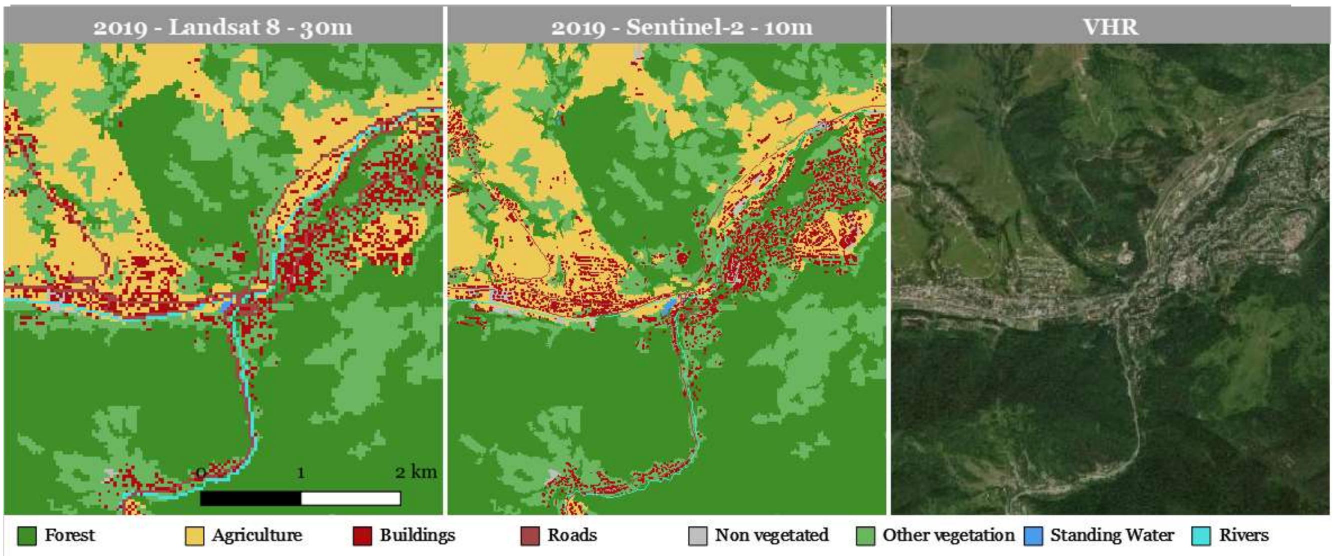

Figure 4: 2019 LC Product Examples: The first image shows the LC based on Landsat 8 in 30m resolution, the second image depicts the Sentinel-2 based product in 10m, the third image shows a VHR reference image. (left to right)

Table 3: Product specifications for Service 1 Land Cover and Land Cover Change Maps

General	

Resolution and Data Input	**<u>Land Cover</u>**
	• 2019 – 2 products available:
	  ○ 10m Sentinel-2
	  ○ 30m Landsat 8
	• 2015 – 30m Landsat 8
	• 2010 – 30m Landsat 5/7
	• 2005 – 30m Landsat 5/7
	• 2002– 30m Landsat 7
	• 2000– 30m Landsat 7
	• 1995– 30m Landsat 5
	• 1991– 30m Landsat 5
	
	<u>Land Cover Changes</u>
	Available for each subsequent epoch (1991-1995, 1995-2000, etc.) as well as for the entire period (1991-2019) in 30m

Geographic Projection	UTM Zone 38N
Format	GeoTIFF
Datatype	Byte
Thematic information	
Classes and Codings	**<u>LC and LCC</u>** 1. Forest 2. Agriculture 3. Settlements 4. Primary roads 5. Bare soil 6. Other vegetated areas 7. Water bodies 8. Rivers 255/NA – Outside of Area of Interest **<u>Only applicable for LCC:</u>**

	0. No Change
Accuracies	
Geometric positional accuracy:	1 pixel
Thematic accuracy:	85%
Minimum Mapping Unit (MMU)	
Sentinel-2 (10m)	0.25 ha (25px) for vegetated classes and bare soil No MMU for other classes and for changes
Landsat 5-8 (30m)	1 ha (11px) for vegetated classes and bare soil No MMU for other classes and for changes

Data input (cf. chapters 4.1-4.2 for a detailed discussion on data suitability)

Generally, two input data types were distinguished for the LC and LCC products. Firstly, data necessary for the (historic) classification of the area of interest (input features). These consist of optical satellite imagery derived from the **Landsat** Archive (Landsat 5-8) and **Sentinel-2** for the most recent epoch. Table 3 provides an overview which sensor was used in the production for each time step. Secondly, reference data used for training and testing was necessary, this included the following external data sources:

- OSM Buildings
- OSM Roads
- OSM Waterbodies
- OSM Rivers
- Hansen Forest 2015
- Global 30m Cropland Extent 2015

Method

For the production of the LC status and LCC products two separate methods were applied that are described in more detail below.

Land Use / Land Cover (LULC) classification

For the generation of the LULC classification the following processing steps were applied: Starting from the Sentinel-2 L2A and the Landsat data, clouds, cloud shadows, snow and cirrus pixels were masked as part of the pre-processing steps. Secondly, spectral indices for each time step were derived, these included the NDVI and NDWI. To reduce data volume and speed up the classification process and its quality meaningful temporal metrics (percentiles p) were derived for each sensor and epoch of interest, e.g.: p80, p50, p20 and p80-p20.
These metrics were used together with the above listed reference data in combination with manually sampled points (for bare soil and vegetated areas) to train a random forest classifier for the year 2019 and the Sentinel-2 input data. (Note: The Forest class was not part of the classification since this information was directly taken from the Forest Mapping Service). After the classification, the product was enhanced by directly incorporating information from OSM (Buildings, Roads, Rivers and Waterbodies) and the 10m Forest Mapping Product derived in Service 2. The same procedure was applied for the Landsat 8 (30m) 2019 data separately. This yielded two LULC products for the year 2019 that served as a baseline for the change detection process.

Change detection

To assess historical land cover changes, a spectral change vector analysis was performed (this is possible because the sensor and band properties are more or less consistent over time (Landsat Legacy)). Using this method, spectral properties of the reference year 2019 Landsat data were compared to its historic spectral properties on a yearly basis and for each pixel, respectively. If a spectral difference between two compared epochs (i.e. 2019-2015) for a certain pixel lies above a predefined threshold a potential change is identified and flagged.

Figure 5a depicts the basis of the change vector analysis in a two-dimensional space where two spectral bands of two time steps are compared to each other. The spectral difference (change vector or often referred to as the change vector length) stands for the magnitude of change.

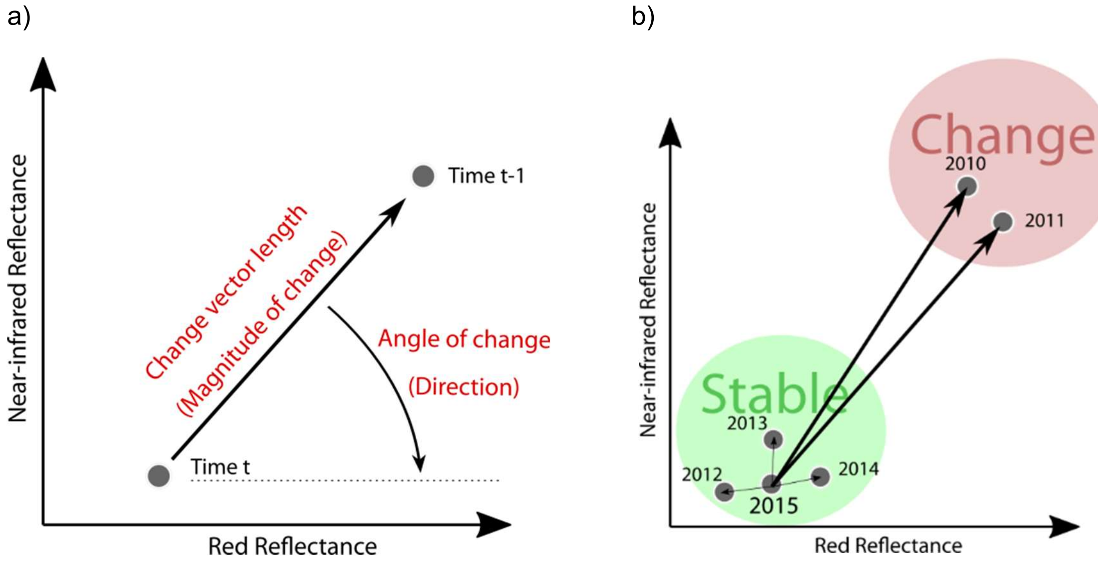

Figure 5: Example of a two dimensional change vector analysis between two time steps using the red and near-infrared spectral bands and b) Example of a time-series based two-dimensional change vector analysis.

A high change vector length value is, for example, expected during urbanisation activities (i.e. the conversion of vegetation into sealed surface). Short change vector lengths may occur if there is no change at all and the spectral properties only differ due to meteorological effects, i.e. because of a delayed or shortened rain season or also during vegetation regrowth due to afforestation activities (see Figure 5b).

The applied change vector analysis is not based on a single comparison of the spectral properties of two spectral bands but considers the comparison of the entire spectrum and can therefore be called a *multidimensional change vector analysis*. The resulting vector length is then calculated by the Euclidean Distance, defined as the "ordinary" straight-line distance between two points (time steps) in the Euclidean space.

The robustness of the method is increased by the incorporation of a time series of change vectors. As already highlighted above, the algorithm considers each year of the reference period (1991 – 2019) and compares it to the reference year (2019). Ultimately, change areas are detected by dynamically thresholding each comparison individually via a high percentile value (i.e. 0.99).

Figure 5b depicts this approach in a two-dimensional space where small change vector lengths are considered stable and high differences are flagged as change. By summing up the occurrences of abnormally high differences over time, a probability of change or even an exact timing of change can be derived if of interest.

The flagged "change candidate areas" are then manually controlled to eliminate false positives. Subsequently, the change areas are combined with all change areas that were identified by the Service 2 Forest Mapping and reclassified into target change classes via a supervised classification. The training samples for this classification are automatically derived from the base line classification but only by considering "stable non-change areas" for each epoch separately. The algorithm itself is a supervised stratified random forest classifier as described in the "*Land Use / Land Cover (LULC) classification*" section above.

Quality Control and Validation

Quality Control (QC) was part of the production phase and consists in an internal quality check with independent reference data. QC included the following checks, with check-ups of the completeness, logical consistency and geometric accuracy mainly implemented in an automated manner:

- Thematic accuracy performed by means of visual check by another image analyst to ensure the product quality and homogeneity
- Geometric and thematic compliance by means of visual check over randomly selected area samples
- Absence of unlikely changes
- Completeness (omissions/commissions)

Validation of the thematic product accuracy (overall accuracy, classification correctness and completeness) was implemented independently from the production and once the products are generated for ensuring the compliance with the specifications. The quality control design applied was as follows:

- **Sampling design** – by means of a stratified random sampling approach: Each class was handled as a separate stratum with a predefined minimum sample size of 30 samples per class. The equation below calculates an adequate overall sample size for stratified random sampling that can then be distributed among the different strata.
    - N is number of units in the area of interest (number of overall pixels if the spatial unit is a pixel, number of polygons if the spatial unit is a polygon)
    - S(O) is the standard error of the estimated overall accuracy that we would like to achieve
    - Wi is the mapped proportion of area of class i
    - Si is the standard deviation of stratum i.

$$n = \frac{(\sum W_i\, S_i)^2}{[S(\widehat{O})]^2 + (1/N)\sum W_i\, {S_i}^2} \approx \left(\frac{\sum W_i\, S_i}{S(\widehat{O})}\right)^2$$

- **Response design** – The reference data were generated independently (double-blind approach) by means of visual interpretation using the EO satellite imagery used for the production as no better resolution and/or ground-truth data were made available.
- **Analysis** – The analysis method consists in the comparison of the classes assigned to features from the product with the reference data. The result of this assessment is presented through confusion matrices.

Confusion matrices were established for each LULC product of selected most relevant epochs (2019, 2002, 1991) and weights have been applied to the points considering the stratified sampling approach for calculating the accuracy indicators (user accuracy, producer accuracy, overall accuracy).

The resulting overall accuracy is satisfactory (>= 85%) and individual and confusion matrices can be made available upon request.

- LULC 1991 – 85.83 % (95% CI : 80.7-89.9)
- LULC 2002 – 89.67 % (95% CI : 81.7-90.7)
- LULC 2019 – 89.17 % (95% CI : 84.5-92.8)

3.1.2. Outputs

The first category of outputs for Service 1 are the Land Cover Land Use classification for each epoch (2019, 2015, 2010, 2005, 2002, 2000, 1995 and 1991). The second one is the LCLU change maps between all epochs.

Delivery package:

- 9 LULC raster layers (one for each epoch – 2 for 2019 in 30 an 10m respectively)
- 16 LULCC raster layers (two for each subsequent epoch)
- INSPIRE compliant metadata .xml file
- Summary report including overview map and basic statistics in PDF format

The LULC map generated for the 2019 reference year is exemplary presented in Figure 6.

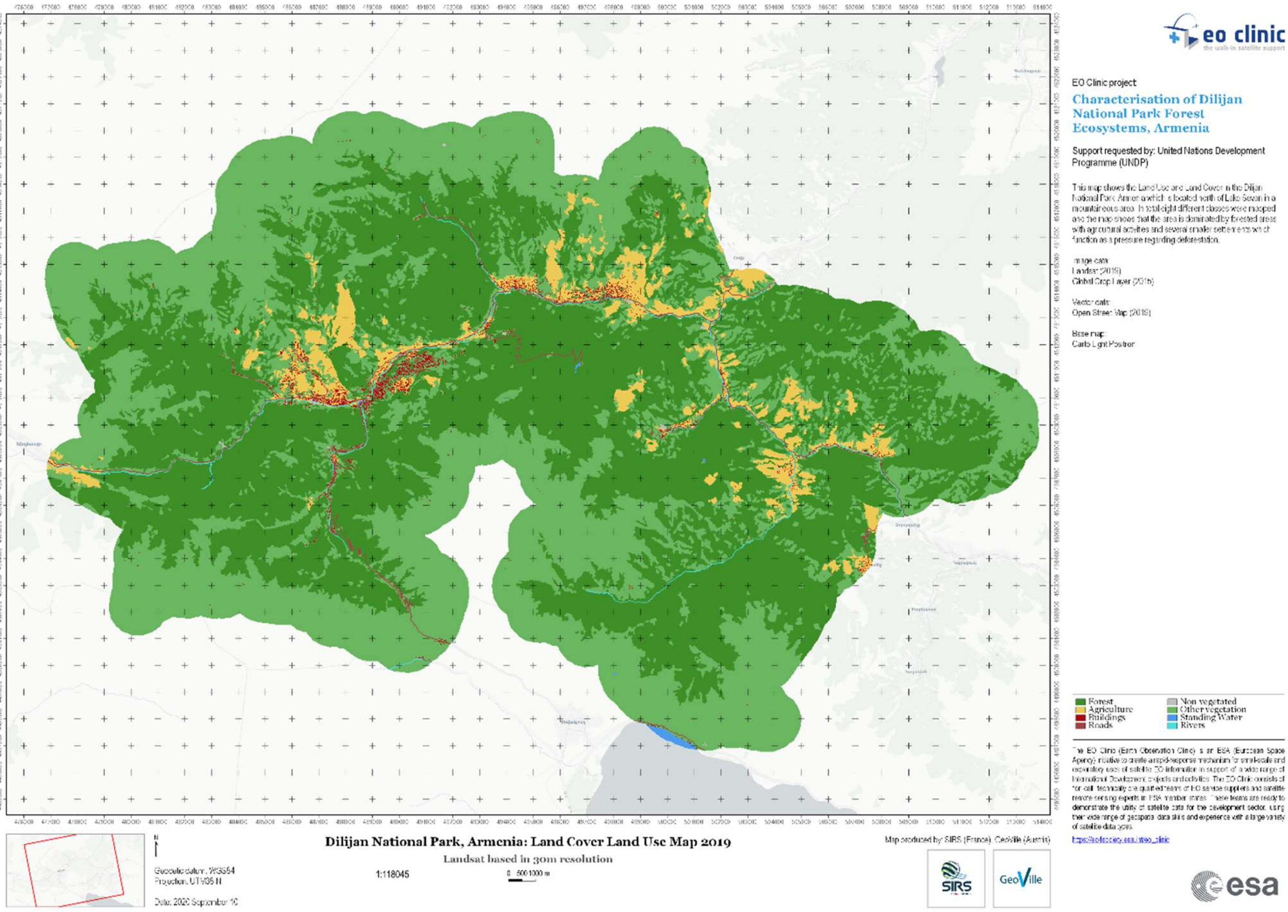

Figure 6: Land Use Land Cover 2019 product (30m)

Based on LULC products generated for the 8 requested epochs (1991, 1995, 2000, 2002, 2005, 2010, 2015, 2019), LULC changes can be easily isolated and analysed. Figure 7 shows the spatial distribution, extent and type of the changes occurred over the whole period of 1991-2019.

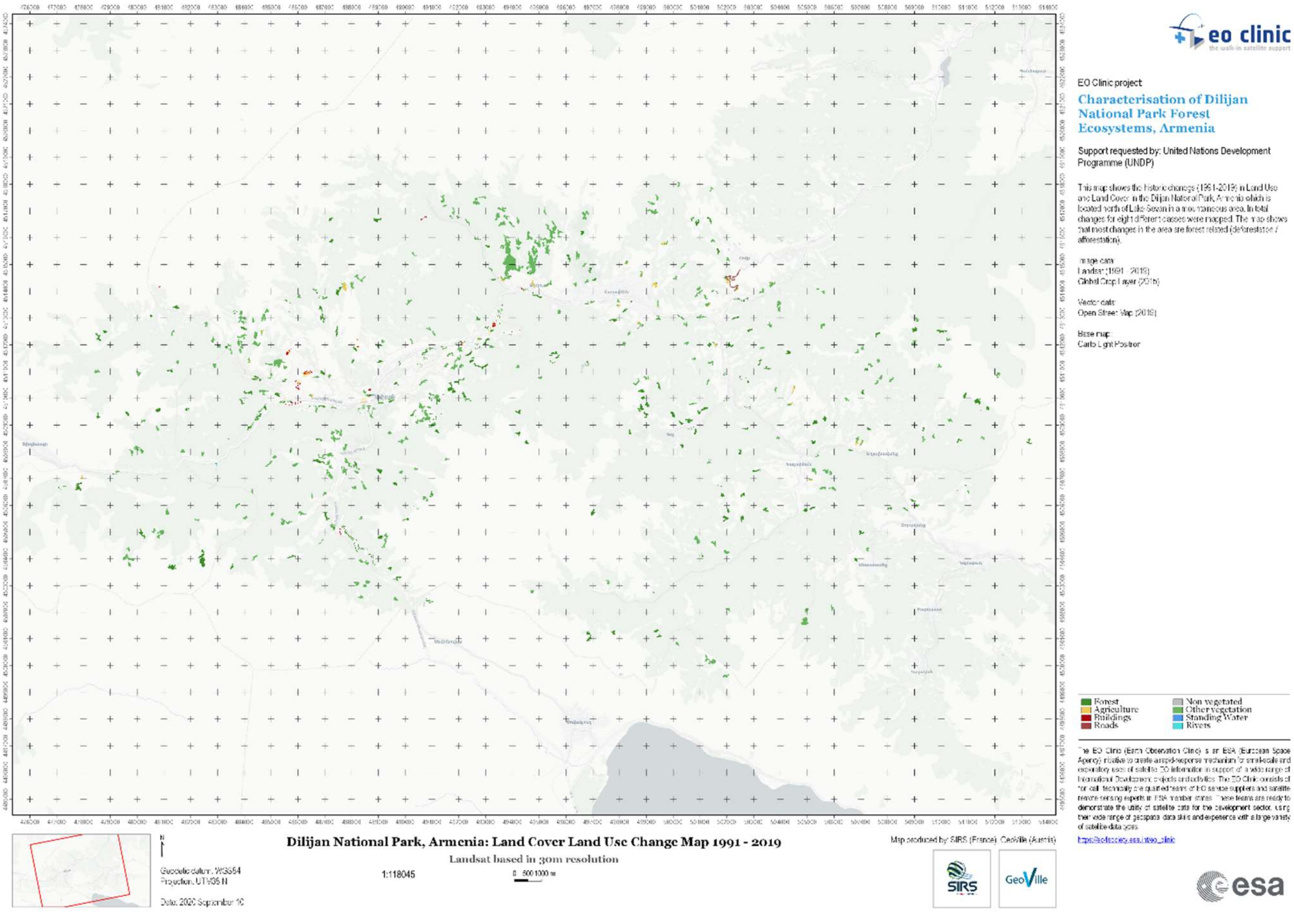

Figure 7: LULC changes occurred over the period 1991-2019

3.1.3. Usage, Limitations and Constraints

The provided LULC products for 8 epochs between 1991 and 2019 should enable the user to assess historic land cover changes (especially in regard to forest) in the Dilijan National Park, Armenia. Furthermore, the 2019 Sentinel-2 based 10m product should serve a solid baseline for a future possible forest monitoring with earth observation data.

Due to the fact that the Dilijan National Park is located in a mountainous region with relatively high cloud cover, the satellite imagery contains unwanted artefacts that are a consequence of the terrain (shadows) and poorly masked clouds. To overcome these data quirks the focus of the processing was to minimize false positive changes by lowering recall and simultaneously increasing true positives (higher precision). This was on one side performed by a very conservative algorithm (high change detection threshold) and on the other side by a manual post-processing step where uncertain changes were manually removed, and obvious / larger change areas were manually added. This implies that changes might not be complete, however the changes that were detected have a **high confidence level.**

With the advent of Sentinel-2 a future Earth observation based monitoring of this area should be more feasible and less exposed to above mentioned data quirks, mainly due to the higher temporal revisiting time which increases the chance of getting cloud free images in every season, which is key for a high quality land cover (change) assessment.

3.2. Service 2 – Forest Mapping

3.2.1. Specifications

The technical specifications of the Forest products are in line with the proposed properties in the technical proposal. This includes 9 Tree Cover Density layers, 2 Forest Type layers and 7 Change layers representing the degradation/deforestation combined into the "perturbation" term.
For reference year 2019 where both Landsat and Sentinel2 imagery were available, the status products are delivered at both spatial resolution of 30m and 10m.
For consistency reason, change products are only available at 30m spatial resolution. A detailed list of delivered products can be found on Table 4, and their specifications are listed on Table 5.

Table 4: Forest Product list

Product	Category	Reference year	File name
Tree Cover Density	Status layer	1991	tcd_1991_30m_dilijan.tif
Tree Cover Density	Status layer	1995	tcd_1995_30m_dilijan.tif
Tree Cover Density	Status layer	2000	tcd_2000_30m_dilijan.tif
Tree Cover Density	Status layer	2002	tcd_2002_30m_dilijan.tif
Tree Cover Density	Status layer	2005	tcd_2005_30m_dilijan.tif
Tree Cover Density	Status layer	2010	tcd_2010_30m_dilijan.tif
Tree Cover Density	Status layer	2015	tcd_2015_30m_dilijan.tif
Tree Cover Density	Status layer	2019 (Sentinel)	tcd_2019_10m_dilijan.tif
Tree Cover Density	Status layer	2019 (Landsat)	tcd_2019_30m_dilijan.tif
Forest Type	Status layer	2019 (Sentinel)	fty_2019_10m_dilijan.tif
Forest Type	Status layer	2019 (Landsat)	fty_2019_30m_dilijan.tif
Forest Perturbation	Change Layer	1991-1995	dilijan_1991-1995_forest_perturbation.tif
Forest Perturbation	Change Layer	1995-2000	dilijan_1995-2000_forest_perturbation.tif
Forest Perturbation	Change Layer	2000-2002	dilijan_2000-2002_forest_perturbation.tif
Forest Perturbation	Change Layer	2002-2005	dilijan_2002-2005_forest_perturbation.tif
Forest Perturbation	Change Layer	2005-2010	dilijan_2005-2010_forest_perturbation.tif
Forest Perturbation	Change Layer	2010-2015	dilijan_2010-2015_forest_perturbation.tif
Forest Perturbation	Change Layer	2015-2019	dilijan_2015-2019_forest_perturbation.tif

Table 5: Product specifications for Service 2 Forest Mapping

General	

Resolution and Data Input	**Tree Cover Density**
	• 2019 – 2 products available:
	  o 10m Sentinel-2
	  o 30m Landsat 8
	• 2015 – 30m Landsat 8
	• 2010 – 30m Landsat 5/7
	• 2005 – 30m Landsat 5/7
	• 2002– 30m Landsat 7
	• 2000– 30m Landsat 7
	• 1995– 30m Landsat 5
	• 1991– 30m Landsat 5
	
	Forest Type & Dominant Leaf Type
	• 2019 – 30m Landsat 8 – Sentinel 2
	
	Forest degradation / deforestion
	Available for each subsequent epoch (1991-1995, 1995-2000, etc.) as well as for the entire period (1991-2019) in 30m

Geographic Projection	UTM Zone 38N
Format	GeoTIFF
Datatype	Byte
Thematic information	
Classes and Codings	**Tree Cover Density** 0-100 : 0-100% tree cover density 255/NA – Outside of Area of Interest **Forest Type :** 0: all non-forest areas 1: broadleaved forest 2: coniferous forest 255: outside area / no data **Dominant Leaf Type :** 0: Non tree cover 11: Pure broadleaved (>75%) 12: Dominantly broadleaved (50-75%) 21: Pure needle leaved (75%) 22: Dominantly needle leaved (50-75%) **Forest degradation / deforestation** 0: Non forest stable 1: Forest regeneration 2: Deforestation 31: Anthropogenic forest degradation 32: Natural forest degradation 4: Forest stable
Accuracies	
Geometric positional accuracy:	1 pixel
Thematic accuracy:	85%

Minimum Mapping Unit (MMU)	
Sentinel-2 (10m)	0.25 ha (25px) for Forested area No MMU for other classes and for changes
Landsat 5-8 (30m)	1 ha (11px) for forested area No MMU for other classes and for changes

Data input (cf. chapters 4.1-4.2 for a detailed discussion on data suitability)

Service 2 products used the same input data as Service 1 product (see Table 3), but also used very high resolution (VHR) EO data to model the tree cover density information. Below can be found a descriptive of each data set used for the mapping of each epoch :

- High Resolution (HR) Landsat 5 or 7 time series at 30m spatial resolution for 1991, 1995, 2000, 2002, 2005 and 2010 epochs
- HR Landsat 8 time series at 30m spatial resolution for 2015 epoch
- HR Sentinel-2 times series at 10m spatial resolution for 2019 epoch
- Very High Resolution (VHR) Ikonos at 4m spatial resolution for the year 2007
- VHR Pléiades of 17/07/2014 at 0.5m resolution (Panchromatic) and 2m (Multispectral)
- VHR Pléiades of 24/07/2014 at 0.5m resolution (Panchromatic) and 2m (Multispectral)
- VHR Pléiades of 28/06/2018 at 0.5m resolution (Panchromatic) and 2m (Multispectral)

Method

Forest Mask

The Tree Cover Mask (TCM) processing workflow can be divided into 7 main steps : (i) Pre-processing of EO data, (ii) Classification, (iii) Post-processing, (iv) Computing of the raw Tree Cover Change Mask (TCCM) for all epochs (v) Manual Enhancement of polygons of changes, (vi) Quality Check of the consistency of the TCM and TCCM for all epochs.

i. *Pre-processing*
   - Atmospheric, radiometric and topographic corrections, using MAYA algorithm (for Sentinel-2 data)
   - Cloud masking
   - Selection of images for epoch n ± 1 in enlarged vegetation season from 1st of May to 31st of October to obtain a full coverage of area of interest.

ii. *Classification and Tree Cover Mask*
   - Selection of reference samples, i.e. ~ 30 forest samples (examples) & 30 non-forest samples (counter-examples) to train the classifier
   - Segmentation and Random Forest based Classification algorithm

The classification output is a probability map, depicting the probability for each pixel to .belong to the forest class. This output is converted into a binary layer Tree Cover / non Tree Cover

iii. *Post-processing*
   - Application of a Minimum Mapping Unit (MMU) of 1 ha for Landsat data, i.e. 10 Landsat pixels at 30m spatial resolution
   - Application of a MMU of 0.5 ha for Sentinel-2 data, i.e. 25 Sentinel-2 pixels at 10m resolution

iv. *Computing of raw Tree Cover Change Mask (TCCM)*
   - Computing of the TCCM at 30m resolution by difference between 2 monitoring epochs (subtraction of the previous epoch from the most recent epoch), as specified in the offer: 1991-1995, 1995-2000, 2000-2002, 2002-2005, 2005-2010, 2010-2015, 2015-2019
   - The TCCM 1991-2019 over the whole 28-years monitoring cycle is also computed in order to get a first glimpse of Service 2 Deforestation and Forest Degradation map
   -

v. *Manual Enhancement of polygons of change*
   - Each TCCM is then converted to vector format and each polygon ≥ 1 ha MMU is labelled as either real gain for the most recent epoch, omission from the previous epoch (undetected tree), commission from the most recent epoch (false tree), real loss for the most recent epoch, commission for the previous epoch

(false tree), omission from the most recent epoch (undetected tree).

- The polygons of changes are rasterized and the TCM of each epoch is recoded in accordance with the identified real or false changes.
- Resampling of the TCM 2019 from 30m to 10m spatial resolution (coregistered to the TCM 1991 grid extent at 30m spatial resolution)

vi. Quality Check of the consistency of the TCM and TCCM for all epochs

Considering TCM 2019 as the reference and the most precise product based on Sentinel-2 data at 10m spatial resolution, the consistency of the changes between each epoch is checked retrospectively.
It should be noted that TCCM are not deliverables and independent products from the raw subtraction of 2 TCMs.

The TCM maps generated for 2019 reference year is presented in Figure 8. A cartographic version of the map layout is provided as a pdf file for each TCM of each epoch in addition to the geo-spatial product.

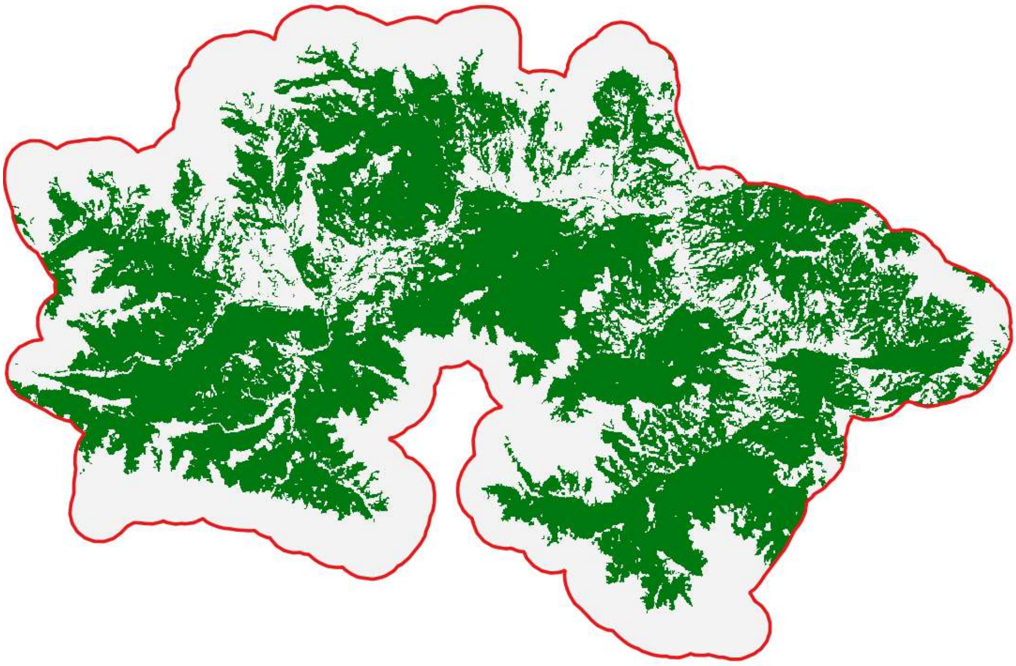

Figure 8: Tree Cover Mask (TCM) 2019 at 10m resolution product

Based on TCM products generated for the 8 requested epochs (1991, 1995, 2000, 2002, 2005, 2010, 2015, 2019), tree cover changes can be isolated and analyzed. Figure 9 shows the spatial distribution, extent and type of the changes occurred over the period 1991-2019.

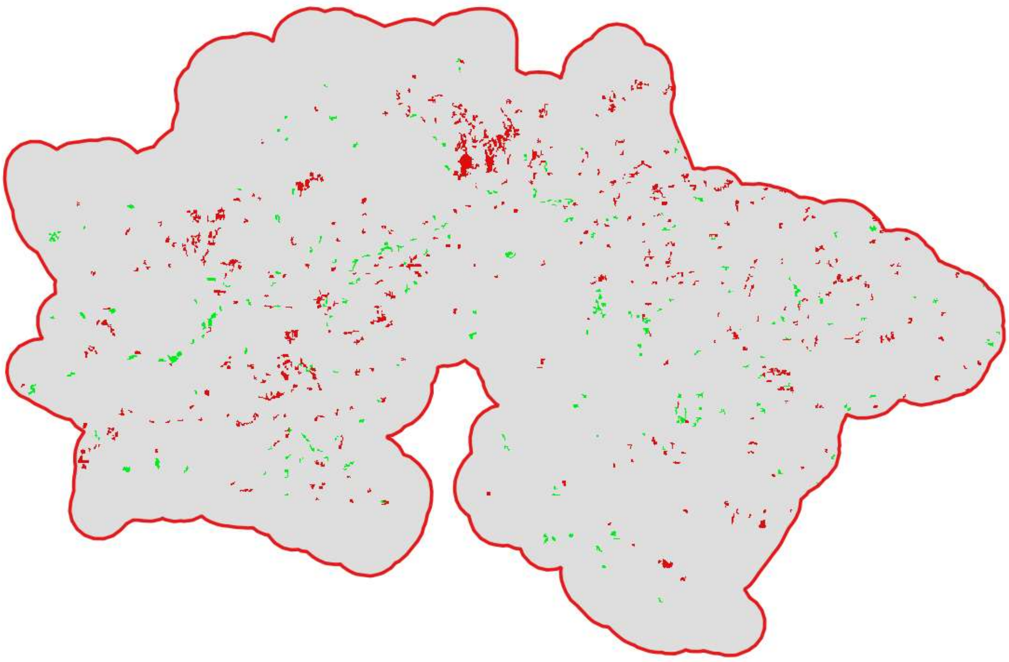

Figure 9: Tree Cover Change Mask (TCCM) over the period 1991-2019 at 30m resolution (red: deforestation, green: reforestation)

Tree Cover Density

The Tree Cover Density (TCD) is defined as the vertical projection of tree crowns to a horizontal earth's surface and provides information on the proportional tree canopy coverage per pixel, in the range of 1-100% values.

The method used for the estimation of TCD is similar to the one used for the Copernicus Land Monitoring Service High Resolution Forest at Pan-European level (https://land.copernicus.eu/pan-european/high-resolution-layers/forests) and REDD+ (Reducing Emissions from Deforestation and Forest Degradation) Copernicus project, for example in African countries. (https://www.reddcopernicus.info/).

TCD modelling is based on the multiple linear regression between reference samples and vegetation indexes derived from HR time series available. TCD reference data is assessed by means of visual interpretation of VHR data following a point grid approach (See Figure 10 below). The processing workflow of the TCD can be divided into 5 main steps: (i) Sample drawing and interpretation, (ii) Computing of vegetation indexes, (iii) Multiple linear regression modelling, (iv) Quality Check of the consistency of the TCD between all epochs, (v) Validation.

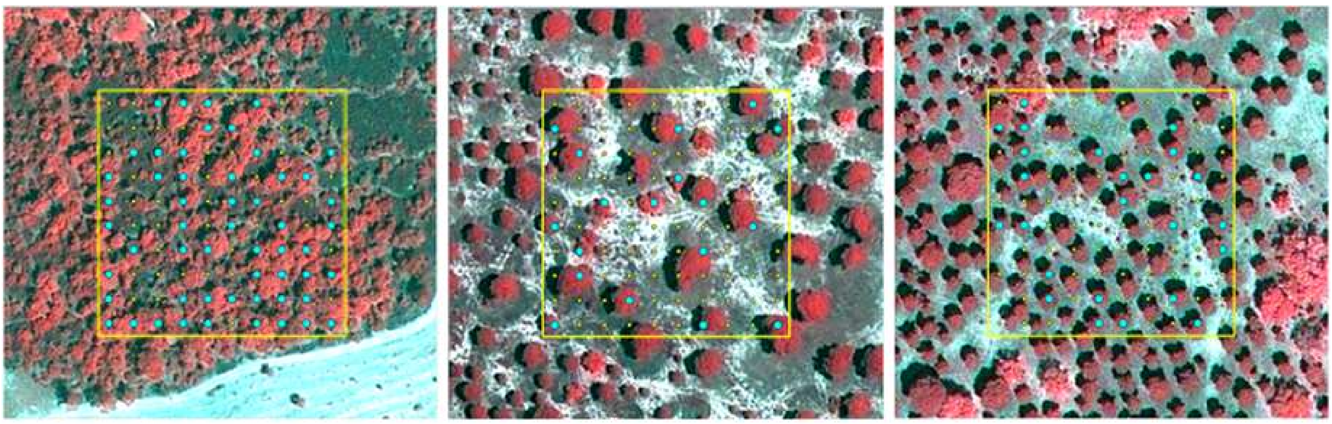

Figure 10: Reference samples over VHR data for TCD modelling

i. *Sample drawing and interpretation*

First step consists in establishing a reference value of TCD for samples unit, based on the interpretation of VHR imagery (Ikonos, Pleiades). Detailed steps are :

- Coregistration of VHR data to HR data:
  - Ikonos 2007 and Landsat 5 nearest epoch 2005

- Pléiades 2014 and Landsat 8 nearest epoch 2015
- Pléiades 2018 and Sentinel-2 nearest epoch 2019

- Random sampling of 100 PSUs within the forest stratum
- Creation of Secondary Sample Unit (SSU) within each PSU
- Computing of the percentage of tree cover for each PSU through the visual interpretation of SSUs

ii. Computing of vegetation indexes

Second step consists in computing several vegetation indexes within the PSU over the HR time series, in order to establish a correlation between those indexes and the TCD value obtained through the interpretation of samples. Those indexes are :

- Normalized Difference Vegetation Index (NDVI)

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

- Brightness Index (BI)

$$BI = \frac{(RED \times RED)/(GREEN \times GREEN)}{2}$$

- Normalized Burn Ratio (NBR)

$$NBR = \frac{NIR - SWIR}{NIR + SWIR}$$

- Green Normalized Difference Vegetation Index (GNDVI)

$$GNDVI = \frac{NIR - GREEN}{NIR + GREEN}$$

- Modified Normalized Difference Water Index (MNDWI)

$$MNDWI = \frac{RED - SWIR}{RED + SWIR}$$

- Mean Blue, Green, Red, Near Infrared (NIR), Short Wave Infrared (SWIR)

iii. Multiple linear regression analysis

Third step consist in establishing the model that will predict the TCD value, through an analysis of the best multiple linear regression model

$$Y = a_1 x_1 + a_2 x_2 + a_3 x_3 + ... + a_n x_n + b$$

Y = estimated TCD value
a_n = coefficients
x_n = explanatory variables (vegetation indexes)
b = constant
Candidate model are assessed through the use of the Bravais-Pearson correlation coefficient, and the model with the higher coefficient is selected.

$$r = \frac{\frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sigma_x \times \sigma_y}$$

$\bar{x}$ = mean
σ_x= standard deviation

Finally, the most accurate model is applied over the complete area of interest to derive the TCD values, as can be seen in Figure 11 for the year 2005.

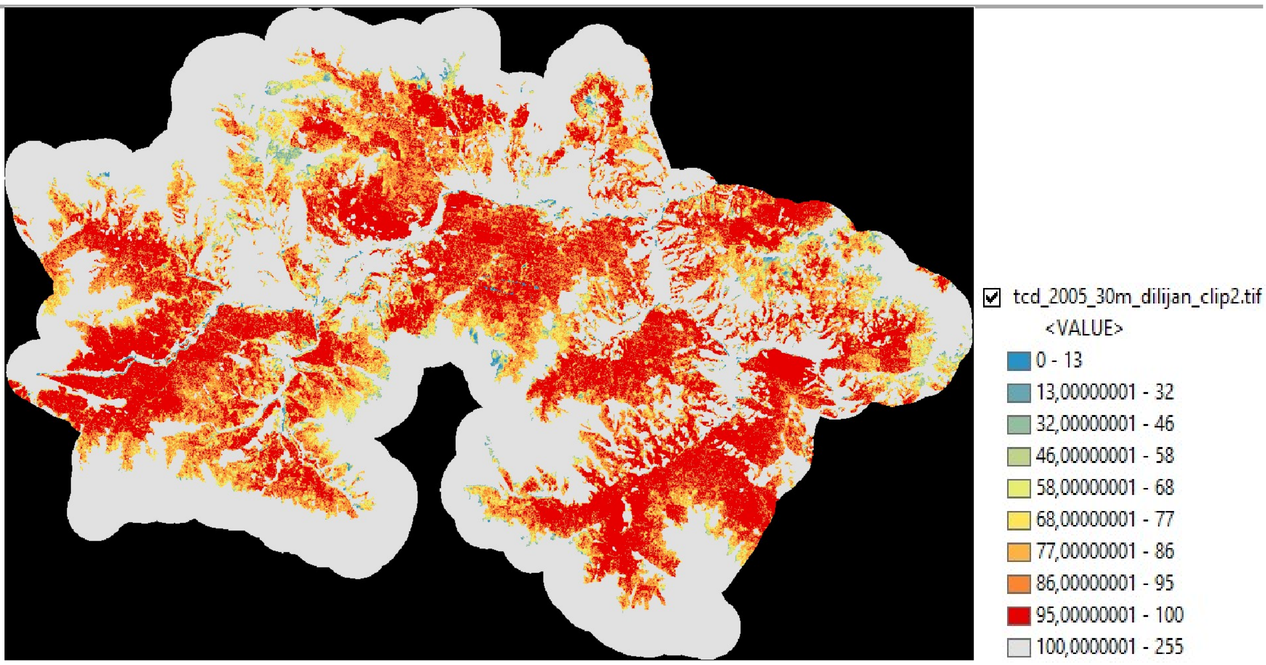

Figure 11: Tree Cover Density 2005 product

iv. *Quality Check of the consistency of the TCD between all epochs*

Computed TCD value over a stable area can presents change over the 1991-2019 due to several factors : for instance, EO imagery from various sensors or acquisition time of EO image reflecting seasonality. To avoid artificial changes in TCD value, a smoothing of the TCDs is applied in order to ensure the consistency between the different epochs. Small variations of TCD values between epochs are then considered as artefacts unless proven as real changes on EO data. For those stable areas, TCD values is then averaged between two successive epochs.

v. *Validation*

The validation of the TCD products comes into the form of a correlation between reference values (interpretation of samples on VHR EO data) and modelized TCD values present in the corresponding product, as show in Figure 12 below.

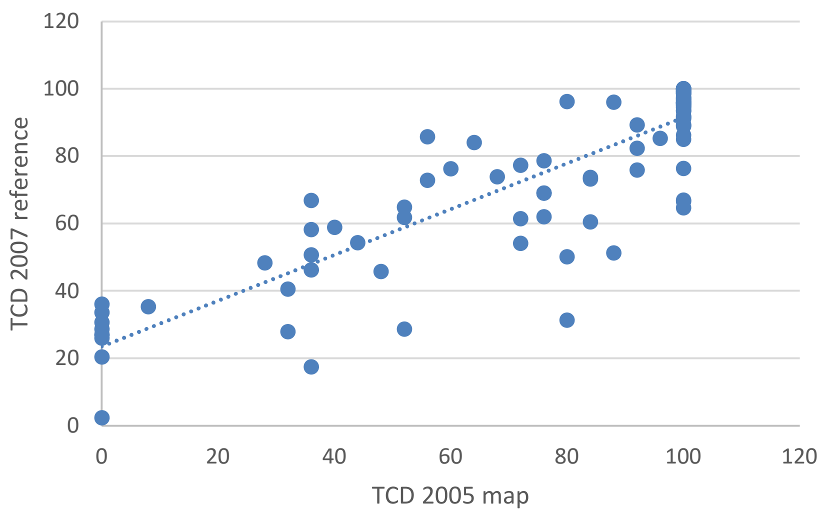

Figure 12: Correlation between TCD 2007 reference (computed from interpretation of SSUs) and TCD 2005 map values ($R^2 = 0.7756$)

The correlation coefficient between reference and map TCD values for each epochs are presented in the table below.

Table 6: Correlation between TCD value of reference data and product

Epoch	Coeff. Correlation R^2 between reference and product
1991	0.7559
1995	0.6988
2000	0.6991
2002	0.7864
2005	0.7903
2010	0.7988
2015	0.8336
2019	0.8901

Forest Type and Dominant Leaf Type for the 2019 epoch

Forest Type (FTY) is the distinction between broadleaved and coniferous tree cover.
Dominant Leaf Type (DLT) is the majority of broadleaved and coniferous tree cover.
The processing workflow can be divided into 4 main steps: (i) Digitizing of coniferous training samples and analysis of spectral signatures (ii) Thresholding on NDVI (iii) Crossing with TCD to derive DLT, (iv) Validation.

(i) Digitizing of coniferous training samples and analysis of spectral signatures

Using UNDP ancillary field data provided in the frame of this project, coniferous parcels could be identified in 2007. Visual interpretation over the 2019 Sentinel-2 scenes, using these 2007 parcels as reference, could allow to determine training samples of both broadleaved tree covered area and coniferous tree covered area inside the 2019 forest mask.
NDVI was computed for 5 Sentinel-2 scenes over the 4 annual seasons, to establish a “NDVI signatures” of both tree types.

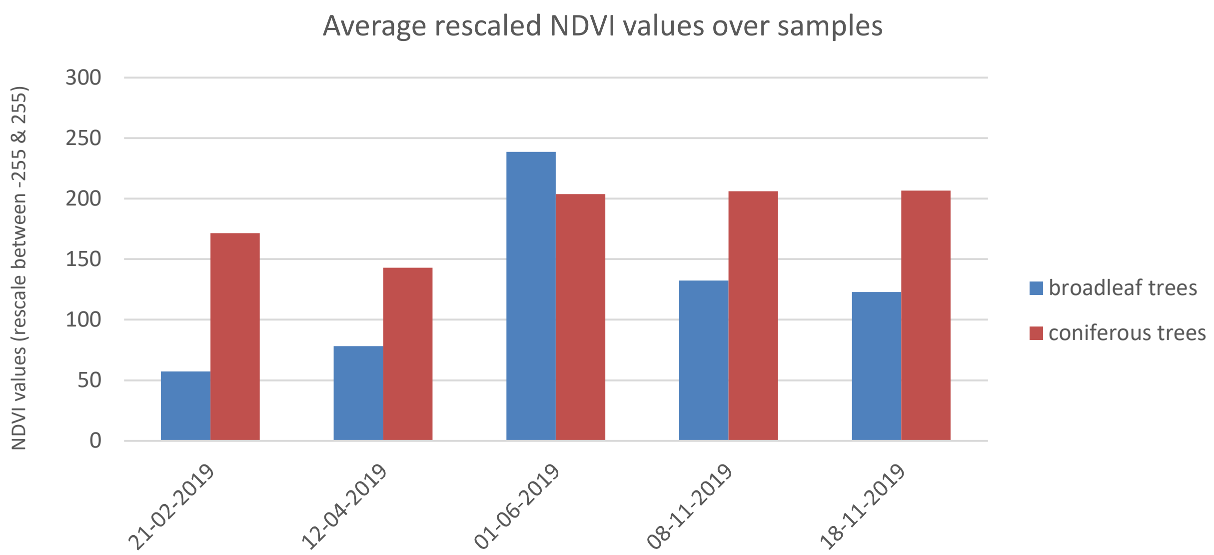

Figure 13: Coniferous and broadleaves samples NDVI signature over 5 periods of the year

(ii) Thresholding on NDVI

Using the NDVI signatures derived in the previous section, it was possible to derive, inside the 2019 forest mask, the discrimination between broadleaved and coniferous trees. Using several observations allowed to reduced artefacts that could derive from shadows.

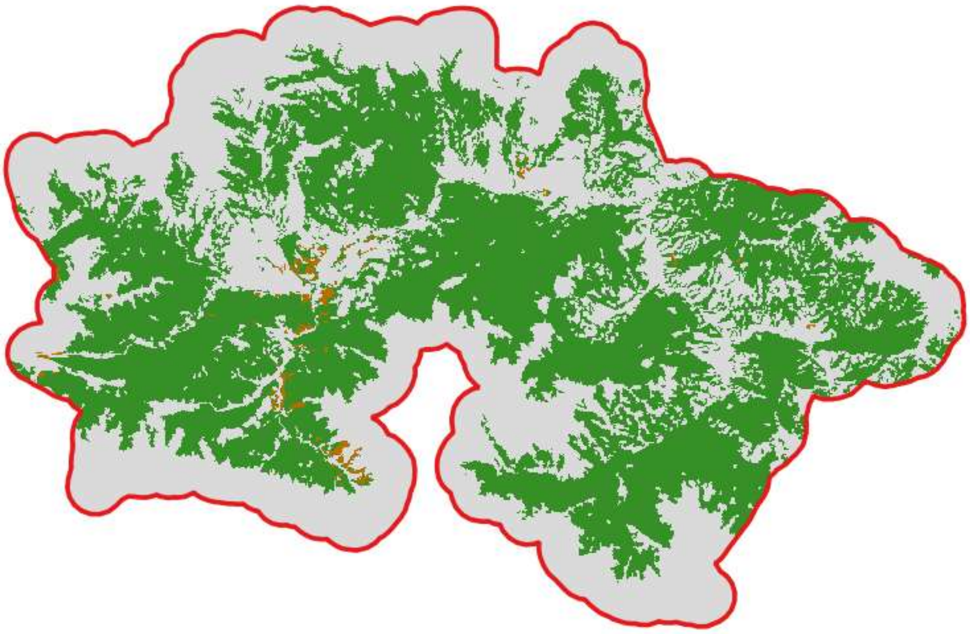

Figure 14: Forest Type 2019 product (grey : non forest ; green : broadleaved trees; brown: coniferous trees)

(iii) Crossing with TCD to derive DLT
Once the coniferous / broadleaf layer is produced, it is possible to combine it with the TCD2019 product to derive the DLT2019 product, with the following nomenclature :

- Needle leaved trees
  - Pure needle leaved (75%)
  - Dominantly needle leaved (50-75%)
- Broadleaved trees
  - Pure broadleaved (>75%)
  - Dominantly broadleaved (50-75%)

Deforestation and forest degradation

According to FAO Forest Resources Assessment definitions, **Deforestation** refers to change of land cover with depletion of tree crown cover to less than 10 percent. Changes within the forest class (e.g. from closed to open forest) which negatively affect the stand or site and, in particular, lower the production capacity, are termed forest degradation.

Forest degradation takes different forms, particularly in open forest formations, deriving mainly from human activities such as over-grazing, over-exploitation (for firewood or timber), repeated fires, or due to attacks by insects, diseases, plant parasites or other natural sources such as cyclones. In most cases, degradation does not show as a decrease in the area of woody vegetation but rather as a gradual reduction of biomass, changes in species composition and soil degradation. Unsustainable logging practices can contribute to degradation if the extraction of mature trees is not accompanied with their regeneration or if the use of heavy machinery causes soil compaction or loss of productive forest area.

Concerning Forest new plantations, **Afforestation** is the Artificial establishment of forest on lands which previously did not carry forest within living memory. As **Reforestation** is the Artificial establishment of forest on lands which carried forest before.

Afforestation/Reforestation is not a deliverable, as specified in the offer.

i. *Deforestation*

Deforestation processing workflow follows the following steps:

- Vectorization of TCM (Union of 1991 + 2019) to obtain stable polygons
- Computing of NDVI for each Landsat image from 1991-2020
- Building of times series for each polygon based on median value with interpolation and filtering where

necessary
- Analysis of time series and identification of breakpoints
- Extraction of values of each key epoch (1991, 1995, 2000, 2002, 2005, 2010, 2015, 2019)
- Computing of NDVI Difference (DNDVI) between each epoch (1991-1995, 1995-2000, 2000-2002, 2002-2005, 2005-2010, 2010-2015, 2015-2019)
- Thresholding on DNDVI, if DNDVI ≤ -0.15: Deforestation, if DNDVI ≥ 0.15: Reforestation

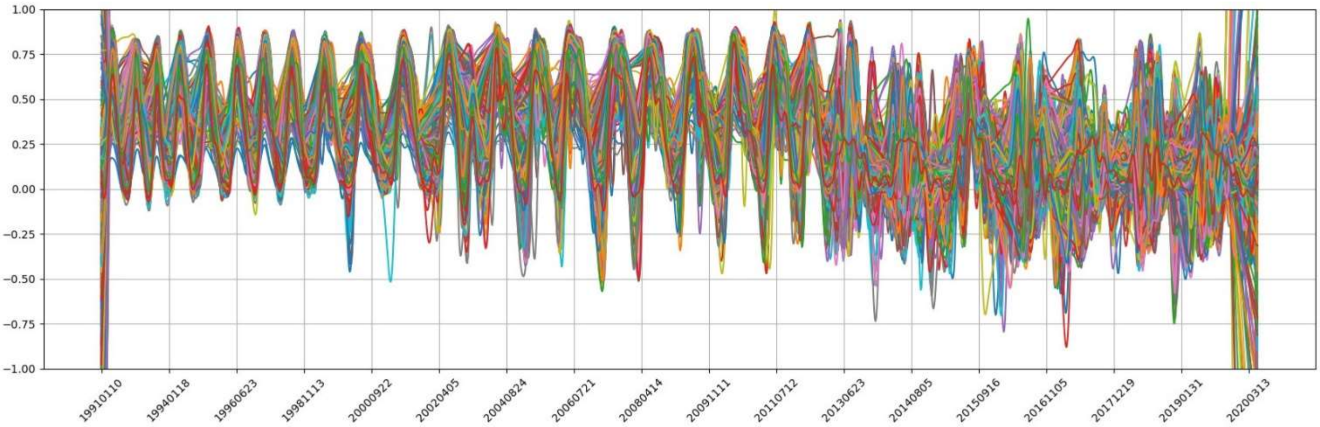

Figure 15: Analysis of NDVI time-series over the 28-years monitoring cycle

The analysis of deforestation is completed with the analysis of TCCM over the different epochs produced during Service 1.
A loss of tree cover is considered as deforestation.

i. *Forest Degradation*

Forest degradation is based on the analysis of the TCD over the different epochs produced during the previous step.
It is completed with the Land Cover/Land Use Classification and associated changes produced during Service 1.
It results from a decrease in the tree cover density value, without any modification of land cover (the area remains classified as forest).
To discriminate anthropogenic forest degradation from forest degradation due to natural causes, we used the forest fire archive available through NASA FIRMS (Fire Information for Resource Management System). However, the anthropogenic cause is certainly greatly overestimated, as FIRMS only records wildfire since 2000, and we were not able to include tree disease factor due to a lack of field data.

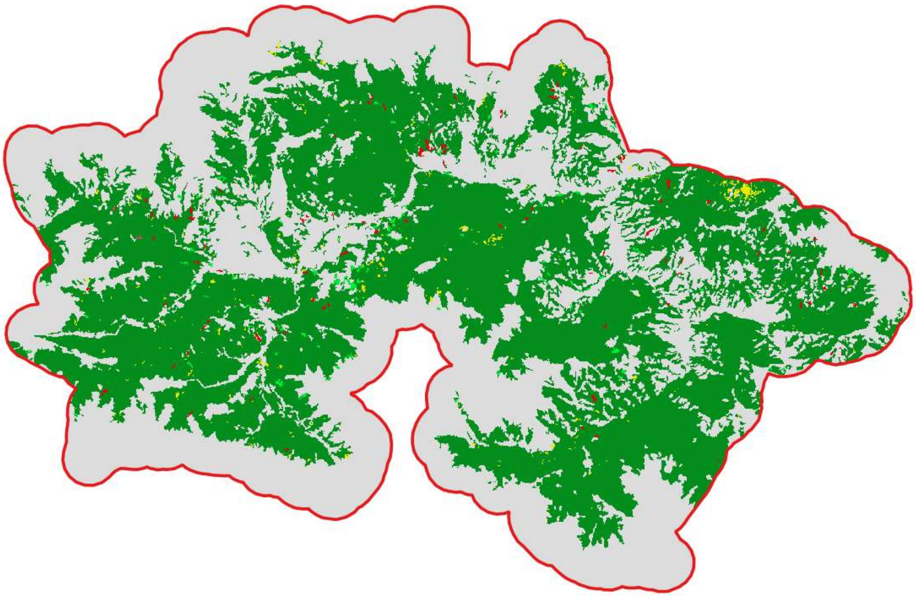

Figure 16: Deforestation and forest degradation map over the period 2005-2010 (grey: stable non forest; green: stable forest; red: deforestation: yellow: forest degradation)

Quality Control and Validation

Quality Control (QC) was part of the production phase and consists in an internal quality check with independent reference data. QC included the following checks, with check-ups of the completeness, logical consistency and geometric accuracy mainly implemented in an automated manner:

- Thematic accuracy performed by means of visual check by another image analyst to ensure the product quality and homogeneity
- Geometric and thematic compliance by means of visual check over randomly selected area samples
- Absence of unlikely changes
- Completeness (omissions/commissions)
- Topological consistency (absence of null geometries, duplicates, multipart features, missing connections due to under/overshoots, invalid slivers, overlaps, gaps, ...)
- Conceptual and domain consistency (attribute table structure and values)

Validation of the thematic product accuracy (overall accuracy, classification correctness and completeness) was implemented independently from the production and once the products are generated for ensuring the compliance with the specifications. The forest mask were validated as part of the Land Cover product. The Tree Cover Density product were validated through the correlation between product and reference TCD values. FTY and DLT products have been validated following the same approach as for the Land Cover products with a stratified approach over 3 strata : non forest / broadleaved trees / coniferous trees. Visual interpretation of samples allowed to derive, through a confusion matrix, the following accuracy figures :

Table 7: Thematic accuracy for FTY 2019 Layer

	User accuracy	Producer accuracy
Non Forest	87.50%	99.80%
Broadleaved trees	92.15%	100%
Coniferous trees	100%	85%

Concerning the degradation/deforestation products, the same validation approach was used, with a stratification over 3 strata : gain of Forest cover, loss of forest cover and stable area. Interpretation of samples based allowed to derive, through a confusion matrix, the following accuracy figures :

Table 8: Thematic accuracy for Forest perturbation layer 1991-2019

	User accuracy	Producer accuracy
Stable area	100%	99.7%
Forest gain	94.44%	89.47%
Forest loss	84.38%	100%

3.2.2. Outputs

The outputs for Service 2 is as followed:
- A density map: a per-pixel classification with a value range of 0-100%.
- A forest type map which distinguishes broadleaved and coniferous tree cover.
- A deforestation and forest degradation map separating between anthropogenic and natural causes.

Delivery package:
- Raster or Vector layer in ESRI shapefile format or any other compatible GIS vector format
- INSPIRE compliant metadata .xml file
- Summary report including overview map and basic statistics in PDF format

3.2.3. Usage, Limitations and Constraints

As Service 1 and Service 2 products are based on the same EO dataset, global usage (historic assessment) and limitations (mountainous region with high cloud coverage) are similar between the 2 services, as described in section 3.1.3.
To overcome the imagery induced artefacts when identifying thematic information or change in thematic information, a conservative approach was favored and uncertain changes were manually removed, and obvious / larger change areas were manually added. This results in a **high confidence level** in the thematic information depicted in Service 2 products, and this is indeed confirmed by accuracy figures derived during validation process.
The Tree Cover Density information being established through a mathematical model and the use of VHR data, its accuracy is very high for the most recent year, where VHR data is available. For more ancient epochs, the closest (timely speaking) model was used with the addition of a conservative approach. A significant change in TCD values between 2 epochs would only be considered as such if confirmed by the visual interpretation of corresponding HR data.
The anthropogenic cause of forest degradation is certainly overestimated : due to lack of historical and field data concerning natural causes of degradation (fire, disease, storm, etc…), only areas where information was available were labelled as natural degradation.

3.3. Data delivery package

Service 1:
- Land Cover Land Use classification for each epoch (2019, 2015, 2010, 2005, 2002, 2000, 1995 and 1991).
- LCLU change maps between all epochs.

Delivery package:
- Raster and / or Vector layer in ESRI shapefile format or any other compatible GIS vector format
- INSPIRE compliant metadata .xml file
- Summary report including overview map and basic statistics in PDF format

Service 2:
- A density map: a per-pixel classification with a value range of 0-100%.
- A forest type map which distinguishes broadleaved and coniferous tree cover.
- A deforestation and forest degradation map separating between anthropogenic and natural causes.

Delivery package:
- Raster or Vector layer in ESRI shapefile format or any other compatible GIS vector format

- INSPIRE compliant metadata .xml file
- Summary report including overview map and basic statistics in PDF format

4 EVALUATION OF DATA AVAILABILITY AND SUITABIL ITY

This chapter evaluates the data used for the current activity describes any problems or deficiencies that must be taken into account for a potential service roll-out.

4.1. EO imagery

To maximise the use of free and openly available resources, the contractor encourages the use satellite images such as Landsat and Sentinel-2 for all services.
Based on a time series approach, the data availability assessment of Sentinel-2 and Landsat (5-8) incorporates all available scenes per year of interest (1991, 1995, 2000, 2002, 2005, 2010, 2015) and yields the total amount of available images and their average cloud cover (by only considering images with a cloud cover of less than 90%) for the area of Dilijan National Park.
Further, a mosaic of high-resolution satellite imagery for 2007-2008 of the Dilijan National Park and surroundings as well as various Pléiades scenes (panchromatic and multispectral) available for 2015 and 2019 are available through UNDP Armenia Office and were used within the activation.

4.2. Other relevant data sources

Table 9: Supporting datasets

Dataset	Source	Specification
Dilijan National Park management plans	UNDP Armenia Office	Dilijan National Park management plans for the years 2007–2011 and 2016–2025
GIS datasets	UNDP Armenia Office	The datasets include park boundaries, basic topographic maps including a DEM (based on ALOS PALSAR, 12 m spatial resolution), hydrology, forest compartments and sub-compartments (videls in Russian), national park zoning, red-listed species, etc. These datasets will be use for the Task 2 Ancillary data preparation (samples)
Cadastral maps	UNDP Armenia Office	Cadastral maps for 2012–2014 and 2016 including cadastral parcels overlapping with the Dilijan National Park: Dilijan, Haghartsin, Teghut, Hovk, Gosh, Khachardzan, Semyonovka, Aghavnavank, Fioletovo, and Tsovagyugh
Elevation	SRTM	NASA Shuttle Radar Topography Mission (SRTM) Version 3.0 Global 1 arc second
Tree cover	Hansen, UMD, Google, USGS, NASA	Forest extent 2018, from Global Forest Change Version 1.6
Roads	OSM	Most recent date via GEOFABRIK downloads

ANNEX I: DELIVERY PRODUCTS KEY TECHNICAL SPECIFICATIONS

No	QC	Name of product	Acronym	Category	Reference year	Abbreviation	Pixel size	Projection	MMU	Classified feature	Data format	Class coding
1		Land Use/Land Cover	LULC	Status layer	2019	LC_Armenia_Dilijan_2019_10m.tif	10m	UTM Zone 38N	0.25 ha	Land Cover Land Use in the reference year	GeoTIFF	1‒Forest 2‒Agriculture 3‒Settlements 4‒Primary roads 5‒Bare soil 6‒Other vegetated areas 7‒Water bodies 8‒Rivers
2		Land Use/Land Cover	LULC	Status layer	2019	LC_Armenia_Dilijan_2019_30m.tif	30m	UTM Zone 38N	1 ha	Land Cover Land Use in the reference year	GeoTIFF	1‒Forest 2‒Agriculture 3‒Settlements 4‒Primary roads 5‒Bare soil 6‒Other vegetated areas 7‒Water bodies 8‒Rivers
3		Land Use/Land Cover	LULC	Status layer	*2015*	LC_Armenia_Dilijan_2015.tif	30m	UTM Zone 38N	1 ha	Land Cover Land Use in the reference year	GeoTIFF	1‒Forest 2‒Agriculture 3‒Settlements 4‒Primary roads 5‒Bare soil 6‒Other vegetated areas 7‒Water bodies 8‒Rivers
4		Land Use/Land Cover	LULC	Status layer	*2010*	LC_Armenia_Dilijan_2010.tif	30m	UTM Zone 38N	1 ha	Land Cover Land Use in the reference year	GeoTIFF	1‒Forest 2‒Agriculture 3‒Settlements 4‒Primary roads 5‒Bare soil 6‒Other vegetated areas 7‒Water bodies 8‒Rivers

No	QC	Name of product	Acronym	Category	Reference year	Abbreviation	Pixel size	Projection	MMU	Classified feature	Data format	Class coding
5		Land Use/Land Cover	LULC	Status layer	*2005*	LC_Armenia_Dilijan_2005.tif	30m	UTM Zone 38N	1 ha	Land Cover Land Use in the reference year	GeoTIFF	1–Forest 2–Agriculture 3–Settlements 4–Primary roads 5–Bare soil 6–Other vegetated areas 7–Water bodies 8–Rivers
6		Land Use/Land Cover	LULC	Status layer	*2002*	LC_Armenia_Dilijan_2002.tif	30m	UTM Zone 38N	1 ha	Land Cover Land Use in the reference year	GeoTIFF	1–Forest 2–Agriculture 3–Settlements 4–Primary roads 5–Bare soil 6–Other vegetated areas 7–Water bodies 8–Rivers
7		Land Use/Land Cover	LULC	Status layer	*2000*	LC_Armenia_Dilijan_2000.tif	30m	UTM Zone 38N	1 ha	Land Cover Land Use in the reference year	GeoTIFF	1–Forest 2–Agriculture 3–Settlements 4–Primary roads 5–Bare soil 6–Other vegetated areas 7–Water bodies 8–Rivers
8		Land Use/Land Cover	LULC	Status layer	*1995*	LC_Armenia_Dilijan_1995.tif	30m	UTM Zone 38N	1 ha	Land Cover Land Use in the reference year	GeoTIFF	1–Forest 2–Agriculture 3–Settlements 4–Primary roads 5–Bare soil 6–Other vegetated areas 7–Water bodies 8–Rivers
9		Land Use/Land Cover	LULC	Status layer	*1991*	LC_Armenia_Dilijan_1991.tif	30m	UTM Zone 38N	1 ha	Land Cover Land Use in the reference year	GeoTIFF	1–Forest 2–Agriculture 3–Settlements 4–Primary roads 5–Bare soil 6–Other vegetated areas 7–Water bodies

No	QC	Name of product	Acronym	Category	Reference year	Abbreviation	Pixel size	Projection	MMU	Classified feature	Data format	Class coding
												8–Rivers
10		Land Use/Land Cover changes	LULCC	*Change layer*	*1991-1995*	LCC_Armenia_Dilijan_1991_1995.tif (source class) LCC_Armenia_Dilijan_1995_1991.tif (target class)	30m	UTM Zone 38N	1 ha	Land Cover Land Use Change between two reference years	GeoTIFF	1–Forest 2–Agriculture 3–Settlements 4–Primary roads 5–Bare soil 6–Other vegetated areas 7–Water bodies 8–Rivers 0-No Change
11		Land Use/Land Cover changes	LULCC	*Change layer*	*1995-2000*	LCC_Armenia_Dilijan_1995_2000.tif (source class) LCC_Armenia_Dilijan_2000_1995.tif (target class)	30m	UTM Zone 38N	1 ha	Land Cover Land Use Change between two reference years	GeoTIFF	1–Forest 2–Agriculture 3–Settlements 4–Primary roads 5–Bare soil 6–Other vegetated areas 7–Water bodies 8–Rivers 0-No Change
12		Land Use/Land Cover changes	LULCC	*Change layer*	*2000-2002*	LCC_Armenia_Dilijan_2000_2002.tif (source class) LCC_Armenia_Dilijan_2002_2000.tif (target class)	30m	UTM Zone 38N	1 ha	Land Cover Land Use Change between two reference years	GeoTIFF	1–Forest 2–Agriculture 3–Settlements 4–Primary roads 5–Bare soil 6–Other vegetated areas 7–Water bodies 8–Rivers 0-No Change
13		Land Use/Land Cover changes	LULCC	*Change layer*	*2002-2005*	LCC_Armenia_Dilijan_2002_2005.tif (source class) LCC_Armenia_Dilijan_2005_2002.tif (target class)	30m	UTM Zone 38N	1 ha	Land Cover Land Use Change between two reference years	GeoTIFF	1–Forest 2–Agriculture 3–Settlements 4–Primary roads 5–Bare soil 6–Other vegetated areas 7–Water bodies 8–Rivers 0-No Change
14		Land Use/Land	LULCC	*Change layer*	*2005-2010*	LCC_Armenia_Dilijan_2002_2005.tif (source class)	30m	UTM Zone 38N	1 ha	Land Cover Land Use Change between two reference years	GeoTIFF	1–Forest 2–Agriculture

No	QC	Name of product	Acronym	Category	Reference year	Abbreviation	Pixel size	Projection	MMU	Classified feature	Data format	Class coding
		Cover changes				LCC_Armenia_Dilijan_2005_2002.tif (target class)						3‑Settlements 4‑Primary roads 5‑Bare soil 6‑Other vegetated areas 7‑Water bodies 8‑Rivers 0-No Change
15		Land Use/Land Cover changes	LULCC	*Change layer*	*2010-2015*	LCC_Armenia_Dilijan_2010_2015.tif (source class) LCC_Armenia_Dilijan_2015_2010.tif (target class)	30m	UTM Zone 38N	1 ha	Land Cover Land Use Change between two reference years	GeoTIFF	1‑Forest 2‑Agriculture 3‑Settlements 4‑Primary roads 5‑Bare soil 6‑Other vegetated areas 7‑Water bodies 8‑Rivers 0-No Change
16		Land Use/Land Cover changes	LULCC	*Change layer*	*2015-2019*	LCC_Armenia_Dilijan_2015_2019.tif (source class) LCC_Armenia_Dilijan_2019_2015.tif (target class)	30m	UTM Zone 38N	1 ha	Land Cover Land Use Change between two reference years	GeoTIFF	1‑Forest 2‑Agriculture 3‑Settlements 4‑Primary roads 5‑Bare soil 6‑Other vegetated areas 7‑Water bodies 8‑Rivers 0-No Change
17		Land Use/Land Cover changes	LULCC	*Change layer*	*1991-2019*	LCC_Armenia_Dilijan_1991_2019.tif (source class) LCC_Armenia_Dilijan_2019_1991.tif (target class)	30m	UTM Zone 38N	1 ha	Land Cover Land Use Change between two reference years	GeoTIFF	1‑Forest 2‑Agriculture 3‑Settlements 4‑Primary roads 5‑Bare soil 6‑Other vegetated areas 7‑Water bodies 8‑Rivers 0-No Change

Service 2 Deliverables :

No	QC	Name of product	Acronym	Category	Reference year	Abbreviation	Pixel size	Projection	MMU	Classified feature	Data format	Class coding
1		Tree Cover Density	TCD	Status layer	2019	tcd_2019_30m_dilijan	30m	UTM Zone 38N	1 ha	Aggregated tree cover; tree cover density from 1-100%	Unsigned 8 bits	0: all non-tree covered areas 1-100: tree cover density in % 255: outside area / no data
2		Tree Cover Density	TCD	Status layer	2015	tcd_2015_30m_dilijan	30m	UTM Zone 38N	1 ha	Aggregated tree cover; tree cover density from 1-100%	Unsigned 8 bits	0: all non-tree covered areas 1-100: tree cover density in % 255: outside area / no data
3		Tree Cover Density	TCD	Status layer	2010	tcd_2010_30m_dilijan	30m	UTM Zone 38N	1 ha	Aggregated tree cover; tree cover density from 1-100%	Unsigned 8 bits	0: all non-tree covered areas 1-100: tree cover density in % 255: outside area / no data
4		Tree Cover Density	TCD	Status layer	2005	tcd_2005_30m_dilijan	30m	UTM Zone 38N	1 ha	Aggregated tree cover; tree cover density from 1-100%	Unsigned 8 bits	0: all non-tree covered areas 1-100: tree cover density in % 255: outside area / no data
5		Tree Cover Density	TCD	Status layer	2002	tcd_2002_30m_dilijan	30m	UTM Zone 38N	1 ha	Aggregated tree cover; tree cover density from 1-100%	Unsigned 8 bits	0: all non-tree covered areas 1-100: tree cover density in % 255: outside area / no data
6		Tree Cover Density	TCD	Status layer	2000	tcd_2000_30m_dilijan	30m	UTM Zone 38N	1 ha	Aggregated tree cover; tree cover density from 1-100%	Unsigned 8 bits	0: all non-tree covered areas 1-100: tree cover density in % 255: outside area / no data
7		Tree Cover Density	TCD	Status layer	1995	tcd_1995_30m_dilijan	30m	UTM Zone 38N	1 ha	Aggregated tree cover; tree cover density from 1-100%	Unsigned 8 bits	0: all non-tree covered areas

No	QC	Name of product	Acronym	Category	Reference year	Abbreviation	Pixel size	Projection	MMU	Classified feature	Data format	Class coding
												1-100: tree cover density in % 255: outside area / no data
8		Tree Cover Density	TCD	Status layer	1991	tcd_1991_30m_dilijan	30m	UTM Zone 38N	1 ha	Aggregated tree cover; tree cover density from 1-100%	Unsigned 8 bits	0: all non-tree covered areas 1-100: tree cover density in % 255: outside area / no data
9		Forest Type	FTY	Status layer	2019	fty_2019_10m_dilijan	10m	UTM Zone 38N	0.25 ha	Forest Type: broadleaved or coniferous, largely following the FAO forest definition.	Unsigned 8 bits	0: all non-forest areas 1: broadleaved forest 2: coniferous forest 255: outside area / no data
10		Forest Type	FTY	Status layer	2019	fty_2019_30m_dilijan	30m	UTM Zone 38N	1 ha	Forest Type: broadleaved or coniferous, largely following the FAO forest definition.	Unsigned 8 bits	0: all non-forest areas 1: broadleaved forest 2: coniferous forest 255: outside area / no data
11		Dominant Leaf Type	DLT	Status layer	2019	dlt_2019_30m_dilijan	30m	UTM Zone 38N	1ha	Forest Type: broadleaved or coniferous, largely following the FAO forest definition.	Unsigned 8 bits	0: Non tree cover 11: Pure broadleaved (>75%) 12: Dominantly broadleaved (50-75%) 21: Pure needle leaved (75%) 22: Dominantly needle leaved (50-75%)
12		Dominant Leaf Type	DLT	Status layer	2019	dlt_2019_10m_dilijan	10m	UTM Zone 38N	1ha	Forest Type: broadleaved or coniferous, largely following the FAO forest definition.	Unsigned 8 bits	0: Non tree cover 11: Pure broadleaved (>75%) 12: Dominantly broadleaved (50-75%) 21: Pure needle leaved (75%)

No	QC	Name of product	Acronym	Category	Reference year	Abbreviation	Pixel size	Projection	MMU	Classified feature	Data format	Class coding
												22: Dominantly needle leaved (50-75%)
13		Degradation and deforestation map		Change layer	1991-2019		30m	UTM Zone 38N	1 ha			0: Non forest stable 1: Forest regeneration 2: Deforestation 31: Anthropogenic forest degradation 32: Natural forest degradation 4: Forest stable
14		Degradation and deforestation map		Change layer	1991-1995		30m	UTM Zone 38N	1 ha			0: Non forest stable 1: Forest regeneration 2: Deforestation 31: Anthropogenic forest degradation 32: Natural forest degradation 4: Forest stable
15		Degradation and deforestation map		Change layer	1995-2000		30m	UTM Zone 38N	1 ha			0: Non forest stable 1: Forest regeneration 2: Deforestation 31: Anthropogenic forest degradation 32: Natural forest degradation 4: Forest stable
16		Degradation and deforestation map		Change layer	2000-2002		30m	UTM Zone 38N	1 ha			0: Non forest stable 1: Forest regeneration 2: Deforestation 31: Anthropogenic forest degradation 32: Natural forest degradation 4: Forest stable

No	QC	Name of product	Acronym	Category	Reference year	Abbreviation	Pixel size	Projection	MMU	Classified feature	Data format	Class coding
17		Degradation and deforestation map		Change layer	2002-2005		30m	UTM Zone 38N	1 ha			0: Non forest stable 1: Forest regeneration 2: Deforestation 31: Anthropogenic forest degradation 32: Natural forest degradation 4: Forest stable
18		Degradation and deforestation map		Change layer	2005-2010		30m	UTM Zone 38N	1 ha			0: Non forest stable 1: Forest regeneration 2: Deforestation 31: Anthropogenic forest degradation 32: Natural forest degradation 4: Forest stable
19		Degradation and deforestation map		Change layer	2010-2015		30m	UTM Zone 38N	1 ha			0: Non forest stable 1: Forest regeneration 2: Deforestation 31: Anthropogenic forest degradation 32: Natural forest degradation 4: Forest stable
20		Degradation and deforestation map		Change layer	2015-2019		30m	UTM Zone 38N	1 ha			0: Non forest stable 1: Forest regeneration 2: Deforestation 31: Anthropogenic forest degradation 32: Natural forest degradation 4: Forest stable