EO Clinic project:

Preparation of a National Coffee Sector Development Plan for Timor-Leste

Work Order Report

Support requested by:
Asian Development Bank (ADB)

TABLE OF CONTENTS

ABOUT THIS DOCUMENT

This publication was prepared in the framework of the EO Clinic (Earth Observation Clinic, see below), in partnership between ESA (European Space Agency), the Asian Development Bank (ADB) and team of service providers contracted by ESA: e-GEOS S.p.A. (Italy) and Planetek Hellas (Greece).

This Work Order Report (WOR) describes the context of the ADB activities on Preparation of a National Coffee Sector Development Plan for Timor-Leste, the geoinformation requirements of the activities and finally, the EO products and services delivered by the EO Clinic service providers in support of those activities.

ABOUT THE EO CLINIC

The EO Clinic (Earth Observation Clinic) is an ESA (European Space Agency) initiative to create a rapid-response mechanism for small-scale and exploratory uses of satellite EO information, in support to 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 aimed to the developing or improving of methodologies for deriving socio-economic and environmental parameters and indicators.

The EO Clinic initiative, launched on March 2019, 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 Valeria Donzelli, Project Manager, e-GEOS S.p.A. with support from the following contributors: Isabella Di Marco, EC & GIS expert, e-GEOS S.p.A., Mariano Biscardi, thematic expert, e-GEOS S.p.A., Vasiliki Avgikou, Thematic expert, Planetek Hellas, Dimftrios Bliziotis, Technician, Planetek Hellas, Kleanthis Karamvasis, EO and SAR Expert, Planetek Hellas, Alexandros Voukenas, Technician, Planetek Hellas.

ACKNOWLEDGEMENTS

The following colleagues provided valuable inputs, insights and evaluation feedback on the work performed: Paolo Manunta (Senior Infrastructure EO Specialist, Asian Development Bank), and Zoltan Bartalis (ESA Coordinator and Technical Officer).

For further information	Please contact Valeria Donzelli, Project Manager, e-GEOS S.p.A., valeria.donzelli@e-geos.it , with copy to Zoltan.Bartalis@esa.int if you have questions or comments with respect to content or if you wish to obtain permission to use the material in this report. Visit the ESA EO Clinic: https://eo4society.esa.int/eo_clinic.

1 DEVELOPMENT CONTEXT AND BACKGROUND

Timor-Leste has a long and often tumultuous history of coffee production. Since its early beginnings, under Portuguese colonial rule and later under Indonesian occupation, major coffee production was often main-obtained through forced labour schemes and exploitation of smallholders. Production by smallholders has persevered throughout these periods of conflict and change. Throughout its turbulent past, indigenous Timorese were often required to produce coffee by the colonial authorities or by their own tribal leaders, often under terrible conditions.

According the Timor-Leste Coffee Sector Development Plan prepared by the MAF (Ministry of Agriculture and Fisheries), improvements in coffee production and processing offer one of the clearest pathways for poverty reduction and growth of the non-oil economy. In Timor-Leste, there is an urgent need to increase coffee production volume and quality to support livelihoods without adversely affecting the environment. One way of increasing productivity of coffee crops is performing crop condition assessments and season-long monitoring, to support agronomic decision-making. Within this perspective, Timor-Leste's Strategic Development Plan 2011-2030 identifies coffee as a priority sector and set the goal to rehabilitate 40,000 ha of coffee plantations by 2020.

The proposed solution aims to provide an up-to-date mapping of coffee plantations. A satellite based service able to get an up-to-date situation on coffee crops (with land cover monitoring also in the surrounding landscape) can represent a valid support for regions, like Timor-Leste, engaged in setting strategies for proper crops recovery actions and productivity increase.

e-Geos (www.e-geos.it) is s company leader in geoinformation services and applications. Moreover e-GEOS has a consolidated knowledge of the morphology and features of Timor Leste territory. In the framework of Copernicus Hot Spot Monitoring Programme, e-Geos is responsible for monitoring activities on Timor Leste territory. The program is devoted to the providing of detailed land information on specific areas of interest, answering to ad hoc requests concentrated mainly on the domain of the sustainable management of natural resources. The initial focus was posed on Protected Areas or Key Landscapes for Conservation. The program gives support to projects and policies by the EU, in the framework of EU international policy interest. In this context, e-GEOS is in charge of the Land Cover (LC) and Land Cover Change (LCC) layers for the whole surface of Timor Leste, according to the legend LCCS FAO/UNEP

The main features of the delivered products are:

- Land Cover:
- LCCS Level B, MMU = 0,5 ha, Period 2016
- Land Cover Change:
- LCCS Level B, MMU =0,5 ha, Periods: (1) 2010 (+/- 2) – Present (last 2 years), (2) 2005 (+/- 2) – 2010 (+/- 2), (3) 2000 (+/- 2) – 2005 (+/- 2)

The product is currently under validation by the customer.

Planetek Hellas (www.planetek.gr), member of the Planetek Group that, since 1994 operates in the field of Satellite Remote Sensing, Spatial Data Infrastructure and Software development for the "on board" and "ground" segment space applications. Founded in 2006, Planetek Hellas provides solution oriented services in the domain of Geomatics, involving the use of EO data and systems for environmental & critical infrastructure monitoring, urban planning, civil protection and security.

Planetek Hellas bases its offer in the high involvement in the research and in the analysis of new techniques, which process and integrate remote sensing information with the state of the art technologies of nowdays such as HPC, AI and Internet.

2 PROPOSED WORK LOGIC FOR EO-BASED SOLUTIONS

The scope of the project is to create customized products from remote sensing data aimed to assess the present status and the historical evolution of the coffee cultivation in Timor Leste. The products are focused on providing location and extension of coffee cultivations, collecting information about the state of coffee plantations, understanding the patterns in land use change related to (and affecting) coffee plantations.

These products are a relevant resource for a deeper knowledge of the situation and for the setup of proper correction strategies to optimize the cultivation and increase productivity. They will support the ordinary and extraordinary territorial management activities by dedicated Entities.

It was paid specific attention in product generation through the setup of proper processing workflows focused on maximizing the extraction of information from the integrated usage of radar and optical EO-based data, and aimed to identify actual limits of what can be extracted by satellite data in support to coffee cultivation monitoring, with specific reference to Timor-Leste geographic location.

The project is structured in 5 tasks or Work Packages (WP):

- WP1 takes care of all the management activities and covers the whole project's duration.
- WP2 covers data acquisition and pre-processing phase. It began immediately at the start of the project.
- WP3 generates historical land cover mapping. It is dependent on the success of data procurement from WP2 and consists of the following activities:
    - Over the area of interest it's generated an historic land cover mapping for Epoch3, adopting 2000 as reference year.
    - Over the area of interest it's generated an historic land cover mapping for Epoch2, based on 2010 as reference year, as well as a change detection layer between Epoch2 and Epoch3
- WP4 deals with the implementation of an updated land cover and coffee plantations mapping, as well as a characterization of coffee plantations. It targets the following performances:
    - Generate a coffee plantations map of the year 2018/2019 divided in open and shaded coffee crops.
    - Provide a characterization of the coffee plantations according to their conditions in terms of vegetation density and cultivation practices, in order to identify potential critical areas of poor productivity and set priority actions.
    - Generate a land cover map for Epoch1, with updated knowledge about the surroundings of the plantations.
    - Extract analytics and trends about the land cover changes and coffee crops distribution over the three epochs identified in the RFP.
- WP5 provides a WebGIS publication system on which to upload the outputs of WPs 3 and 4 and through which they will be shown and identified.

3 DELIVERED EO-BASED PRODUCTS AND SERVICES

The project provides the following products:

- Land cover map Epoch 3 (WP3)
- Land cover map Epoch2 (WP3)
- Land cover map Epoch1 (WP4), based on a 8 classes legend
- Coffee plantations map (WP4), with delineation of coffee plantations divided in open and shaded coffee crops and characterized by their conditions in terms of vegetation density, well-maintained and spaced vs. unmaintained/abandoned crops
- Land cover change maps (WP4), with special focus on the forest class

3.1 Historic land cover mapping

3.1.1 Specifications

On the area of interest, the historical Land Cover maps for the year 2000 (Epoch 3) and the year 2010 (Epoch 2), were generated.

The adopted legend bases on the latest specifications of the CLC Copernicus backbone (01-31-2018).

CLASS CODE	DESCRIPTION
a	Sealed surfaces (buildings and flat sealed surfaces)
b1	Forest vegetation evergreen
b2	Forest vegetation not evergreen and shrubs
c	Permanent herbaceous (i.e. grassland)
d	Periodically herbaceous (arable land, natural grasslands with periodic vegetation cover)
e	Permanent bare soil
f	Non-vegetated or scantly vegetated surfaces (i.e. rock, sand and sparsely vegetated area)
g	Water surfaces

The maps uses the following images as reference data:

EPOCH 2 (2010): LANDSAT5_20090319

LANDSAT5_20090607

EPOCH 3 (2000): LANDSAT7_20001028

LANDSAT7_20010913

LANDSAT7_20010929

The Minimum Mapping Unit adopted for the photointerpretation is 4 ha
The Reference system, WGS84 / UTM 51S, EPSG: 32651

The workflow for the generation of historical Land cover maps is:

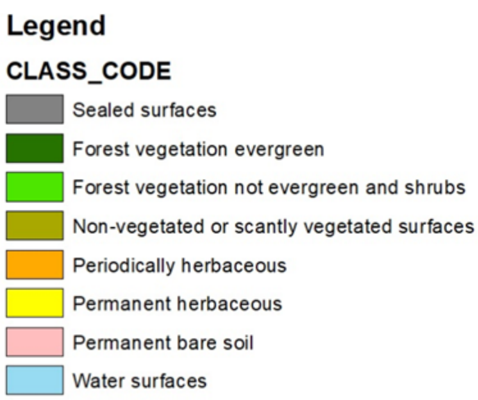
- Satellite multitemporal images collection, for providing a multitemporal view of the area close to reference 2000 year
- Radiometric processing, aimed at preparing the image for the interpretation.
- Identification of interpretation keys for the identified classes: through the usage of ancillary data made available by ADB, as well as open source higher resolution images, will be identified the multitemporal spectral features for each of the classes to be recognized
- Interpretation of the multitemporal images, with generation of the Epoch2 and Epoch 3 land cover map. The interpretation has been based on image composed by the usage of near infrared and red band together with mid infrared or green band

The use of images at different dates (multitemporal) is particularly useful to be able to differentiate, in the photo-interpretation phase, the Evergreen Forest from the not Evergreen Forest and Permanent herbaceous from Periodically herbaceous.

Regarding the map of epoch 3, this originates from the map of epoch 2 according to the following procedure:

- Overlap of first thematic map as starting layer
- Identification of polygon to be modified because of:
  - Addition (enlargement) of the area of the class polygon
  - Reduction of the area of the class polygon
  - Change of the class of the polygon
- Generation of new polygons geometry

Below the legend adopted and the overall view of the Land Cover historical maps



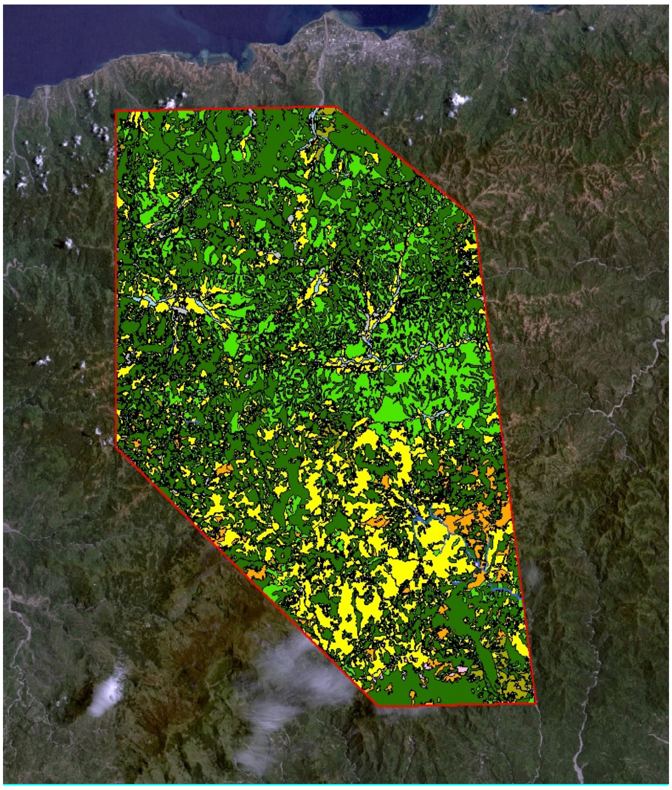


Figure 1: Land Cover Map- Epoch 2- 2010

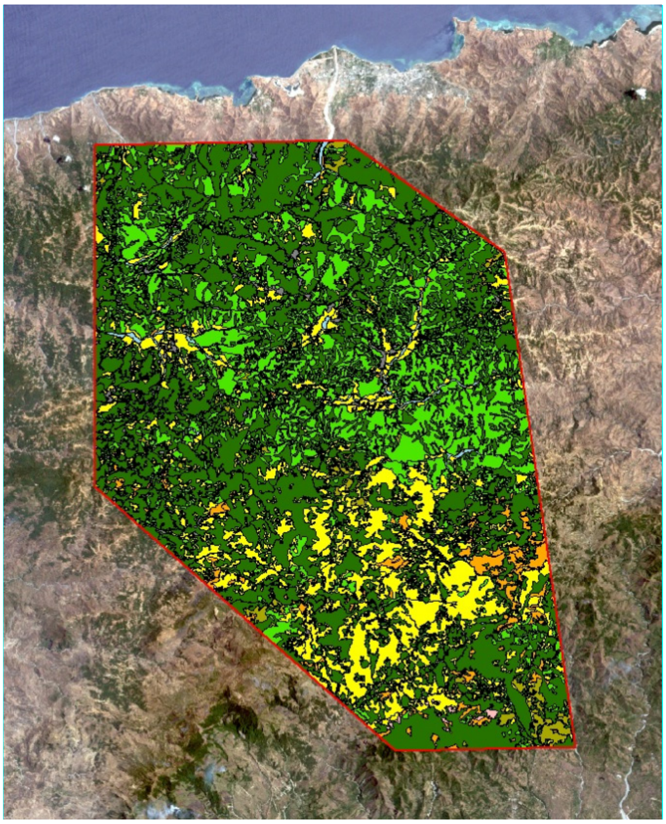


Figure 2: Land Cover Map- Epoch 3 – 2000

3.1.2 Quality Control and Validation

<u>Thematic checks</u>

All delineated features are further examined through a visual double-check process carried out by experienced image analysts not previously involved in the raw production. This visual inspection aims to the identification of potential quality issues, and to the correction of potential interpretation errors or delineation imprecisions.

<u>Topological checks</u>

Topological checks are performed through GIS Tools, related to

- Completeness
- No gaps, No overlap
- Thematic coding/attributes/consistency
- Missing vertices
- Unnecessary boundaries
- Single part polygon
- MMU

3.2 Actual Land cover and coffee plantations mapping

3.2.1 Specifications

It was produced the following products over the area of interest:

1. **Land cover map for Epoch 1 (2018-2019)**
2. **Coffee plantations map (2018-2019)**
3. **Land cover change map (Epoch 3 – Epoch 2; Epoch 2 –Epoch 1)**

3.2.1.1 Land cover map for Epoch 1 (2018-2019)

The land cover map originates from the application of a supervised random forest classifier to the multitemporal Sentinel-2 data available on the Copernicus sci-hub in the time range 2018-2019 (i.e. cloud free data).

The legend adopted for the Land cover map bases on the same used for the Historical land cover products, with some integration related to the forest classes and to the rice fields. In particular, the analysis classifies the evergreen forest in three sub-classes with respect to the tree cover density into dense, medium dense and low density.

Furthermore, it is implemented the separation of the rice field.

As a result, the following classes results in the Land cover map for Epoch 1:

a Sealed surfaces (buildings and flat sealed surfaces)

b1 Forest vegetation evergreen

b11 Forest vegetation evergreen dense

b12 Forest vegetation evergreen medium dense

b13 Forest vegetation evergreen low dense

b2 Forest vegetation not evergreen and shrubs

c Permanent herbaceous (i.e. grassland)

d Periodically herbaceous (arable land, natural grasslands with periodic vegetation cover) e	Permanent bare soil

f	Non-vegetated or scantly vegetated surfaces (i.e. rock, sand and sparsely vegetated area)

g	Water surfaces

h	Rice fields

The Minimum Mapping Unit adopted for the photointerpretation is 0,1 ha

The Reference system, WGS84 / UTM 51S, EPSG: 32651

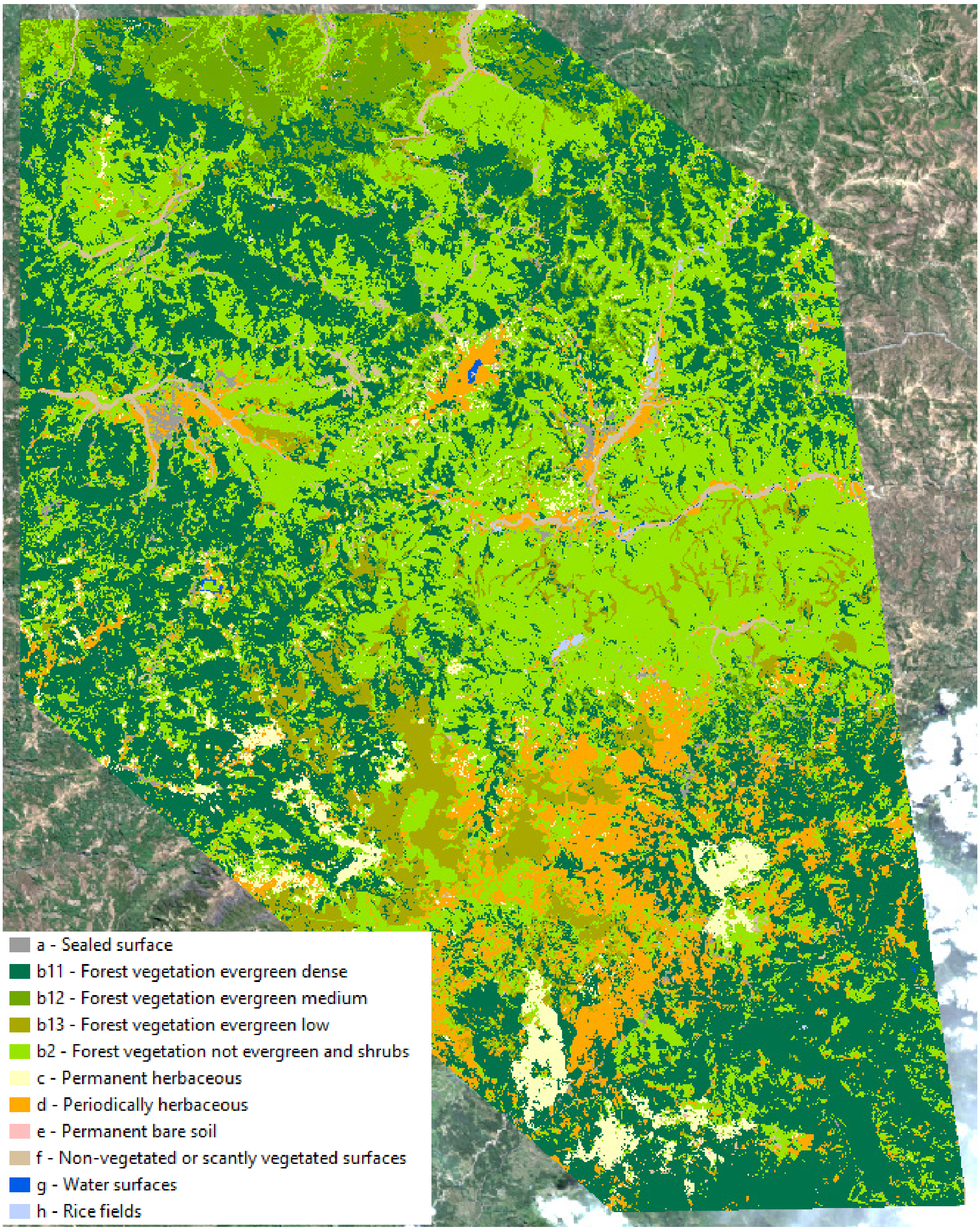


Figure 3: Overview of the Land cover map Epoch 1

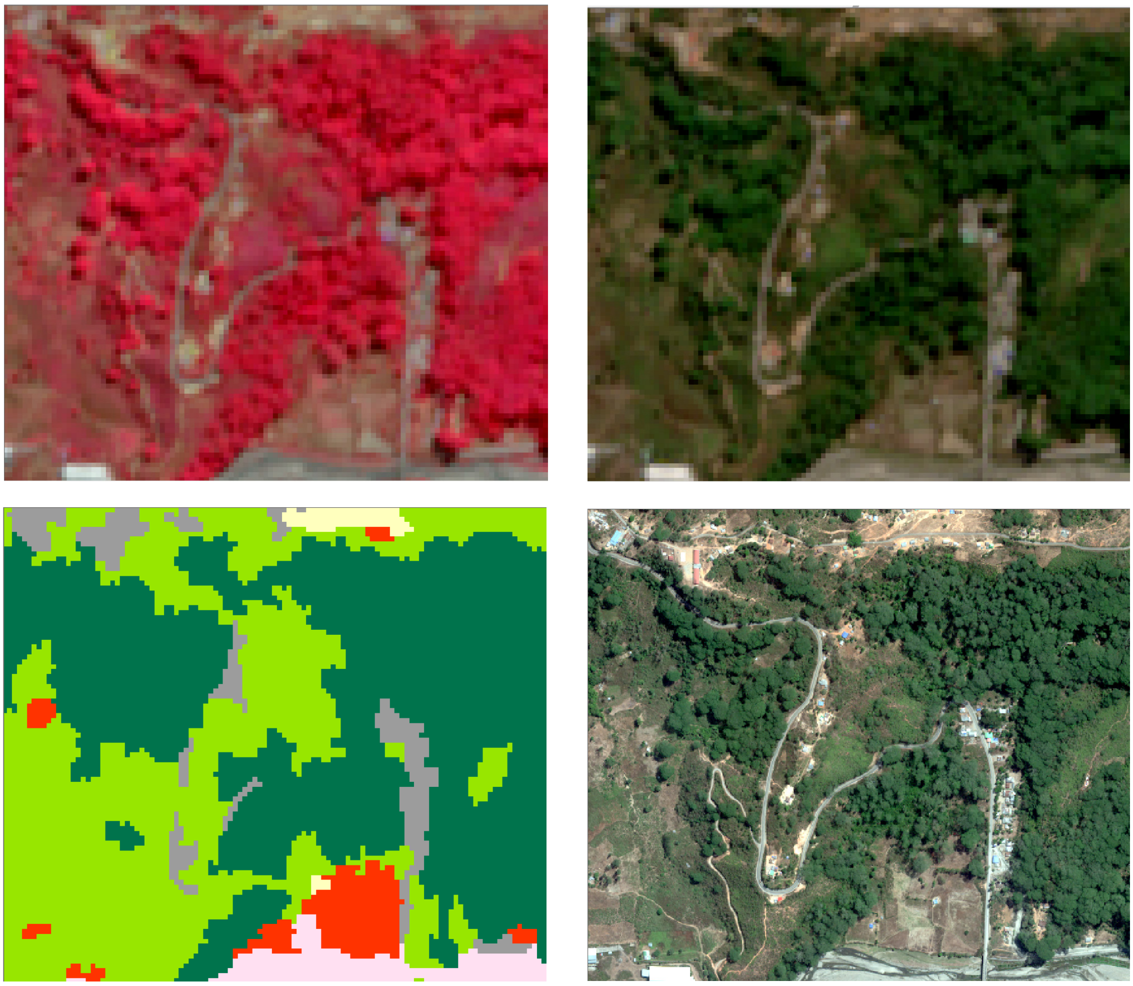


Figure 4 Example of a subset of Sentinel-2 data in NIR and real color combination (pictures above), Land cover map (bottom left) and VHR subset of the same area (bottom right).

3.2.1.2 Coffee plantations map (2018-2019)

It realized a coffee plantation map providing the distribution of the coffee crops according to a sort of plausibility approach. The output map gives evidence of the probability of crops occurrence as calculated by the proposed classification. The coffee plantations are divided into three level of probability of the plantation occurrence (high, medium, low) approach. The coffee plantation map generates from the application of the training sample made available by AdB to the supervised classifier. The training consists of three polygons, which have been useful to spectrally characterise the fields, but probably not enough to cover all their variability.

As a result, the classifiers recognizes several coffee fields in the western part of the area of interest (i.e. Ermera district), without separation between open and shaded crops.

In order to further improve the information content of the output map (including separation between open and shaded fields, farming conditions, etc), it would be useful to have at disposal more extended ground truth data, covering shaded and open plantations, with different farming conditions and with homogeneous distribution over the study area.

It is worth to note that, during the first phase, the results showed how the coffee fields (both the ground truth fields and coffee fields classified from Sentinel data) were all positioned within the forest more dense areas in Ermera region.

During the second phase, the integration of SAR data to the original Sentinel-2 image dataset resulted in an increase in the extent of the detected fields and a general improvement of the plausibility level of the classification (see Figure 3). As shown in the charts below (Figure 4) the coffee plantation maps are mostly located in Ermera district with about 600 ha of mapped crops.

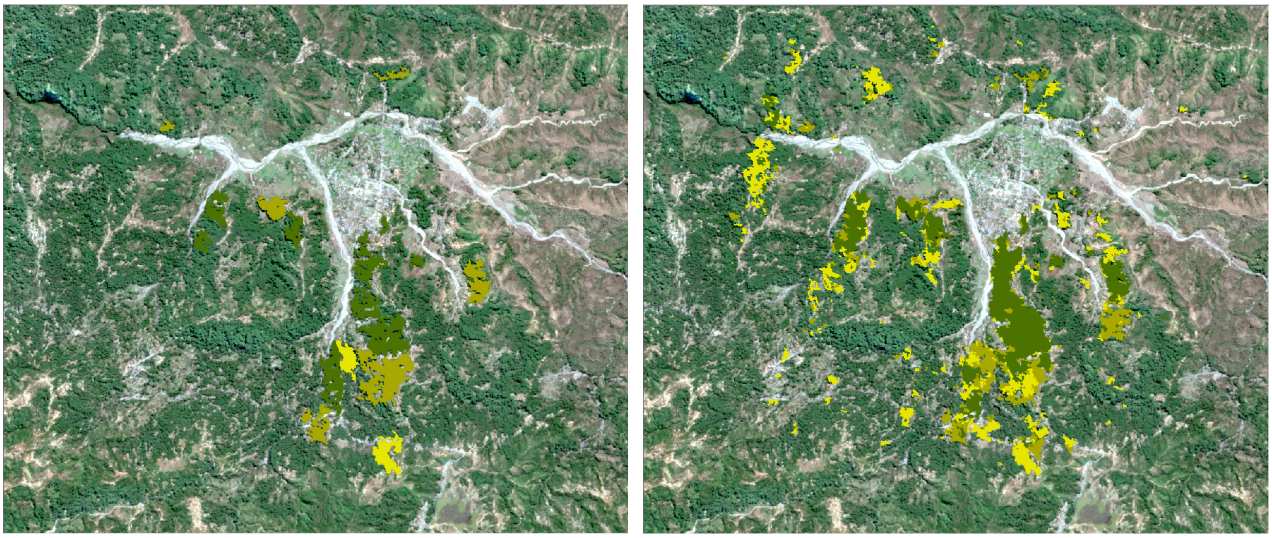


Figure 5: Comparison between the preliminary version of the coffee map and the final map realized with the contribution of SAR component

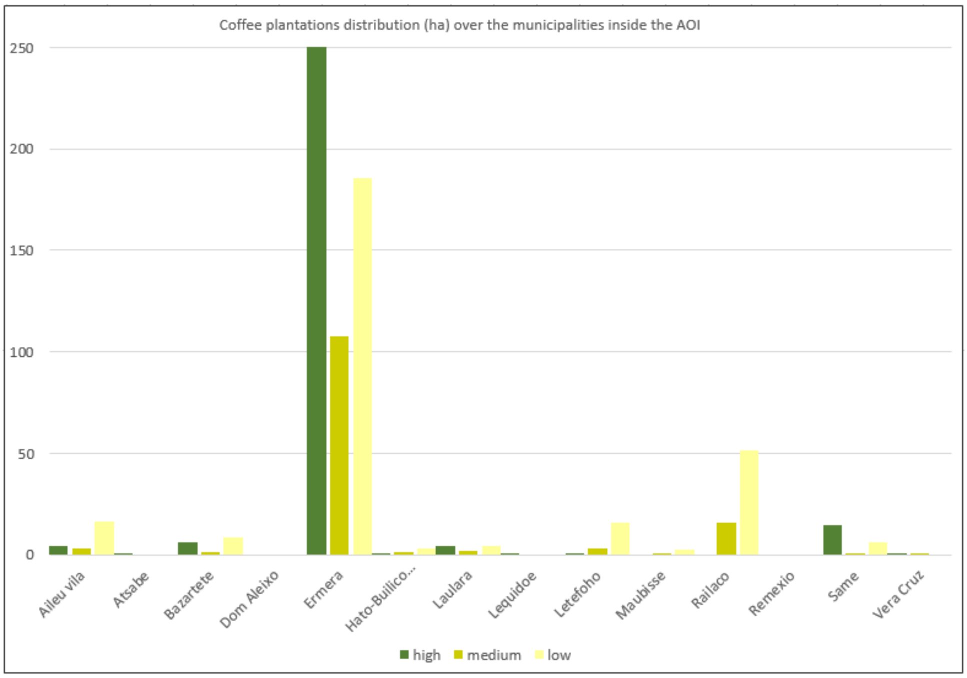


Figure 6: Coffee plantations distribution over the sub-district/municipalities under the study area.

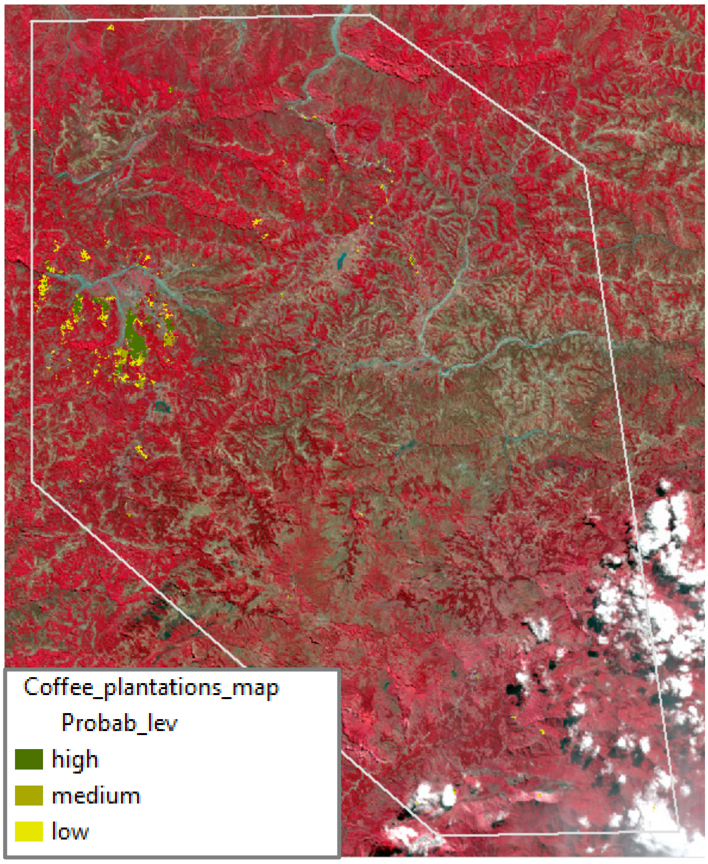


Figure 7: Overview of the Coffee plantations map

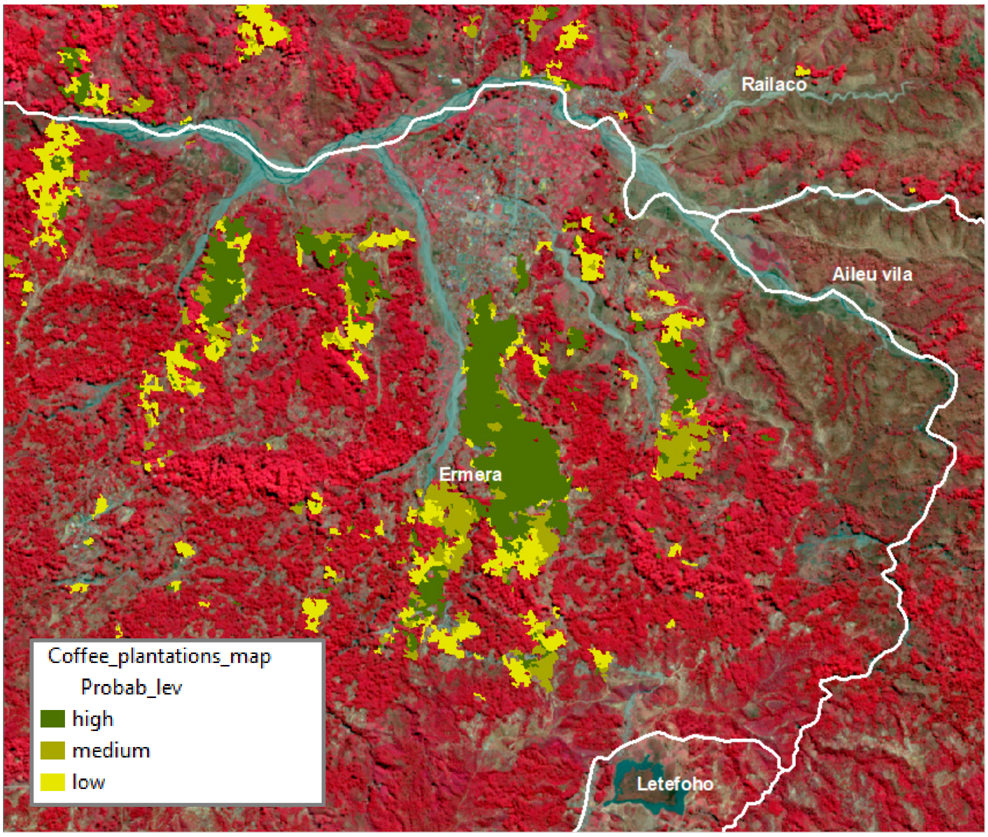


Figure 8: Example of coffee plantations in Ermera region

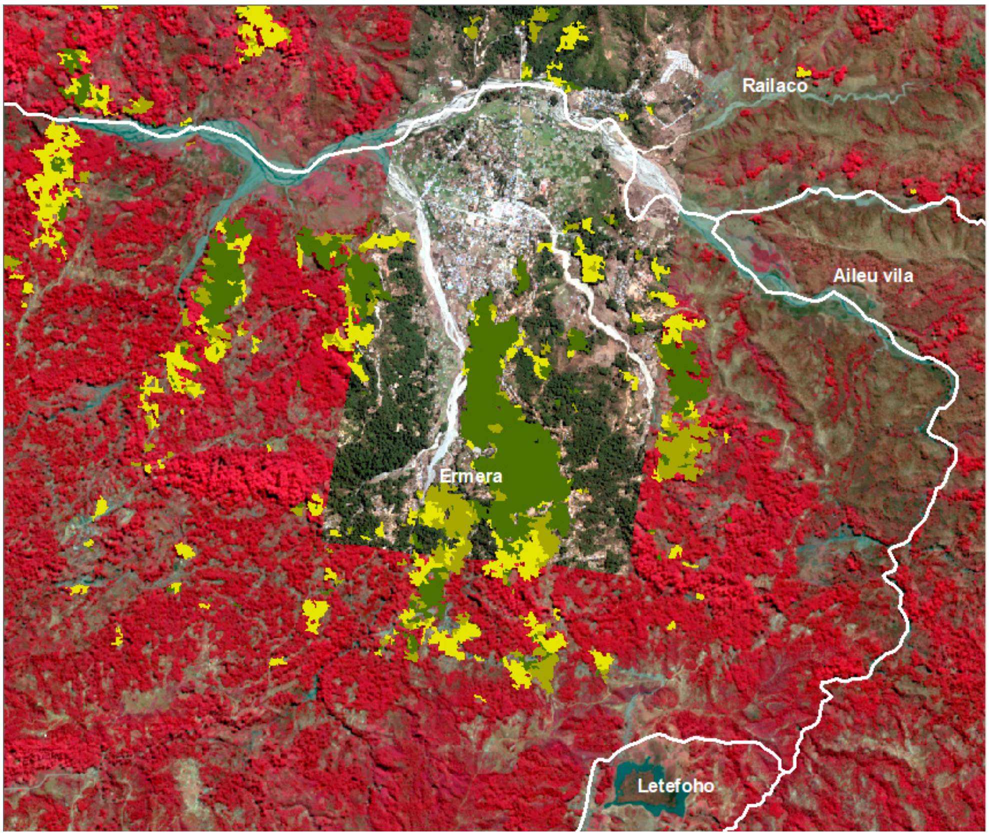


Figure 9: VHR data (Worldview-2, 2018) over a coffee plantation area in Ermera overlapped to the Sentinel-2 data

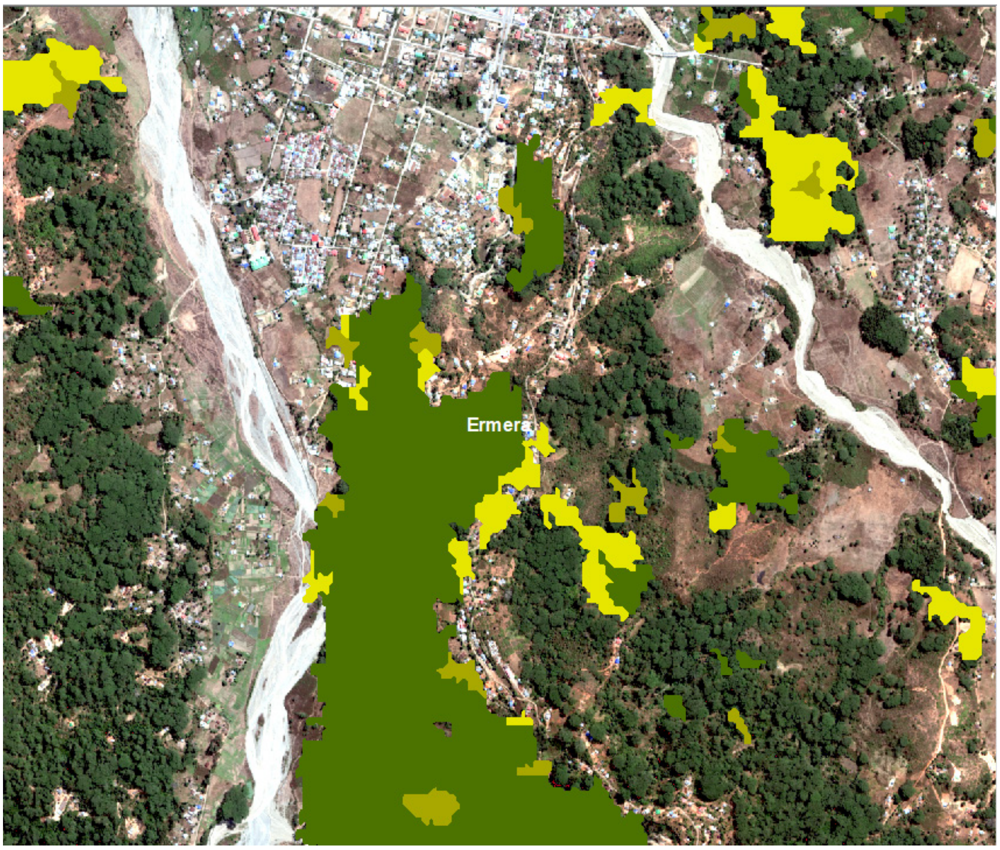


Figure 10: Subset of VHR data (Worldview-2, 2018) in the area surrounding a coffee plantation

3.2.1.3 Land cover change maps (Epoch1-Epoch2-Epoch3)

It was provided the maps of the LC changes mapped along the three epochs. The LC maps produced for the three epochs was combined in order to produce the changes maps. It was followed a map-to-map approach, with a particular focus on the forest classes which are more related to the coffee plantations distribution. Furthermore, change information on the urban expansion are also provided, as they could be also interesting to understand the evolution of the territory.

A preliminary normalization process has been performed on the three land cover maps, (4 ha for the historic maps and 0.1 ha for the 2018-2019 land cover map), because of the different cover scales. It was carried out a final visual check of the resulting changes, in order to exclude false positive changes detected from the automatic maps comparison.

Some statistics calculated for the land cover changes in the three epochs for the forest classes (more related to the coffee crops) and sealed surfaces are in the following charts (see Figure 9; Figure 10; Figure 11).

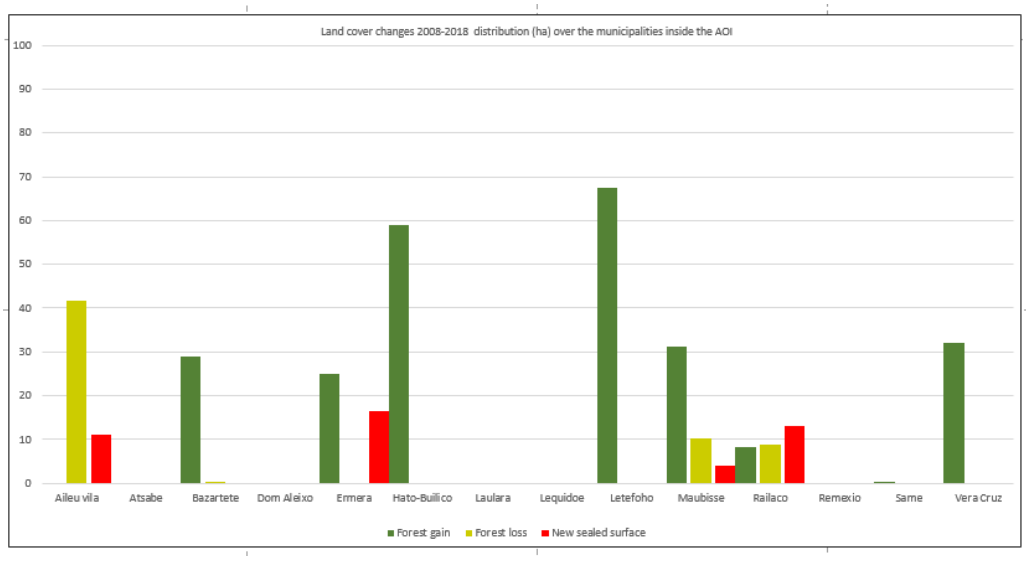


Figure 11: Distribution of the Land cover changes Epoch 2 – Epoch 1 over the sub-districts

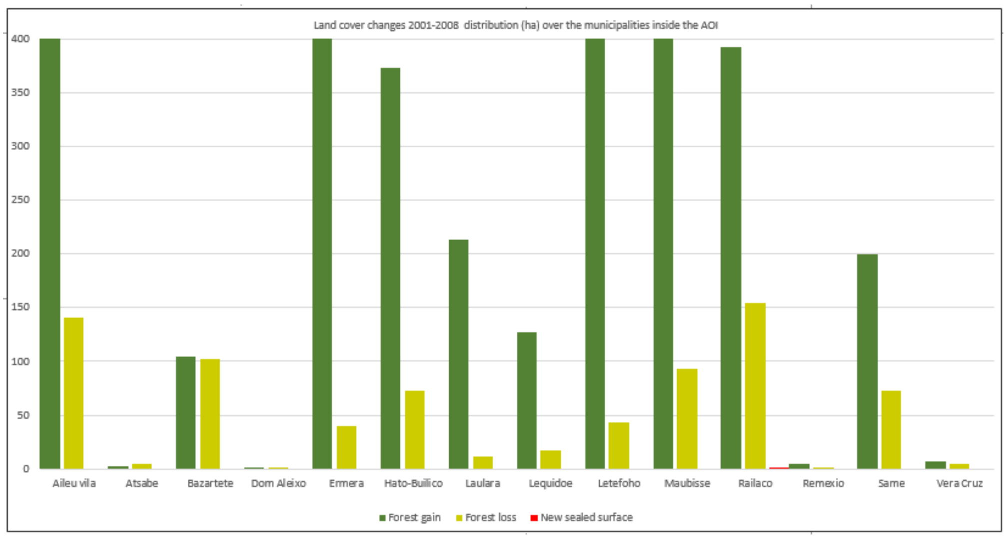


Figure 12: Distribution of the Land cover changes Epoch 3 – Epoch 2 over the sub-districts

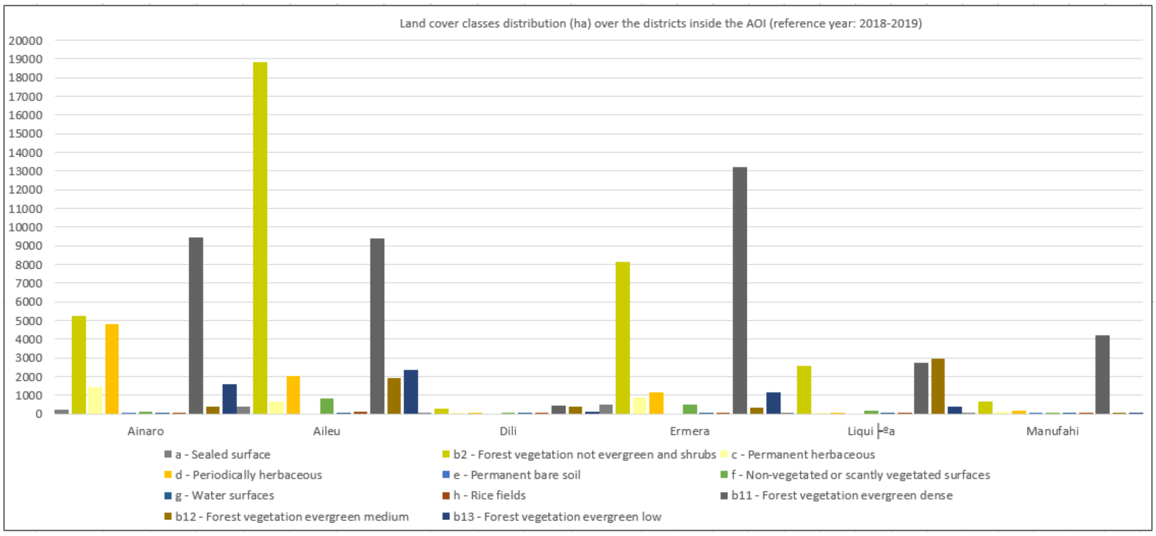


Figure 13: Distribution of the Land cover classes Epoch 1 over the districts

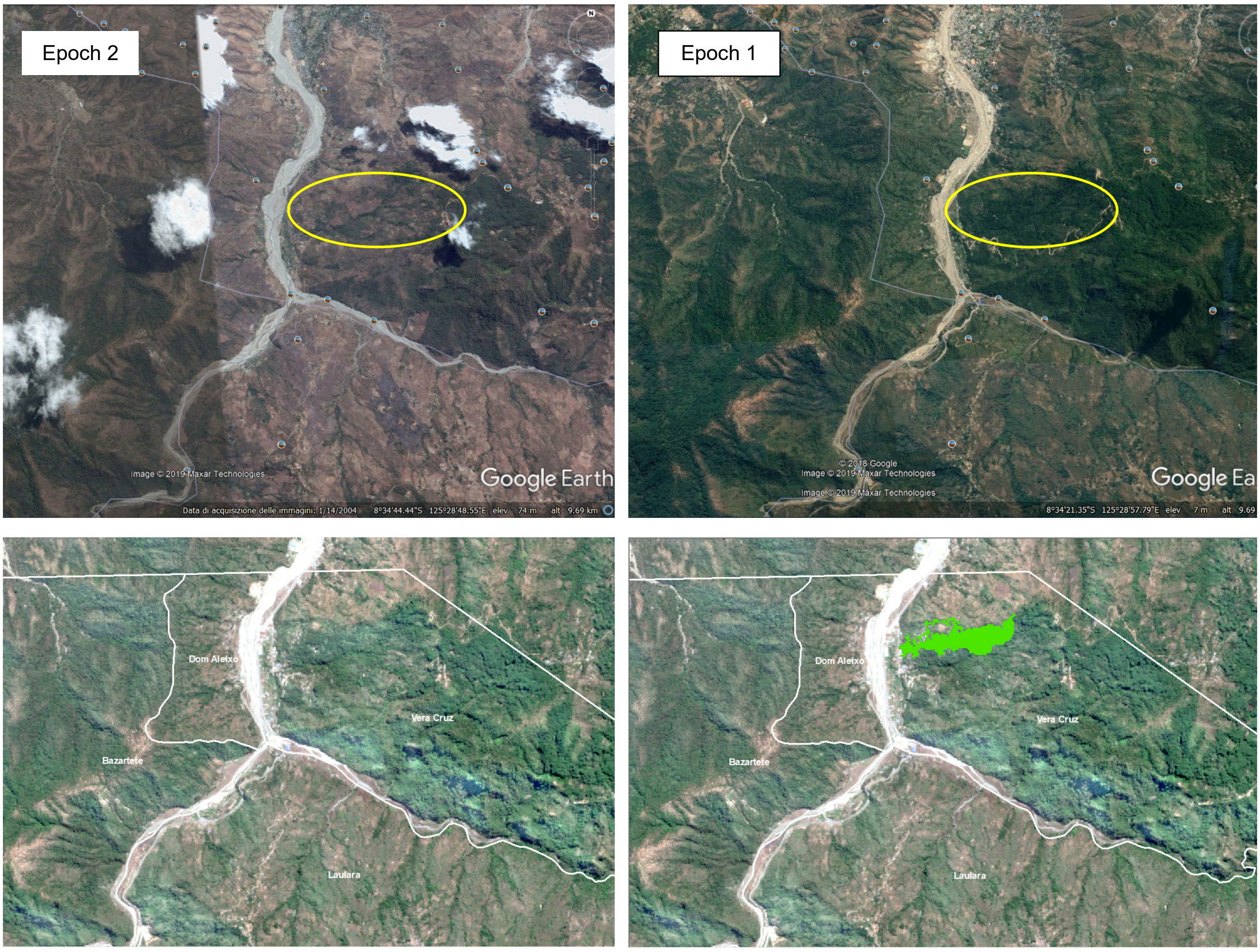


Figure 14: Example of a forest gain from Epoch 2 to Epoch 1 (pictures above are taken from Google Earth in the two epochs, pictures below are taken from Sentinel-2 Epoch 1 image)

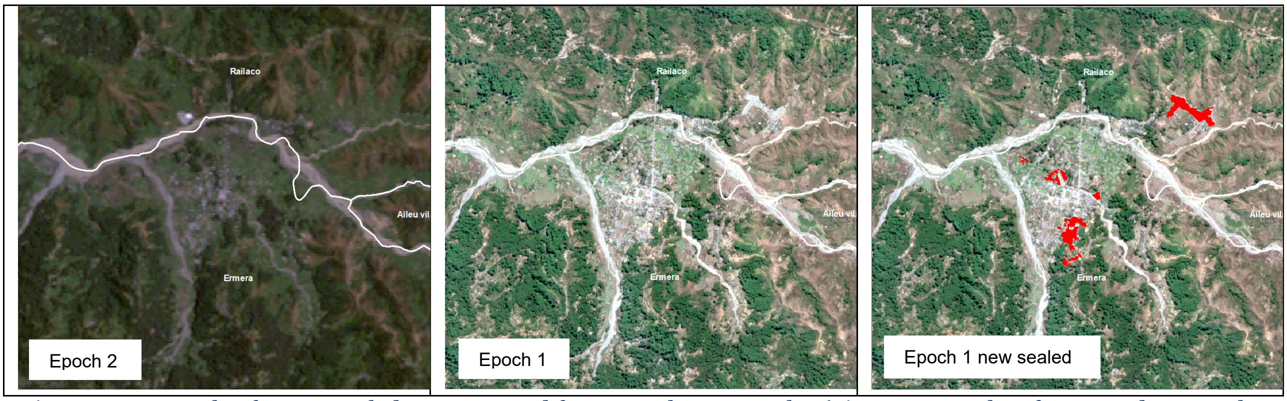


Figure 15: Example of a new sealed area mapped from Epoch 2 to Epoch 1 (pictures are taken from Landsat Epoch 2 image and Sentinel-2 Epoch 1 image)

3.2.2 Methodology

In this paragraph the methodologies implemented in order to classify the land cover Epoch 1 and find coffee plantations using classification algorithms are described. With time series Sentinel data, several artificial intelligence methods can be used to extract information about land use/ land cover. Depending on AI methodologies selected, each pixel, the basic objects used to extract information from data, have to be prepared in a specific way and then, the training with ground truth may happen. In particular, for this kind of problem, in the preliminary phase, only a Light Gradient Boosting Model (***LGBM*** that has a specific random forest architecture) have been tested. In the final phase, on the contrary, a deep learning method called **U-NET** (a specific convolutional architecture) have been integrated with LGBM in order to use probability mask (the u-net output) with classification mask (LGBM output).

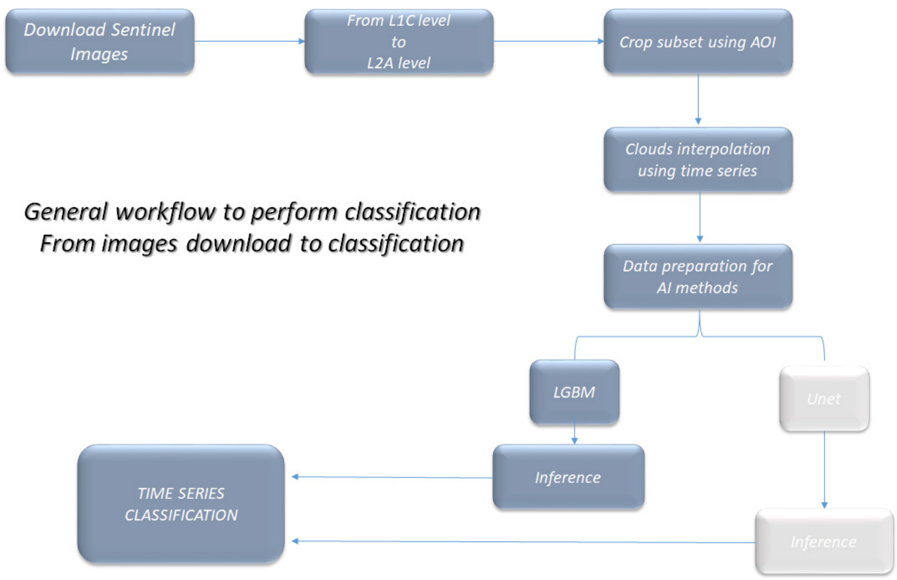


Figure 16: General workflow of first stage

The figure shows the general workflow implemented in the first phase, that is able to automatically perform all steps to reach pixel classification, from data download to final image classification.

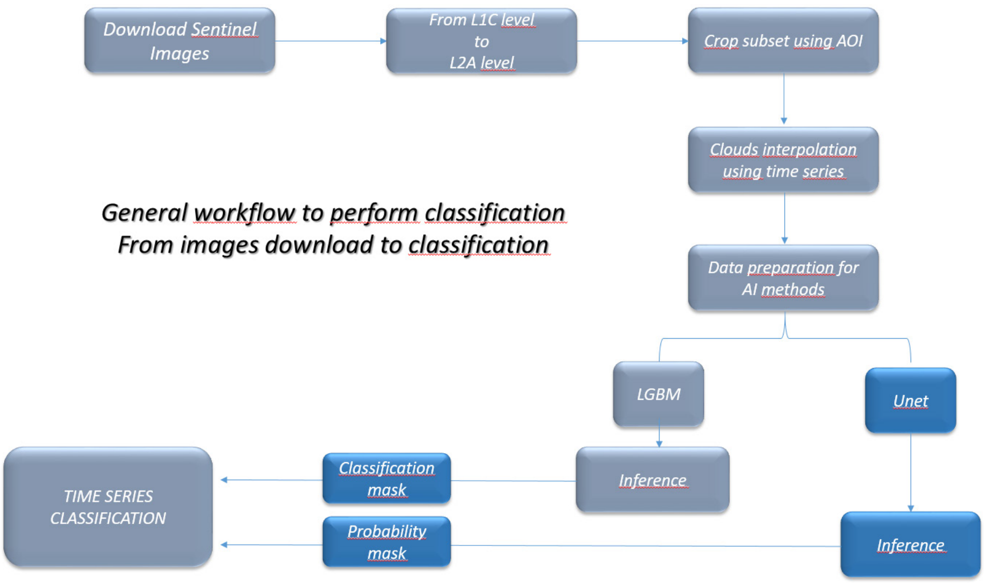


Figure 17: General workflow of final stage

The Figure displays the final workflow where it was used the U-NET output to improve the LGBM result. Furthermore, in the final stage, SAR information, coming from Sentinel1 data, have been added. Typically, there are several problem deriving from the exclusive use of optical images, especially in the tropical zone: there are only just a few optical images without clouds and then the use of SAR images can overcome this drawback because of its independence from weather condition. Moreover, in order to highlight the difference between coffee plantations characteristics with the other classes, the use of SAR information is crucial. In the following paragraphs, it will be described the details about each implemented block steps in the different phases.

3.2.2.1 Input data

Using configuration file, based on needs, it is possible to select a list of parameters to download data. In particular, in the first phase uses the following input:

1. Start and stop date: from 2018-01-01 to 2019-07-25
2. Product type: S2MSI1C;
3. Platform name: Sentinel-2
4. Cloud Coverage: from 0% to 1%.

The script downloaded automatically 15 Sentinel2 images from ***scihub copernicus system*** with following characteristics:

1. Date: 8 images from 2018 and 7 from 2019;
2. Level: Sentinel2 L1C subsequently transformed in L2A level using sen2cor algorithm;
3. Size: ~14Gb.

In the final phase, in order to improve final classification, it has been added SAR information, coming from Sentinel1 images. As mentioned before, SAR images are extremely important to extract the difference between coffee plantation characteristics respect to other land use classes. To reach the best accuracy and to improve classification of the first stage, it has been used two SAR images a month. Each month has therefore four additional information due to the two different orbits considered, each one with two polarization. In particular:

1. Date: 8 images from 2018 and 16 images from 2019;
2. Level: S1A with two different relative orbits on the same area;
3. Size: ~5Gb

3.2.2.2 Input data preparation

The first step of data preparation was the implementation of a script that crop image using information coming from AoI. Moreover, for all cropped images, indices have been calculated and added to the stack.

In the final phase, also SAR information of Sentinel-1 data were integrated to the Sentinel-2 dataset with the realization of a final stack image with the following characteristics:

1. **Size**:4002(rows) x 3174(columns) x *243(bands)*;
2. **Space in memory**: *~7Gb*;
3. **Bands** for each images: B2 Blue-B3 Green-B4 Red-B8 NIR (10m), B5-B6-B7 (Vegetation, 20m), B8A Narrow NIR(20m) and B11 SWIR – B12 SWIR (20m), *2 polarization from SAR*;
4. **Indices**: NDVI, NDII and MSAVI2.
5. Bands with 60m have been used to perform atmospheric correction in the sen2cor algorithm and then they have not been used for the classification

In this way, we have 15 images x (10bands+3indices) from Sentinel2 and 24 images with 2 bands from Sentinel1 that form 243 information for each pixel as shown in the figure.

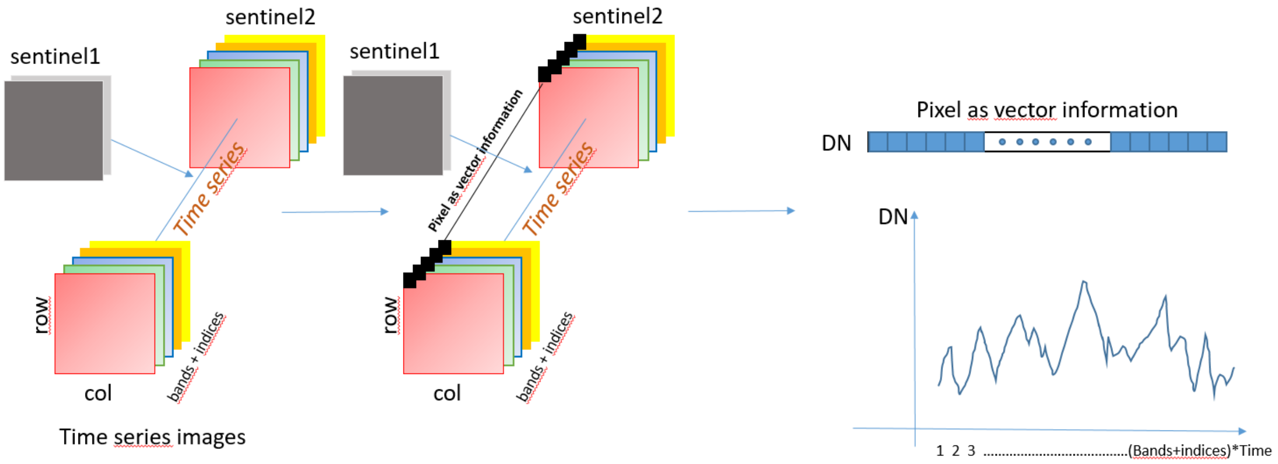


Figure 18: Pixel transformation as vector that contains Sentinel2 and Sentinel1 information

3.2.2.3 Model set-up

As mentioned before, in the first phase, only LGBM, a particular machine learning algorithm based on Random Forest theory, have been used for classification.

As input, the model needs a set of vector pixels each one associated to class coming from ground truth. In the Figure it is explained what input data the LGBM is able to handle. All images, concatenated in order to form one single 3D stack are transformed in a 2D matrix and a random number of 1D-vector pixels are selected with reference class to train algorithm.

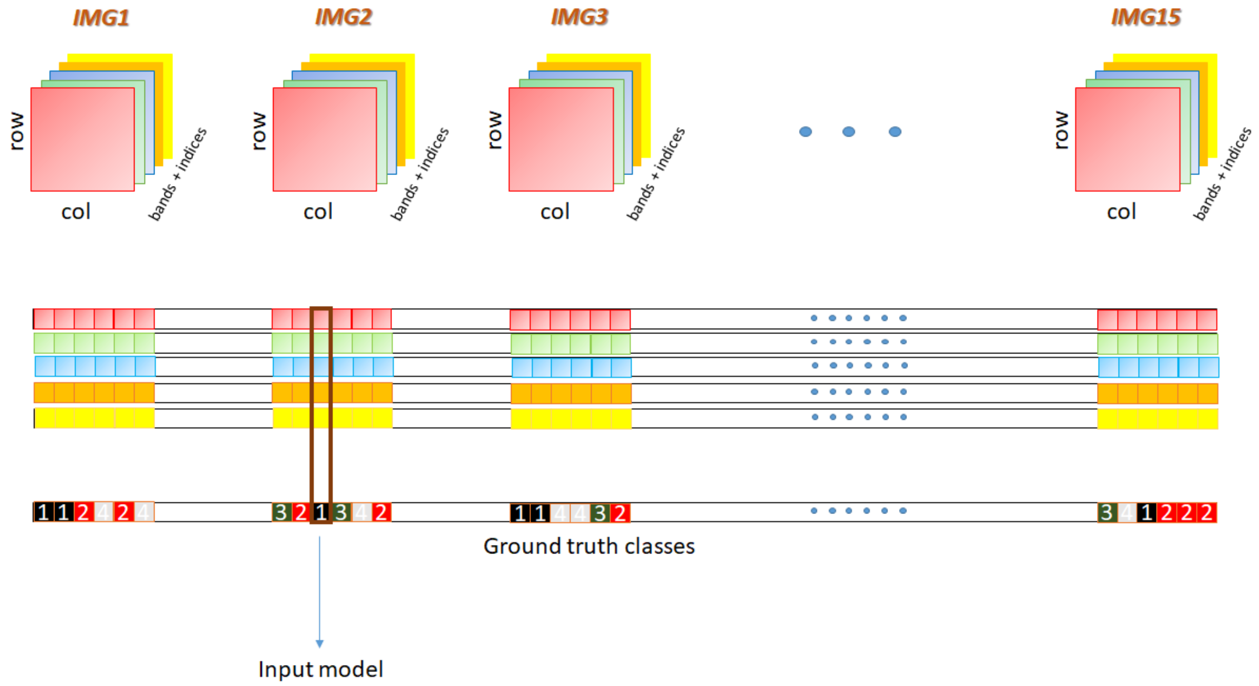


Figure 19: Data preparation to LGBM algorithm

In this case, using only pixels that have ground truth different by 0 (that is the no-data element) ~800Milions of vector pixels, have been used to train algorithm.

In the final phase, it was added U-NET output. Olaf Ronneberger et al. for Bio Medical Image Segmentation developed the U-NET. The architecture contains two paths. First path is the contraction path (also called as the encoder) which is used to capture the context in the image. The encoder is just a traditional stack of convolutional and max pooling layers. The second path is the symmetric expanding path (also called as the decoder) which is used to enable precise localization using transposed convolutions. Thus, it is an end-to-end fully convolutional network (FCN), i.e. it only contains Convolutional layers and does not contain any dense layer because of which it can accept image of any size.

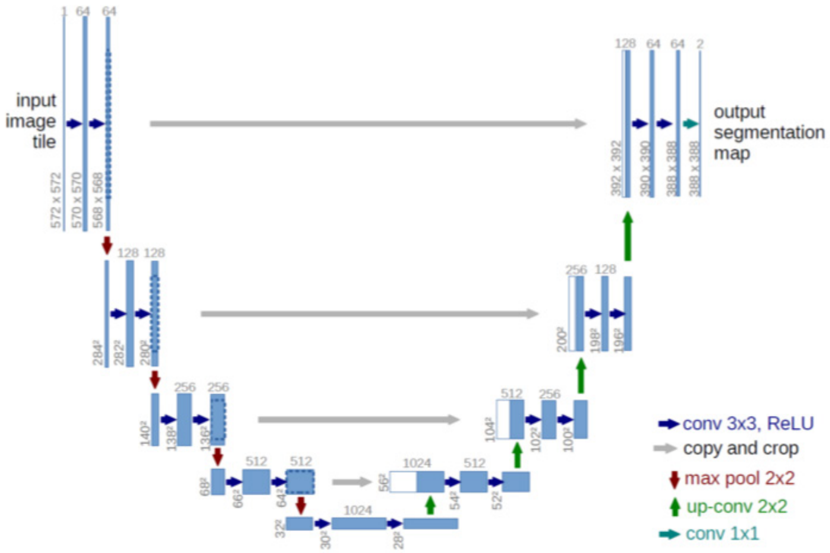


Figure 20: First formulation of U-Net. This architecture can be modified related to specific problem

The architecture can be different related to the problem, A specific architecture was implemented considering computational resources, in order to use spatial, temporal and spectral behaviour. The U-NET architecture typically needs to train a huge amount of parameters. In fact, in our case, we have 7836924 parameters. In order to use the U-NET in the best possible way and reduce computational cost, the initial stack has been divided in 3038 small images with size 64x64x243 (Figure 14) and only images that have enough ground truth have been used.

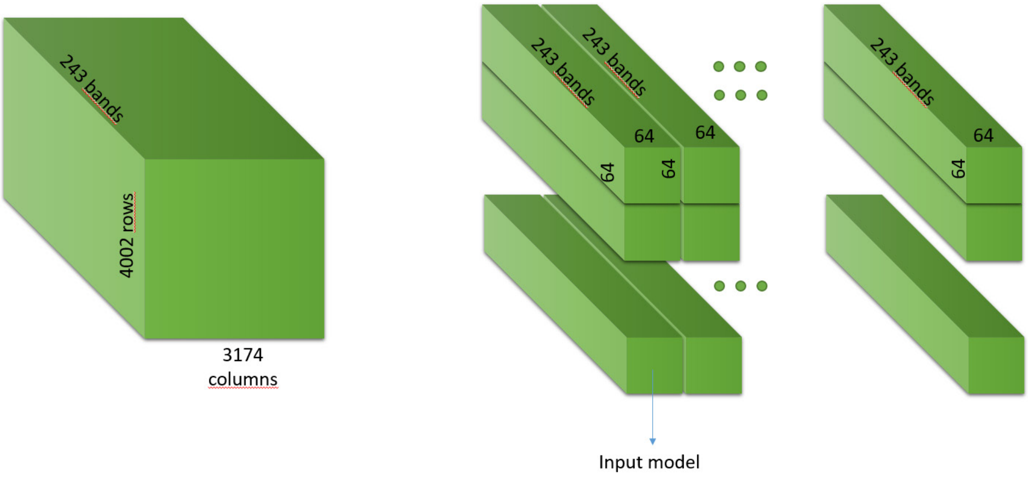


Figure 21: Data preparation to u net algorithm

3.2.2.4 Training

For the Land cover map, it was selected a set of training samples on screen using Sentinel-2 images and Google Earth as main references for a total amount of about 80 sqkm (almost 10% of the whole AoI).

It was also exploited the availability of VHR data over a subset of the area, to better delineate and derive a more precise interpretation of the territory.

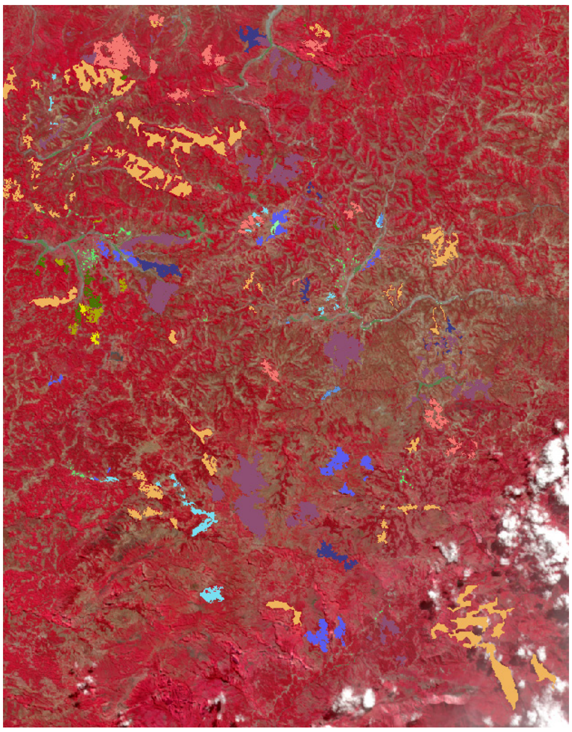


Figure 22: Overview of the land cover training sample distribution

For the coffee plantation map, the sample polygons made available by AdB were applied for the spectral characterization of the fields. As mentioned above it becomes important to increment the availability of ground truth data in order to improve the completeness and the correctness of the mapped plantations.

3.2.2.5 Classification

For the land cover classification, the output of the LGBM model has been generalized from a pixel level to an object level. It was performed a segmentation process and the final class assignment has been carried out for each object with a majority approach. The realization of the coffee plantation map includes also the assignment of a plausibility component associated to each polygon classified as coffee crop.

After the realization of the land cover maps for the three epochs, a map-to-map comparison allows to derive the corresponding land cover change maps Epoch 3 – Epoch 2 and Epoch 2 – Epoch 1.

3.2.2.6 Quality Control and Validation

The product passed through thematic and topological verification checks. From the thematic aspect, visually double-check of the land cover mapping has been carried by experienced image analysts with the aim to identify potential quality issues, and implement corrections of interpretation or geometry inaccuracies.

From the topological verification, the test checked the following items:

- completeness
- no gaps,
- no overlap
- thematic coding/attributes/consistency
- Missing vertices
- Unnecessary boundaries
- Single part polygon
- MMU

3.2.3 Usage, Limitations and Constraints

Not applicable

3.3 WEBGIS publication

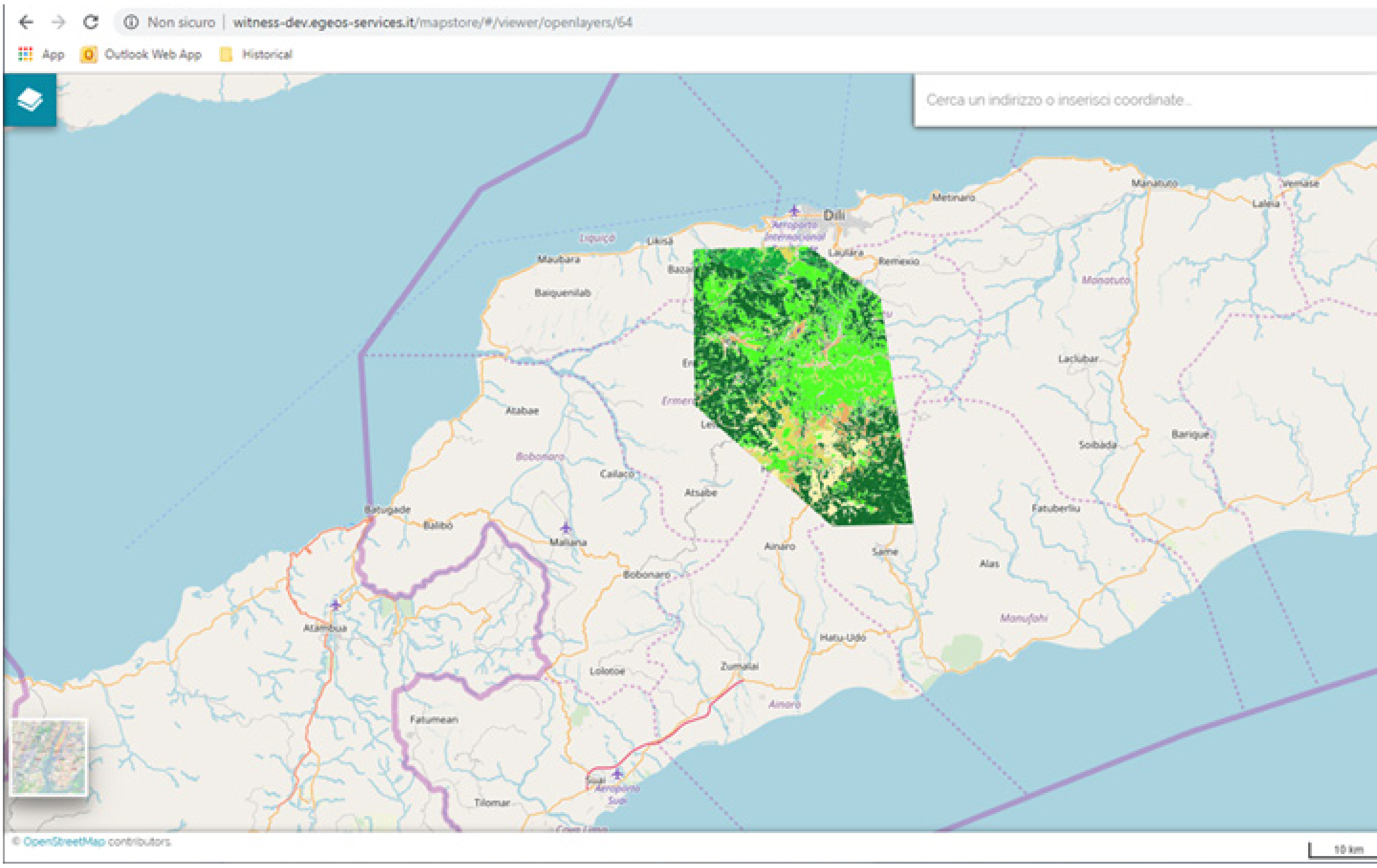
All the outputs of project's activities are loaded on a Web-GIS platform, allowing the user to visualization and consultation of data.

This is the list of the available products loaded in the Web-GIS:

- Coffee Plantations Map V2
- Land Cover epoch 1
- Land Cover Changes epoch 2-1
- Land Cover Changes epoch 3-2

The Web-GIS is available at: http://witness-dev.egeos-services.it/mapstore/#/viewer/openlayers/64

This is the screenshot of the interface:


Non sicuro | witness-dev.egeos-services.it/mapstore/#/viewer/openlayers/64
App
Outlook Web App
Historical
Cerca un indirizzo o inserisci coordinate...
Dili
Metinaro
Manatuto
Laleia
Vemase
Liquiçá
Likisá
Maubara
Baiquenilab
Laulára
Remexio
Manatuto
Laclubar
Atabae
Bobonaro
Cailaco
Atsabe
Soibada
Barique
Batugade
Balibó
Maliana
Ainaro
Same
Fatuberliu
Alas
Bobonaro
Atambua
Hatu-Udo
Manufahi
Zumalai
Lolotoe
Ainaro
Fatumean
Suai
Tilomar
© OpenStreetMap contributors
10 km