

Meeting of the Ecosystem Approach Correspondence Group on Monitoring (CORMON) Coast and Hydrography

Marseilles, 28-29 March 2023

Agenda item 5: The Guiding Factsheet for the Candidate CI 25 "Land cover change"

Manual for IMAP Candidate Common Indicator 25 "Land cover change" calculation

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UNEP/MAP PAP/RAC Split, 2023



UNEP/MED WG.522/4 Manual for IMAP Candidate Common Indicator 25 "Land cover change" calculation

MedProgramme Child Project 2.1

Frane Gilić version 1.0 September 2022





2.1 Mediterranean Coastal Zones Climate Resilience Water Security and Habitat Protection"

PROGRAMME

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ACRONYMS

AOI - area of interest ASL – above sea level CCI25 - IMAP EO8 Candidate Common Indicator 25 "Land cover change" CGLS-LC100 - Copernicus Global Land Services: Land Cover 100 m CRS - coordinate reference system DEM - digital elevation model EO8 - IMAP Ecological Objective 8 "Coastal ecosystems and landscapes" EPSG – European Petroleum Survey Group ETRS89/LAEA - European Terrestrial Reference System 1989 / Lambert Azimuthal Equal Area EU – European Union FABDEM – Forest And Buildings removed Copernicus DEM FOSS - free and open source GDAL - Geospatial Data Abstraction Library GeoJSON - geospatial data interchange format based on JavaScript Object Notation (JSON) GeoTIFF - Geographic Tagged Image File Format GIS - geographic information system GPKG - GeoPackage IBAT – Integrated Biodiversity Assessment Tool IMAP - Integrated Monitoring and Assessment Programme of the Mediterranean Sea and Coast and Related Assessment Criteria IUCN – International Union on Conservation of Nature LC/LU - land cover/land use LEZ - low elevation zone NSA – United States National Security Agency NUTS 3 – Nomenclature of territorial units for statistics, level 3 OSM - OpenStreetMap TIF/TIFF - Tagged Image File Format **UNEP – UN Environment Programme** WDPA – World Database on Protected Areas WGS84 - World Geodetic System 1984

WKT - well-known text



1 INTRODUCTION

This manual provides step-by-step instructions on how to carry out IMAP EO8 Candidate Common Indicator 25 "Land cover change" (CCI25) calculation using free and open source (FOSS) software and data.

IMAP stands for the Integrated Monitoring and Assessment Programme of the Mediterranean Sea and Coast and Related Assessment Criteria that was adopted at the 19th Ordinary Meeting (February 2016) of the Contracting Parties (21 Mediterranean country and the European Union) to the Barcelona Convention (short for "Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean") with the aim to quantitatively and integratively assess the status of the Mediterranean sea and coast [1]. IMAP common indicators are the backbone of the Barcelona Convention which defines them as [2]: "indicator that summarizes data into a simple, standardized, and communicable figure and is ideally applicable in the whole Mediterranean basin, or at least on the level of sub-regions, and is monitored by all Contracting Parties". Currently, there are 24 common indicators and 4 candidate common indicators that are developed. IMAP (candidate) common indicators are linked to one of 11 Ecological Objectives (EO). Candidate common indicators still have some issues that have to be resolved, and one of them is the Candidate Common Indicator 25 "Land cover change" (CCI25), which is linked to the EO8 - Coastal ecosystems and landscapes. The main aim of the EO8, and consequently of the CCl25, is monitoring human activities that are causing "coastal artificialization by sealing the coast with the implementation of coastal structures and therefore impact coastal ecosystems and landscapes" [2].

Main steps in CCI25 calculation which are also chapters of this manual are:

- 1. preparing software (GIS and spreadsheet application)
- 2. acquiring all data that are necessary for CCI25 calculation
- 3. preprocessing acquired data
- 4. calculating indicator parameters and representing calculation outputs



2 REQUIRED SOFTWARE AND BASIC CONCEPTS

Software applications that are required for the CCI25 calculation include applications that are suitable for managing spatial data, and applications that are designed for working with tabular data – spreadsheet applications.

2.1 GIS application

Dealing with spatial data (i.e., data that have a location) requires a specialized application from the geographic information system (GIS) software domain. One of the most widely used free and opensource (FOSS) GIS applications is QGIS [3]. Its extensive documentation, supportive and large user community, and ability to extend its basic features with many FOSS plugins are the reasons for its popularity and why we have decided to use it for CCI25 calculation. QGIS can be downloaded from https://www.qgis.org/en/site/forusers/download.html. It is available for Windows, macOS, and Linux operating systems. In this manual, we have been using QGIS version 3.22 "Białowieża", which is currently the latest long-term release version. Although CCI255 calculation can be done in other QGIS versions, we suggest using this one to avoid problems with differences in user interface and algorithm names.



Figure 1: QGIS logo [2]

2.1.1 Preparing the QGIS interface and defining basic settings

After opening QGIS, we can immediately save a new blank QGIS project by going to Project ► Save As... and defining the name and location where the QGIS project file (file with QGZ extension) will be saved. All algorithms that are available in QGIS cannot be accessed from menus in the top menu bar, but rather through the Processing Toolbox panel (highlighted in Figure 2). The Processing Toolbox panel can be made visible by clicking on the Processing ► Toolbox (Figure 2). If the

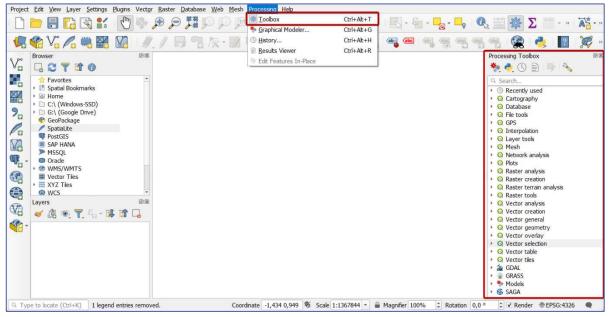


Figure 2: QGIS graphical user interface (Processing Toolbox panel is highlighted)



Processing menu is not available in the QGIS menu bar, the Processing plugin needs to be activated: open the Plugins dialog window by going to Plugins \blacktriangleright Manage and install plugins..., click on the Installed tab on the left side of the window, and check the box next to the Processing item (Figure 3). Also check if the box is ticked next to the GRASS GIS provider plugin and, if it is not, tick it.

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Figure 3: Activating Processing plugin

To activate (or deactivate) a QGIS toolbar or a panel, you should go to View ► Toolbars or View ► Panels and then tick (or untick) ones that are required (or not required). To install, uninstall, activate, or deactivate plugins, go to Plugins ► Manage and install plugins... The plugin that should be installed is the "QuickMapServices" plugin. To install it, while in the All tab of the Plugins dialog window, enter "QuickMapService" in the search bar on top, select the QuickMapServices plugin from the list and click the Install Plugin button (Figure 4). Repeat the same procedure for the "Shape Tools" plugin. The Shape Tools plugin enables conducting calculations on the surface of the ellipsoid and is developed by the United States National Security Agency (NSA).

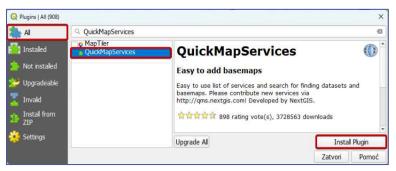


Figure 4: Installing the "QuickMapServices" plugin

QuickMapService plugin enables loading many basemaps in the current QGIS project. After installing it, it is possible to load new basemaps by going to Web ► QuickMapServices and choosing one of the basemaps that are grouped by its producers. Figure 5 shows how to add OpenStreetMap (OSM) Standard map to the QGIS project (highlighted with red rectangles). It is possible to load multiple basemaps in the QGIS project. After clicking on one of the basemaps, that basemap is being loaded into the QGIS project and listed in the Layers panel (Figure 6). Only some basemaps are listed under Web ► QuickMapServices, and to search all available basemaps, click on Web ► QuickMapServices



► Search QMS, and in the new Search QMS panel that opens, search by entering keywords in the search bar (Figure 5, blue rectangles), or by filtering basemaps based on availability in the currently zoomed-in location (click on the Filter by extent button). When using basemaps from the QuickMapServices plugin, always carefully check the terms of use, and make sure to appropriately attribute the source of a particular basemap.

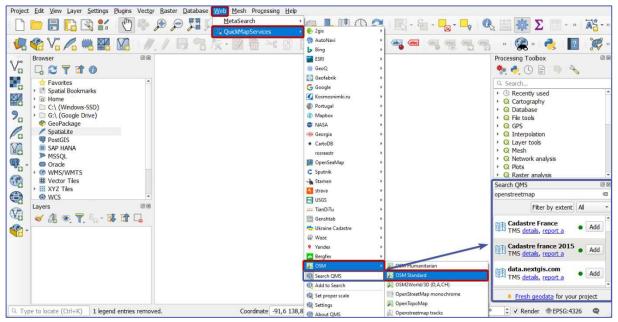


Figure 5: Adding OpenStreetMap (OSM) Standard basemap with the QuickMapServices plugin

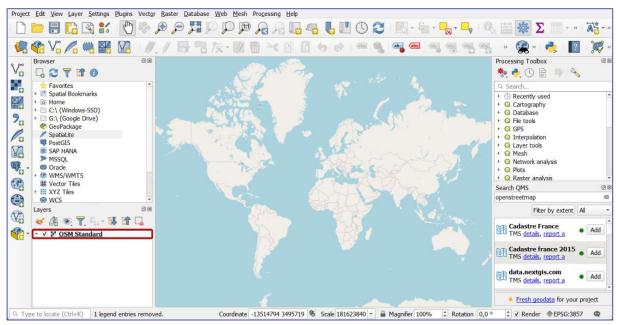


Figure 6: OpenStreetMap standard basemap loaded in QGIS project and listed in the Layers panel (© OpenStreetMap contributors)

Since we will be using only the basic algorithms that are already well established, there should not be any problems with different versions of corresponding libraries. If you want to be completely sure that all versions in your QGIS installation are in line with the versions used for this manual, you can go to Help ► About and compare versions: QGIS version: 3.22.10; GDAL/OGR version: 3.5.1; PROJ version: 9.0.1; EPSG Registry database version: v10.064 (2022-05-19); GEOS version: 3.10.3-



CAPI-1.16.1; SQLite version: 3.38.1; SpatiaLite version: 5.0.1; grassprovider version: 2.12.99; and processing version: 2.12.99.

2.1.2 Calculating area in (Q)GIS

The most important results of CCI25 calculations carried out in GIS applications are areas of different land cover/land use (LC/LU) classes. Area calculations in GIS present a special problem posed by the complexity that is caused by the curvature of the Earth's surface. Curved Earth's surface cannot be transformed on a flat surface of a map or a screen on some device without deformation. This has to be kept in mind during area calculations in GIS. Firstly, points from the Earth's surface, which is complex and ever-changing, are being projected on the surface of ellipsoid or spheroid, fairly simple mathematically defined surfaces. At this point, the location of each point is defined in ellipsoidal or spherical coordinates (latitude and longitude). This type of coordinate reference system (CRS) is in QGIS called a "geographic coordinate system". Secondly, the coordinates of these points are being projected from the ellipsoid or sphere to coordinates on the flat surface by a set of formulas that are defined by the so-called cartographic projection. A flat surface in this sense is called a cartographic projection plane, and in QGIS these coordinate systems are referred to as "projected coordinate systems". This second step, which produces the so-called projected coordinates, is not required, and very often positions in GIS datasets are given in ellipsoidal or spherical coordinates. If location is nevertheless given in projected coordinates, and area needs to be calculated based on those coordinates, it should be ensured that cartographic projection preserves the ratio of the area between points on the ellipsoid and corresponding points in the cartographic projection plane. A special group of that kind of projections is called equal-area projections. Finally, in QGIS and some other GIS applications, there are two approaches when calculating area:

- 1. ensure that all data is being referenced in the projected coordinate system based on equalarea projection, and then make area calculations using projected coordinates
- 2. make all area calculations on the surface of the ellipsoid or spheroid, using ellipsoidal or spherical coordinates

We suggest the second approach since it simplifies and increases the accuracy of area calculation by avoiding the complexity of choosing the right cartographic projection and problems that arise from raster data reprojection. We acknowledge that both of these approaches have a drawback: areas that are being calculated are not areas on the Earth's surface. Ellipsoid or spheroid cannot perfectly fit Earth's surface, and this misalignment inevitably produces differences between the area on the Earth's surface and the corresponding projected area on the ellipsoid or spheroid. The larger the height difference between the Earth's surface and the ellipsoid or spheroid, the larger the area difference. All data in the same region will be similarly affected by this error, so the final percentages that have to be calculated will not be significantly degraded. Currently, in QGIS (and other GIS applications) there is no better straightforward solution.

To be sure that area calculations will be carried out on the surface of the ellipsoid or spheroid, rather than cartographic projection plane by using projected coordinates, go to Project ► Properties... and then in the General tab define suitable ellipsoid in Ellipsoid (for distance and area calculations) dropdown (Figure 7, as explained in [4]). We suggest using WGS84 (EPSG:7030) since the data we will be using are referenced using that ellipsoid. Also, make sure that Units for distance measurement and Units for area measurement are set to the desired unit.

2.1.3 Choosing a coordinate reference system (CRS)

As already discussed in the previous section, choosing the right coordinate reference system (CRS) has to be done carefully. Since settings for area calculations should have already been applied in



۹	▼ General Settings		
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Figure 7: Setting the suitable ellipsoid for distance and area calculations in QGIS

QGIS project properties (section 2.1.2), here we will focus on choosing CRS that is suitable for data visualization. For visualization purposes, it is common to choose a CRS from a group of projected coordinate systems in QGIS. CRS can be defined on a QGIS project-level by going to Project ► Properties..., and then choosing desired CRS in the CRS tab. In Figure 8, ETRS89/LAEA Europe CRS is chosen for project-level CRS (EPSG code is 3035 [5], written as "EPSG:3035"), which is a good choice when the whole of Europe has to be visualized. In Figure 8, EPSG:3035 CRS is filtered from the list of all available CRSs by entering "3035" in the Filter field. Now all data that will be imported in QGIS will be "on-the-fly" reprojected to this CRS, even if they are originally georeferenced/stored in different CRSs. It is important to understand that by changing project-level CRS, data are only temporary, for visualization purposes being "on-the-fly" reprojected to defined CRS, and after closing QGIS, all data remain stored in their original CRSs. For deciding which CRS is the most suitable for a particular area, we suggest consulting Esri's Quick Notes on Map Projections in ArcGIS [6], the United States Geological Survey (USGS) map projections poster [7], or using the web app for interactive choosing the most suitable projection which is available at https://projectionwizard.org (Figure 9).

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🖾 View Settings	Recently Used Coordinate Reference Systems	
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Data Sources	Predefined Coordinate Reference Systems	Hide deprecated CRSs
Relations	Coordinate Reference System * III Projected Coordinate Systems * Lambert Azimuthal Equal Area	Authority ID
Variables	ETRS89-extended / LAEA Europe Transverse Mercator NAD 1092 2011 StatePlace Ulinoir East EUS 1201	EP5G:3035
QGIS Server	ETRS89-extended / LAEA Europe Properties • Units: meters • Static (relies on a datum which is plate-fixed)	
		OK Cancel Apply Help

Figure 8: Defining project-level CRS in QGIS project properties



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© 2020 <u>Bolan Savric</u> Maps created with <u>Leaflet</u> and <u>D3</u> . Tiles: © Esri.	STATES I	PARAMETER["Standard_Parallel_1",32.4327339], PARAMETER["Standard_Parallel_1",32.4327339], PARAMETER["Standard_Parallel_2",44.0227511.	37" 30' 35" N 10" 38 05" E A
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entral meridian: 15º 22' 51" E			- Shart
		Lam	bert conformal conic

Figure 9: Defining properties of projected coordinate system at https://projectionwizard.org

After defining project-level CRS, in the bottom right corner, in the status bar in QGIS, the EPSG code of the chosen CRS is shown (visible in Figure 14).

When changing CRSs, sometimes there are multiple ways of transforming coordinates between them. In those cases, QGIS asks a user to choose one of the applicable transformations (Figure 10). Mostly, as in this case, QGIS already chooses the best available transformation, and it is only needed to click on the OK button.

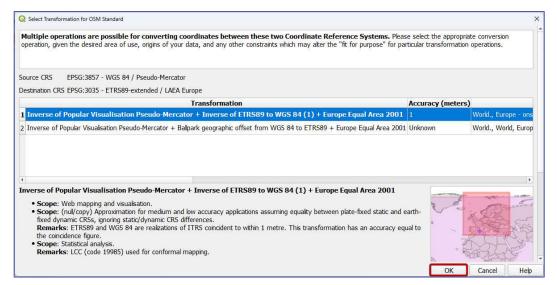


Figure 10: Choosing the most suitable/accurate transformation between CRSs

In case you want to use the projected coordinate system defined at https://projectionwizard.org that is not one of the predefined CRSs with EPSG code, click on the WKT (well-known text) link (highlighted in Figure 9) and copy text from the pop-up. In QGIS, go to Settings Custom Projection... and in a new dialog window (Figure 11) click on the whttps://custom Projection... and in a new dialog window (Figure 11) click on the whttps://custom Projection... and in a new dialog window (Figure 11) click on the whttps://custom Projection... and in a new dialog window (Figure 11) click on the whttps://custom Projection... and in a new dialog window (Figure 11) click on the whttps://custom Projection... and in a new dialog window (Figure 11) click on the whttps://custom Projection... and in a new dialog window (Figure 11) click on the whttps://custom Projection... and in a new dialog window (Figure 11) click on the whttps://custom Projection... and in a new dialog window (Figure 11), under https://custom.org in Figure 11, under whttps://custom.org in Figure 11, under whittps://custom.org in Figure 11, and click the OK button. This new CRS will now be shown on the list of all available CRS in QGIS. It will be listed under the User Defined Coordinate Systems group, and it can be f



	ine your own custom Coordinate Reference System (CRS) efinition must conform to a WKT or Proj string format for CRS.
Name	Parameters 🚽
,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,	PROJCS["ProjWz_Custom_Lambert_Conformal
Name	WGS84 / Mediterranean conformal
Name Format	WG584 / Mediterranean conformal WKT (Recommended) ~

Figure 11: Defining custom CRS

2.1.4 Common data formats used in GIS applications

The most commonly used data formats in GIS applications can be divided into raster and vector formats. Data that are stored in raster and vector data formats are regularly referred to as raster and vector data, or, when imported in GIS application, raster and vector layers. Some raster and vector data formats store data from a single layer in only one file, and some in multiple files.

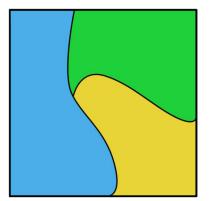
Simply said, raster data are in form of matrix or a raster, each matrix element has a value and is called a pixel. Each pixel, which is regularly a rectangle, has an indirectly assigned location (i.e., coordinates in some CRS) through coordinates that are assigned to pixels in the corners of the matrix and dimensions of each pixel, which are constant in the whole raster. Raster data are in GIS applications commonly used to represent some spatial property that has a value in every point in space, for example, height above sea level, temperature, etc., but they can also be used to represent some discrete objects in space, such as roads, buildings and so on. Raster data format that will be mostly used throughout this manual is TIF (or TIFF), or more precisely, its extension, GeoTIFF (TIF/TIFF file with embedded information that assign location to the raster and then indirectly to every pixel).

Plainly speaking, in vector data formats, spatial features/objects are stored as points that are defined by their coordinates in some CRS, lines that are defined by points, and polygons that are defined by lines. Ultimately, vector data are based on coordinates of points and accompanying data that define which points are just points, and which are forming lines or polygons. Some data formats allow storing only one type (point, line, or polygon) at a time. Different types of information can be stored along with each feature (each point, line, or polygon) and are called attribute values. Attribute values are stored in the so-called attribute table in which each row corresponds to one feature (point, line or polygon), and each column/filed to one attribute. Vector formats are comonly used to represent discrete features, but are also sometimes used to represent spatialy continuous features (for example, land cover). Vector data formats that will be used in this manual are Esri shapefile format, GeoPackage (GPKG), and GeoJSON. Esri shapefile format for a single vector layer consists of at least three files with extensions SHP, SHX, and DBF, while GeoPackage and GeoJSON formats store all information from one layer in a single file. Visual difference between vector layer



with polygonal features and raster layer that both represent land cover over same area are visible in Figure 12.

One important fact that should always be kept in mind while working with QGIS is that in QGZ project file no raster or vector data are stored. QGZ project file stores only, among some other things, locations of raster and vector data storage location. By default settings, always be sure to keep relative location between the QGZ project file and corresponding files of imported raster and vector layers unchanged.



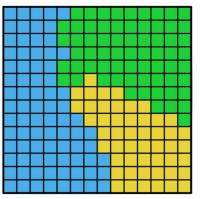


Figure 12: Visual difference between polygonal vector (left) and raster (right) data representing land cover over same area

2.2 Spreadsheet application

Results of spatial analysis conducted in QGIS need to be exported in tabular form and then further analyzed in a spreadsheet application. Any spreadsheet application is suitable for making basic calculations, like proprietary Microsoft Excel [8], free and open-source LibreOffice Calc [9], or even web-based applications like Google Sheets [10]. It is possible that some of these applications will not support some of the more advanced analyses or graphical representations of calculated data.



3 ACQUIRING AND PREPARING DATA

This chapter focuses on acquiring and importing all relevant data in QGIS and then preparing them for conducting spatial analysis. In the following sections, file names that are being used in QGIS will be typed in *italic* style if they can be treated as temporary files, and in *italic bold* style if it is advisable to store them permanently. Of course, mentioned file names are just suggestions, and you can use any file names you like.

Main preparation steps include:

- 1. defining the area of interest (AOI)
- 2. downloading required data
- 3. creating coastal strips and reporting units
- 4. preparing LC/LU and elevation data and data on protected areas for CCI25 calculation

3.1 Defining the area of interest (AOI)

Area of interest (AOI) should be defined as a polygon vector layer with one polygon. To create a new GeoPackage [11] vector layer:

- 1. go to Layer ► Create Layer ► New GeoPackage Layer... (Figure 13)
- 2. by clicking on the three-dots-button (1) in Figure 13), define the name (you can use *aoi.gpkg*) and path on the disc where the new GeoPackage (GPKG) file will be stored
- 3. in the Geometry type dropdown select Polygon (2) in Figure 13)
- 4. select the desired CRS (we suggest selecting WGS84 (EPSG:4326) 3 in Figure 13; if desired CRS is not listed, then by clicking on the button marked with 4 in Figure 13, select desired CRS from the list of all available CRSs in QGIS)
- 5. finally, click on the OK button (**5** in Figure 13)

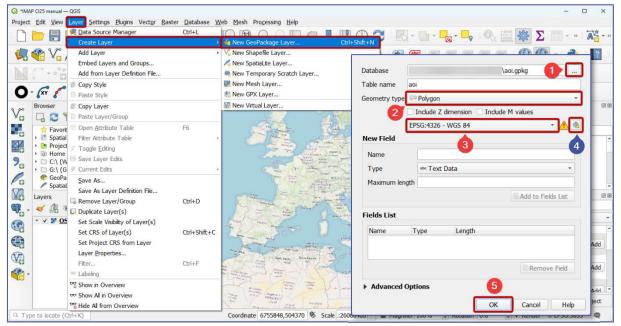


Figure 13: Creating a new GeoPackage vector layer (basemap: ©OpenStreetMap contributors)



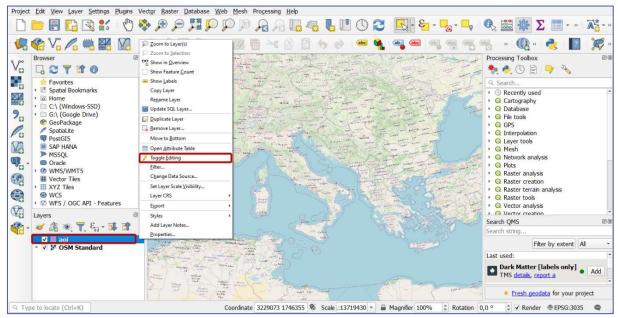


Figure 14: After clicking on the Toggle Editing, new features can be added, or existing features can be modified or deleted from a vector layer (basemap: ©OpenStreetMap contributors)

The newly created GeoPackage layer will automatically be loaded into the QGIS and listed in the Layers panel (Figure 14). To add a new polygon in a GPKG vector layer, follow these steps:

- 1. toggle (i.e., enable) editing of GPKG layer (*aoi.gpkg*) by right-clicking on the layer name in the Layers panel, and then clicking on Toggle Editing (Figure 14)
- if you did not already, add one of the basemaps using the QuickMapServices plugin (it can be OpenStreetMap: Web ► QuickMapServices ► OSM ► Standard, as shown in Figure 5), and zoom (by scrolling the mouse wheel) and pan (by moving the mouse while mouse wheel is pressed) map to the AOI
- 3. while the AOI layer is selected in the Layers panel, go to Edit ► Add Polygon Feature or click on the R icon marked with 1 in Figure 15 (it is a part of the Digitizing toolbar)

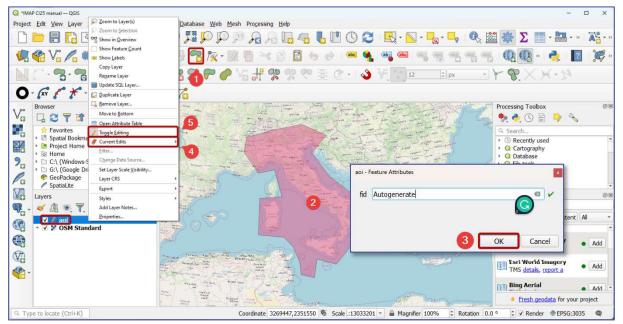


Figure 15: Creating a new polygon in a vector layer (basemap: ©OpenStreetMap contributors)



- 4. on the map, with left mouse clicks, encircle a polygonal AOI that contains an area for which CCI25 has to be calculated (points that define polygonal AOI do not need to be densely spaced and it is a good practice to encircle a little bit wider area to be sure that you have included the whole AOI, example for Italy is shown on Figure 15, marked with (2)
- 5. finish polygonal AOI definition by right mouse click (right mouse click will not add a new point)
- 6. click the OK button in a new dialog window (③ in Figure 15)
- save changes in the AOI vector layer by right-clicking on its name in the Layers panel, then clicking on the Save Layer Edits (3 in Figure 15), and then again on Toggle Editing (4 in Figure 15) to lock the layer from further edits

This AOI polygon in *aoi.gpkg* file will be used to clip input layers with the main purpose to speed up the processing by limiting calculations to its extent.

Metadata and settings for each layer in QGIS can be accessed by right clicking on the layer name in the Layers panel, and then clicking on Properties... (visible in Figure 14), or, by default settings, by double-click on the layer name in the Layers panel. If you double-click on the **aoi.gpkg** layer in the Layers panel, the Layer Properties window that is shown on Figure 16 will open. Layer Properties window that is shown in Figure 16 list options for vector layer, which are On the left side of the window, there are different tabs. In the Information tab, you can read data format that is used for storing data, path on the computer storage where data is stored, CRS that is used to georeference data and some other metadata. In the Source tab, you can again see CRS information, you can build spatial index (it is always advisable to build spatial index if it is not already, by clicking on the Create Spatial Index button), and define query that will be used to filter features in vector layer based on their attributes values. In the Symbology tab, you can define different options for visualization of data stored in each layer. In the Labels tab, you can define setting for showing attribute values in the QGIS map view, and in the Fields tab you can edit, add, or delete fields/attributes from the attribute table.

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🕖 Information	▲ Fill	· · · · · · · · · · · · · · · · · · ·
💸 Source	Simple Fill	
😻 Symbology		
abe Labels		
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脊 3D View	OpacityO	50.0 % 🚳 🗘 🖶
Diagrams	Unit Millimeters	•
Fields	Q All Symbols	a - K
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Auxiliary Storage	gradie Colorful gradie Colorful	
Actions		Save Symbol Advanced *
P Display	 Layer Rendering 	
🎸 Rendering	_ Style -	OK Cancel Apply Help

Figure 16: The Layer Properties window with the Symbology tab opened

To open an attribute table for a vector layer, right click on the layer name in the Layers panel and click on the Open Attribute Table (visible in Figure 14). If you open attribute table for the *aoi.gpkg* layer, a new window, which is visible in Figure 17, will open. Since *aoi.gpkg* layer has only one polygon feature, attribute table has only one row.



aoi — Features Total: 1, Filtered: 1, Selected: 0	<u></u> -	×
' 12 G 2 6 6 × 8 6 4 5 5 5 7 1 8 7 1 8 1 1 1 1 8		
fid		
1		
Show All Features 🖕		3

Figure 17: Attribute table for a vector layer

3.2 Downloading required data

Data that have to be downloaded for CCI25 calculation are:

- 1. Land cover/land use (LC/LU) data
- 2. Elevation data
- 3. Coastline data
- 4. Administrative units data
- 5. Data on protected areas

3.2.1 Land cover/land use (LC/LU) data

As stated in [12], Copernicus Global Land Services: Land Cover 100 m (CGLS-LC100) is proposed as a source for LC/LU data. CGLS-LC100 rasters can be downloaded from https://lcviewer.vito.be by following these steps:

- 1. click on the "Download" link in the top menu bar (Figure 18)
- 2. on a new map that opens (Figure 19), on which are shown 20°×20° CGLS-LC100 tiles that can be downloaded, click on one tile that fully or partly overlaps with the AOI
- 3. in a new window that pops up (Figure 20), and click on desired year to initiate downloading; only a discrete classification layer has to be downloaded, so all options can be left unchanged, as shown in Figure 20



Figure 18: Download link in the top menu bar of the CGLS-LC100 viewer



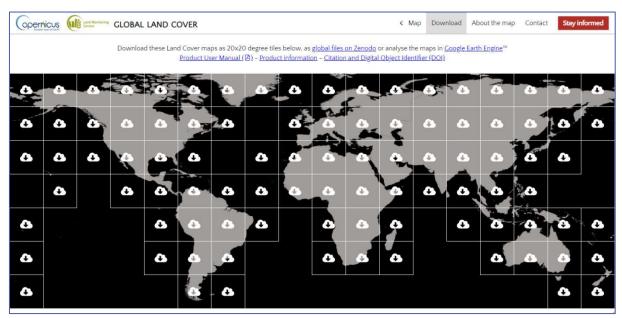


Figure 19: CGLS-LC100 tiles (20°×20°)

Sel	ect the layer to download:	×
Land Cover Classification		
Discrete classification	O Classification probability	
Cover Fractions		
O Bare & sparse vegetation	O Built-up	O Cropland
O Forest	O Herbaceous vegetation	O Moss & lichen
O Seasonal inland water	O Shrubland	O Snow & ice
O Permanent inland water		
Land Cover Changes		
O Change Confidence		
Others		
O Forest types	O Input data density	
Click	on the year to start the downl	oad:
2015 2016 2017	2018 2019	Copy all URLs
	Cancel	

Figure 20: CGLS-LC100 download options

Of course, if AOI intersects with more than one tile, every tile has to be downloaded separately. Also, make sure to download tiles for both years that are chosen for CCI25 calculation.

CGLS-LC100 tiles are $20^{\circ} \times 20^{\circ}$ GeoTIFF raster tiles with a spatial resolution (i.e. pixel dimension on ellipsoid that is used to approximate the Earth's surface) of $1^{\circ}/1008$ [13]. This resolution corresponds to approximately 110 m in the north-south direction, and in the east-west direction, it goes from approximately 110 m at the equator to 0 m at the poles. CGLS-LC100 raster tiles are georeferenced in the geographic coordinate system WGS84 (EPSG:4326). CGLS-LC100 terms of use are defined in the CGLS-LC100 Product User Manual [13].

3.2.2 Elevation data

FABDEM (Forest and Buildings removed Copernicus DEM) elevation data for non-commercial usage (CC BY-NC-SA 4.0 license) can be downloaded from https://data.bris.ac.uk/data/dataset/25wfy0f9ukoge2gs7a5mqpq2j7 (Figure 21) by clicking on one of the ZIP archives containing raster elevation data.



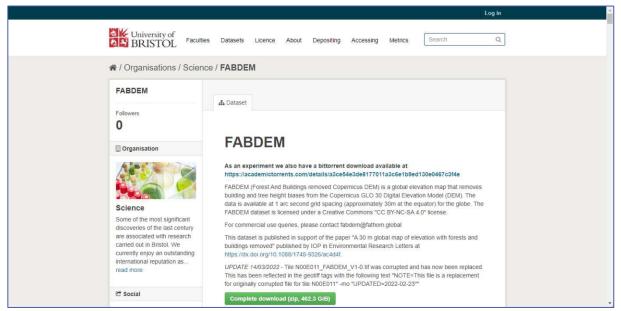


Figure 21: Screenshot of the website from which it is possible to download FABDEM raster data

Selecting the correct ZIP file for downloading might be problematic since there is no map where the coverage of each ZIP file is visible. The coverage of each ZIP file has to be read from the ZIP archive name. For example, if the ZIP archive name starts with "N40E060-N50E070", it corresponds to the tile that covers an area from 40° to 50° north latitude and from 60° to 70° east longitude. Using a map with a 10-degree graticule grid available at https://maps.princeton.edu/catalog/stanford-fr122tq8910 might help determine which tile(s) overlaps with the AOI. Each ZIP archive contains multiple (up to 100) raster tiles that cover $10^{\circ} \times 10^{\circ}$ of the Earth's surface. Each raster tile covers $1^{\circ} \times 1^{\circ}$ and can be visualized by going to https://panda.copernicus.eu/web/cds-catalogue/panda and following steps 1-2-3 from Figure 22. Make sure to download all ZIP files that contain elevation data that intersect the AOI.

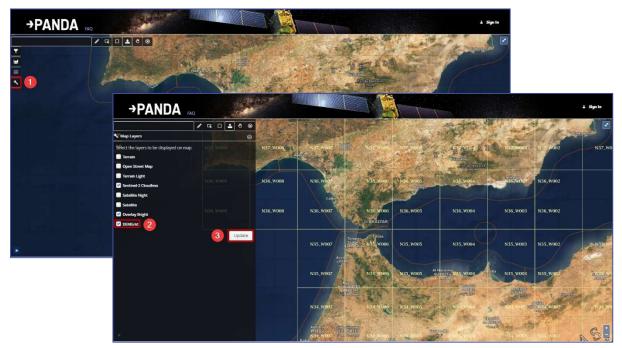


Figure 22: Steps for visualizing 1°×1° Copernicus DEM tiles



This elevation data is a digital elevation model (DEM) called FABDEM (Forest and Buildings removed Copernicus DEM) which is produced from Copernicus DEM [14] by removing heights of buildings and forests and making some other adjustments. As reported by its authors, FABDEM has significantly better accuracy in comparison to other global "freely available" DEMs [15]. Each FABDEM raster tile is georeferenced in the geographic coordinate system WGS84 (EPSG:4326) with a spatial resolution (pixel dimension) in the north-south direction of 1/3600° [16], which is around 30 m. Heights are referenced in Earth Gravitational Model 2008 (EGM08, EPSG:3855 [16]).

If elevation data will be commercially used, then Copernicus DEM GLO-30 should be chosen instead of FABDEM. It can be downloaded by following steps described on https://spacedata.copernicus.eu/web/cscda/data-access.

3.2.3 Coastline data

According to [12], official coastline data is proposed to be used for CCl25 calculation. If official data are not available, or if they are not dense enough or are outdated, then coastline data can be extracted from the OpenStreetMap (OSM) data [17]. Although OSM data are not official and are crowdsourced, our experience shows that OSM coastline data are highly reliable and up-to-date. OSM coastline data can be downloaded from https://osmdata.openstreetmap.de/ data/coastlines.html. There are two download options that differ in CRS that is used to georeference the data. We suggest downloading data from the first option that uses WGS84 (EPSG:4326) as a CRS (highlighted in Figure 23). This coastline data is stored in Esri shapefile linestring vector format. Terms of use are available at https://www.openstreetmap.org/copyright.

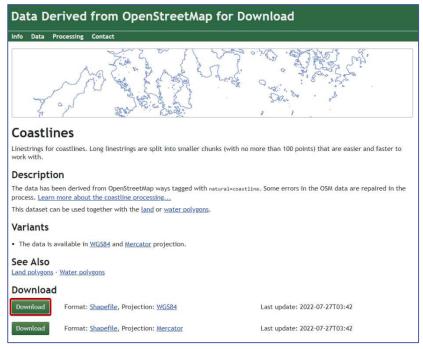


Figure 23: Downloading OSM coastline data from <u>https://osmdata.openstreetmap.de/data/coastlines.html</u>

3.2.4 Administrative units data

The CCI25 indicator guidance factsheet [18] suggests using NUTS 3 (Nomenclature of territorial units for statistics, level 3 - population from 150 000 to 800 000 [19]) or equivalent administrative units for aggregating LC/LU data (i.e. creating coastal strips). According to [12], it is suggested to use national official data on administrative units if they are available. If national official data are



not available or are not suitable, then NUTS administrative units data can be used. Boundaries of NUTS administrative units can be freely downloaded from the Eurostat (statistical office of the European Union) websites in vector format [20]. Nevertheless, we again suggest using the administrative data extracted from the OSM, for two reasons: NUTS administrative units are defined only for the EU countries (and some other European countries outside the EU), and, if for coastline data will be used data extracted from OSM, to avoid potential problems with data incompatibility. OSM administrative units data can be downloaded from https://osm-boundaries.com/Map by following these steps:

- 1. if you do not already have one, create a new OpenStreetMap account by going to <u>https://www.openstreetmap.org</u> and filling out the form that is available after clicking on the "Sign Up" button in the upper right corner (Figure 24)
- go to <u>https://osm-boundaries.com/Map</u> and after clicking on the "Authenticate" button in the top right corner (marked with 1) on Figure 25), and again the "Authenticate" button in a new modal window (2) in Figure 25), you will be redirected to the <u>https://www.openstreetmap.org/</u> where you need to enter your OpenStreetMap account data (previously created username and password or the ones you already had) and after logging in authorize OSM-boundaries to access your OSM account by clicking on the "Grant Access" button (3) on Figure 25)
- 3. find out which "OSM admin level" (the encircled number before the administrative unit name in the list on the left side marked with ④ in Figure 25) is equivalent to NUTS 3: if a country for which CCI25 is being calculated is included in NUTS classification, then it is possible to determine corresponding "OSM admin level" by comparing NUTS 3 maps available at https://ec.europa.eu/eurostat/web/nuts/nuts-maps with OSM administrative units, and if not, then a decision on the appropriate OSM administrative level can be made based on the fact that NUTS 3 administrative units have between 150 000 and 800 000 residents (commonly, OSM administrative units with "OSM admin level" six (6) are equivalent to NUTS 3 administrative units)
- 4. click on the "Download" button (marked with **5** in Figure 25)
- 5. in a new modal window (Figure 26) in a dropdown marked with 6 in Figure 26 select the country for which you want to download administrative units data, in both dropdowns marked with 7 select the same "OSM admin level" that was determined in step 3, switch from "Include water" to "Land only" (marked with 8), and finally click on the "Download" button that is marked with 9 on Figure 26 (all other options may remain unchanged)

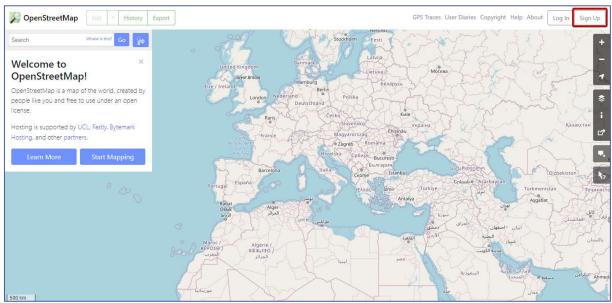


Figure 24: Initiate the creation of a new OpenStreetMap account by clicking on the "Sign Up" button



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(15/13 8353) (15/13 8763 67746 (15/13 8766 67746 (15/13 8766 67746 (15/13 8766 67746 (15/13 67746			OpenStreetMap.org, using oauth technology. By clicking the below I be redirected to OpenStreetMap.org where you need to accept the	Україна Türkiye
2 Israel 2 Italy		Authenticate 2	DpenStreetMap	
Abruzzo Gchieti G'L'Aquila O Pescara			Authorize access to your account	السعودة
			The application OSM-Boundaries is requesting access to your account. Please check wh you would like the application to have the following capabilities. You may choose as many or as f you like.	nether 5

Figure 25: Downloading OSM administrative units data from the <u>https://osm-boundaries.com/Map</u>

	O Selection 🔘 Italy	÷ 6
Admin level	6 ÷ 6 ÷ 7	
File format	GeoJSON CEWKB is the only format preserving floats correctly. KML doe	sn't respect the All tags opt
SRID	4326 🗢	
Land/Water	O Include water 🖲 Land only	
All tags	● Exclude O Include	
	No 🗘	
Simplify	NO	
	https://osm-boundaries.com/Download/Submit?apiKey=bc33	Download
Simplify API url Curl		Download

Figure 26: Setting options for downloading OSM administrative units data

If only options from step 5 have been changed in the modal window shown in Figure 26, and all others remained unchanged, clicking on the "Download" button will initiate the download of OSM administrative data stored in GeoJSON vector polygon format (actually a compressed .geojson.gz file) that is georeferenced in WGS84 CRS (EPSG:4326). Terms of use are available at https://www.openstreetmap.org/copyright.

3.2.5 Data on protected areas

Locations and boundaries of terrestrial and marine protected areas can be obtained from the World Database on Protected Areas (WDPA) available for non-commercial use on Protected Planet websites (<u>https://www.protectedplanet.net</u>). WDPA is a UN Environment Programme (UNEP) and International Union on Conservation of Nature (IUCN) project, it is being created in collaboration



with governments, non-governmental organizations, academic institutions, and industry representatives [21]. WDPA is being updated every month.

The most current WDPA dataset can be downloaded from <u>https://www.protectedplanet.net</u> by following these steps:

- 1. in the "Thematic Areas" dropdown (marked with 1) in Figure 27) in the top menu bar, click on the "Protected Areas (WDPA)" (2) in Figure 27)
- on the new web page, to download the whole WDPA dataset, click on the "Download" button (marked with 3 in Figure 28), and to download only a portion of data, which we suggest, click on the "Explore Protected Areas" button (3 in Figure 28)

Septenced planet About News & Stories Res	sources 1 Thematic Areas A
About News & Stories News Comparison of the News & Stories News Comparison of the News & Stories News News & Stories News Comparison of the News Comparison of the News Comparison of the News News & Stories News Comparison of the News News & Stories News Comparison of the News News & Stories News News & Stories News Comparison of the News News & Stories News News & Stori	Sources 1 Thematic Areas (NDPA) Q Protected Areas (WDPA) Management Effectiveness (PAME) Other Effective Area-Based Conservation Measures (WDOECM) Drintrities and areas conserved by indigenous peoples and local communities (ICCAs) Territories and areas (CCAs) The IUCN Green List of Protected and Conserved Areas Connectivity Equitable Governance Marine Protected Areas

Figure 27: Accessing the WDPA web page on the Protected Planet website

😭 protected planet	About	News & Stories	Resources	Thematic Areas $ ullet $	Q
			9 (f) (in) Downlo	ad 🛃 3
Protected Areas	(WDPA)				
The World Database on Protected Areas (v terrestrial and marine protected areas.	/DPA) is the most comprehensive g	lobal database on			
Explore Protected Areas					
	- Select				
WDPA About Metho	dolomu				

Figure 28: To filter the WDPA protected areas by country, click on the "Explore Protected Areas" button

3. after clicking on the "Explore Protected Areas" button (3) in Figure 28), on a new webpage (Figure 29), it is possible to filter the WDPA protected areas based on region (continental scale), country, or to search for a specific protected area; to filter WDPA protected areas



within a single country, click on "Countries" (4) in Figure 29), enter a name of the country in the field marked with 5, press *Enter*, and click on the country card (6) in Figure 29)

- 4. after clicking on the country card (6 in Figure 29), a new webpage with map and statistics for the selected country opens, and on it, click on the "Download" button (7 in Figure 30)
- after clicking on the "Download" button, a couple of options are shown, we suggest choosing the "SHP" one (8 in Figure 30), which will after clicking on the "Continue" button in the new modal window (9 in Figure 30), prepare data for download in Esri shapefile vector format
- 6. finally, to download prepared WDPA, click on the "Download" button in the bottom right corner (10 in Figure 30)

Filters = Q Italy		× 5	Download 🛃
	Regions Countries	s Individual Areas	
Countries (1)			
http://www.second	0 Company		
Italy 3,948 protected areas and other effe	6		

Figure 29: Filtering the WDPA protected areas by country

😭 protected pla	net' About	News & Stories Resources	Thematic Areas 🗸 🔍 🔍	
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() Italy	Downlo	ad Options	× CSV SHP 8	
Tury	Commercial Use	Non Commercial Use	File Geodatabase PDF	
3948	Meaning any use by or for a commercial entity, whether revenue-generating or	Download data from Protected Plan		
27 With manager	not, or any use that generates revenue for any type of entity. Further details <u>here</u> . For commercial use, please visit IBAT .	Continue		
Terrestrial and Inla Protected Areas				
Marine Protected				
Other effective area-base conservation measures	ed.	Citation		
0			anet: The World Database on Protected Areas (WD a-based Conservation Measures (WD-OECM) [Onlin	
Total Other effective an conservation measures	ea-based	2022, Cambridge, UK: UNEP-WCMC and IUCI	N. Available at: <u>www.protectedplanet.net</u> .	
Polygons/Points ratio		WDPA_WDOECM_Jul2022_Publi	lic 10 Download 🛃	×

Figure 30: Downloading country-filtered WDPA data on protected areas

Clicking on this "Download" button will initiate downloading of a ZIP archive that contains WDPA data on protected areas stored in Esri shapefile polygon and point vector format. Data are georeferenced in WGS84 (EPSG:4326) CRS. Terms of use are available at <u>https://www.</u>



protectedplanet.net/en/legal, and attribution is also specified above the "Download" button marked with 10 in Figure 30.

If WDPA data will be commercially used, then data should be obtained from the Integrated Biodiversity Assessment Tool (IBAT) website: <u>https://www.ibat-alliance.org/</u>.

3.3 Creating coastal strips and reporting units

So far, in QGIS we have OSM basemap and GPKG vector layer with the polygonal area of interest (*aoi.gpkg*). For constructing coastal strips and reporting units, the following datasets are required: coastline data and administrative units data. All directions and suggestions in the following sections and chapters of this manual that require defining options in dialog windows within QGIS are limited only to those parts that are required to be changed. All other options that are not mentioned should be left in their default state.

Three coastal strips have to be constructed as inland zones that are 0 - 100 m, 300 - 1000 m, and 1 - 10 km away from the coastline. Since QGIS does not natively support creating the so-called geodesic buffer zones (what is a straight line between two points in a plane, is a geodesic between two points on a surface of the ellipsoid – path with the shortest distance) and all downloaded data are in the geographic coordinate system EPSG:4326, we will need the Shape Tools plugin (installation procedure is explained in section 2.1). To construct coastal strips and reporting units, we suggest the following workflow (some of these steps (especially step 6) are computationally expensive, so be prepared for a longer processing time):

although not necessary, unzip the downloaded ZIP file with the coastline data (originally named coastlines-split-4326.zip), import the Esri shapefile in QGIS by going to Layer ► Add Layer ► Add Vector Layer..., and then after clicking on the three-dots-button in a new dialog window (1) in Figure 31) locate *lines.shp* file in the folder created after unzipping (as already mentioned, one Esri shapefile consists of at least three files that have SHP, SHX, and DBF extension), and import it by clicking on the Add button (2) in Figure 31)

Q Data Source Manager Vector						×
🚞 Browser	Source Type					
V Vector	• File O Directory O Dat	tabase 🔿 Protocol: HTTP(S),	cloud, etc.			
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2. Delimited Text	= Ontions					-
🍄 GeoPackage	Options	the second s				U
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MSSQL	ADJUST_GEOM_TYPE	<default></default>				•
📮 Orade	AUTO_REPACK	<default></default>				•
🙀 Virtual Layer	DBF_EOF_CHAR	<default></default>				•
SAP HANA					2	
🦣 WMS/WMTS				Close	Add	Help

Figure 31: Importing coastline data in QGIS



- 2. create a spatial index for the imported layer with coastline data (*lines.shp*), which will, under some circumstances, speed up processing done with this layer:
 - a. go to Vector ► Data Management Tools ► Create Spatial Index...
 - b. in a new dialog window (Figure 32), under the Input layer dropdown (1) in Figure 32) choose the imported coastline data layer (*lines.shp*)
 - c. click the Run button (2) in Figure 32; this operation does not create a new layer, but only adds a spatial index to the existing one for Esri shapefile format it creates a new file with QIX extension in the same location on the disc as other files that compose corresponding Esri shapefile layer)

Q Create Spatial Index			×
Parameters Log	· · · · · · · · · · · · · · · · · · ·	Create spatial index	
Input layer		reates an index to speed up access t	o the
√ [∞] lines [EPSG:4326]	S	eatures in a layer based on their spatia upport for spatial index creation is dep he layer's data provider.	al location. Jendent on
	0%		Cancel
Run as Batch Process		2 Run Close	Help

Figure 32: Creating spatial index for vector layer

- 3. clip the imported coastline data layer (*lines.shp*) with the AOI layer (*aoi.gpkg*):
 - a. go to Vector ► Geoprocessing Tools ► Clip...
 - b. in a new dialog window (Figure 33), under the Input layer dropdown (marked with
 1 in Figure 33), choose the imported layer with coastline data (*lines.shp*)
 - c. in the Overlay layer dropdown choose the vector layer in which the area of interest is defined (*aoi.gpkg*) marked with (2) in Figure 33
 - d. after clicking on the three-dots-button (③ in Figure 33) and choosing Save as File..., define storage location, name the output clipped coastline file with *coastline-aoi*, and choose GPKG as filetype (output file will be named *coastline-aoi.gpkg*), as shown on Figure 34

Q Clip	
Parameters Log	Clip
Input layer V Ines [EPSG:4326]	This algorithm dips a vector layer using the features of an additional polygon layer. Only the
Selected features only	parts of the features in the Input layer that fall within the polygons of the Overlay layer will be
Overlay layer	added to the resulting layer.
aoi [EPSG:4326] Selected features only	The attributes of the features are not modified, although properties such as area or length of th features will be modified by the clipping operatio
Clipped	
/coastline-aoi.gpkg	If such properties are stored as attributes, thos graduates will have to be manually updated.
✓ Open output file after running algorithm 4	
0%	5 Cano
Run as Batch Process	Run Close Help

Figure 33: Clipping coastline data to the extent of the AOI



- e. although it should already be ticked, if it is not, always tick the Open output file after running algorithm option to load the output layer into QGIS after algorithm finishes with processing (4) in Figure 33)
- f. click the Run button to start the clipping algorithm (**5** in Figure 33)

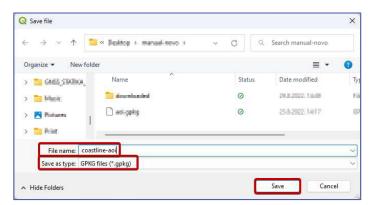


Figure 34: Defining file name and file type when saving a new file (under Windows operating system)

- 4. densify line vertices in the previously created layer (coastline-aoi.gpkg):
 - a. go to Vector ► Shape Tools ► Geodesic shape densifier
 - b. in a new dialog window (Figure 35), under the Input layer dropdown (marked with
 1 in Figure 35) choose the previously created layer with coastline data clipped to the area of interest (*coastline-aoi.gpkg*)
 - c. for Maximum line segment length (in kilometers) enter 0.02 (2) in Figure 35), and be sure you are using the right decimal separator (point or comma) which can be checked by going to Settings ► Options, in the General tab on the left side, under "Sample data: (...) float:"
 - d. after clicking on the three-dots-button (③ in Figure 35) and choosing Save as File..., define the name and storage location for densified coastline (use *coastline-aoi-densified.gpkg*, choose GPKG as filetype)

С.	click the Kur button to start the densitying agon	
ensifier		
	1	, Coodesis densifier

e. click the Run button to start the densifying algorithm (5) in Figure 35)

Parameters Log	Geodesic densifier	1
Line or polygon layer	Densify a line or polygon vector layer by ad	ding
Coastline-aoi [EPSG:4326] Selected features only Discard inner vertices (lines only) [optional]	geodesic points in between individual line segments. This gives a nice smooth curved appearance. Geodesic lines are the shortest distance between two points on the Earth. I distance between two points on the Earth.	or
Maximum line segment length (in kilometers) [optional]	ine vectors a geodesic line can be drawn ween just the beginning and ending point	:s.
0.020000 a I	Input Layer - Select an existing line or pol	/gon
/coastline-aoi-densified.gpkg	* Output Layer - Specifies the output layer will be created in QGIS.	that
✓ Open output file after running algorithm	* Discard inner vertices (lines only) - When is checked only the beginning and ending po of a line are used when drawing geodesic in This is not used with polygons.	ints
0%		ancel
Run as Batch Process	5 Run Close	Help

Figure 35: Densifying vertices in coastline data

- 5. extract vertices from the densified coastline GPKG layer (result for Italy is visible on Figure 37, point coloring will most certainly be different):
 - a. go to Vector ► Geometry Tools ► Extract vertices...



- b. in a new dialog window (Figure 36), under the Input layer dropdown (marked with
 1 in Figure 36) choose the previously created layer with densified coastline vertices (coastline-aoi-densified.gpkg)
- c. after clicking on the three-dots-button (2) in Figure 36) and choosing Save as File..., define the name and storage location for the output point layer (for name, use *coastline-vertices.gpkg*, choose GPKG as filetype)
- Q Extract vertices × Parameters Log **Extract vertices** Input aver This algorithm takes a line or polygon layer and coastline-aoi-densified [EPSG:4326] ch generates a point layer with points represen the vertices in the input lines or polygons. The Selected features only attributes associated to each point are the same ones associated to the line or polygon that the Vertices t belongs to. -2 ditional fields are added to the point indicating coastline-vertices.gpkg Open output file after running algorithm the vertex index (beginning at 0), the vertex's part and its index within the part (as well as its ring for polygons), distance along original netry and bisector angle of vertex for 0% Cancel 4) Run as Batch Process... Run Close Help
- d. click the Run button to start the algorithm (4) in Figure 36)

Figure 36: Extracting vertices from the densified coastline data

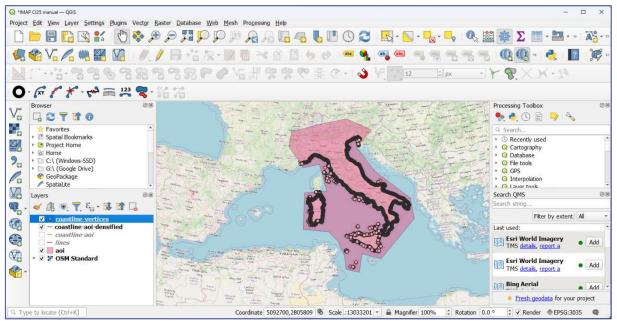


Figure 37: Extracted vertices from the densified coastline data (example for Italy)

- 6. create three buffers (300 m, 1 km, and 10 km) around each extracted vertex in the *coastline-vertices.gpkg* layer:
 - a. go to Vector ► Shape Tools ► Create shape ► Create ellipse, and click on the Run as Batch Process button in the new dialog window (highlighted in Figure 38)
 - b. click twice on the 🖶 button that is marked with 🚺 in Figure 39
 - c. in all three dropdowns highlighted with (2) in Figure 39 select the coastlinevertices.gpkg as an Input layer
 - d. for Shape type select "Polygon" (3) in Figure 39)
 - e. for the Semi-major axis and Semi-minor axis enter values as shown in Figure 39 (the first is 300, the second is 1000, and the third is 10000 marked with (4))
 - f. for Radius units select "Meters" (5 in Figure 39)
 - g. for the Number of drawing segments (approximate) enter 64 (6 in Figure 39)



- h. in the Output layer column (marked with 7) in Figure 40), define names and storage locations for output buffer layers (for names, use *buffer-300m.gpkg*, *buffer-1km.gpkg*, and *buffer-10km.gpkg*, choose GPKG as filetype) by clicking on the corresponding three-dots-buttons while taking care that layer names correspond to Semi-major axis and Semi-minor axis values (marked with 4) in Figure 39)
- i. tick the Load layers on completion option (8) in Figure 40)
- j. finally, click the Run button to start buffer creation (9) in Figure 40)

Q Create ellipse			×
Parameters Log			
Input layer			*
Coastline-vertices [EPSG:4326]		*	ය 🔧 🛄
Selected features only			
Shape type			
Polygon			•
Semi-major axis			
40,000000			: 🖶
1			
	0%		Cancel
Run as Batch Process		Run Clos	se Help

Figure 38: Switching from single-processing to batch-processing point buffer creation

Input layer	Shape type	Semi-major axis	Semi-minor axis	Orientation of axis	Radius units	drawing segments (ap	geome	
Autofill	_ Autofil	_ Autofil	_ Autofil	Autofil	Autofil	Autofill		
🗈 coastline-vertices 🔹 🔧 🗔	Polygon •	300,0000(🚳 🗘 🌾	300,0000(🗠 💲 🗐.	0,000000 🗘 🗐	Meters 🔹	64 🚳 🗘	No	
🖞 coastline-vertices 🔹 🔧 🗔	Polygon	1000,000(🖾 💲 🐔	1000,000(🗠 🗘 🕄	0,000000 🗘 🚍	Meters 🔹	64 🚳 🗘	No	
🖞 coastline-vertices 🔹 🔌 🗔	Polygon *	10000,00(🖾 🗘 🌾	10000,00(🗠 🗘 📢	0,000000 🗘 🗐	Meters 🔹	64 🚳 🗘	No	
Load layers on completion	3		•		5	6		
			0%				Car	

Figure 39: Creating 300 m, 1 km, and 10 km buffers around every extracted vertex from the densified coastline data (1)

			Autofil	ip geon	ing segments (ap	draw	Radius units	ris	Orienteries of an							"B
ouffer-30 <mark>0</mark> m.gpkg	/buffer-300m.	utofil	Carlos Carlos Carlos	•	Autofil				Orientation of ax	5	dXI	-minor	Ser	IS	r ax	į,
0, 0		-			Auconii		Autofil		Autofil			utofill		÷		ļ
'buffer-1km.gpkg	Uniffer time			1 No	© \$	64	feters 🔹 🔻	€.	0,000000 🗘 🕯	€.	-	00(📾 🗄	300,00	€.	\$	
	/buller-1km.	-		1 No	< € €	64	1eters -	€.	0,000000 \$	€,	\$	00(🖾 🗄	1000,0	€.	\$	
ouffer-10km.gpkg	/buffer-10km.	-		* No	@ \$	64	fleters *	€.	0,000000 \$	€.	\$)0(🖾 🗄	10000	€.	\$	
	7				575						ion	ompletic	ers on	d laye	.oa	L
					%	0'					ion	mpletic	ers on	d laye	Loa	∢ ✓ 8

Figure 40: Creating 300 m, 1 km, and 10 km buffers around every extracted vertex from the densified coastline data (2)

- 7. dissolve 300 m, 1 km, and 10 km buffers:
 - a. go to Vector ► Geoprocessing Tools ► Dissolve..., and click on the Run as Batch Process button in the new dialog window (highlighted in Figure 41)



- b. click twice on the 💮 button that is marked with 🚺 in Figure 42
- c. in the Input layer column (marked with 2) in Figure 42), select three previously created buffer layers (*buffer-300m.gpkg*, *buffer-1km.gpkg*, and *buffer-10km.gpkg*)
- d. in the Dissolved column, for each layer click on the three-dots-button and define the name and storage location for each layer (for name, use *buffer-300m-dissoved.gpkg*, *buffer-1km-dissolved.gpkg*, and *buffer-10km-dissolved.gpkg*, choose GPKG as filetype) while taking care that layer names in the Input layer column correspond to names in the Dissolved column (marked with 3 in Figure 42)
- e. tick the "Load layers on completion" option (4) in Figure 42)
- f. finally, click the Run button to start the dissolving algorithm (**5** in Figure 42)

Q Dissolve	×
Parameters Log	Dissolve
Input layer	This algorithm takes a vector layer and combines
🖙 buffer-1km [EPSG:4326] 🔹 🖏 📖	their features into new features. One or more
Selected features only	attributes can be specified to dissolve features belonging to the same class (having the same
Dissolve field(s) [optional]	value for the specified attributes), alternatively all
0 options selected	features can be dissolved in a single one.
Dissolved	All output geometries will be converted to multi geometries. In case the input is a polygon layer,
[Create temporary layer]	common boundaries of adjacent polygons being
☑ Open output file after running algorithm	dissolved will get erased.
0%	Cancel
Run as Batch Process	
Kull as balch Process	Run Close Help

Figure 41: Switching from single-processing to batch-processing dissolving

Batch Processing - Dissolve			
Input layer	Dissolve field(s)	Dissolved	
1 Autofil	_ Autofil	Autofil	
2 🗭 buffer-300m [EPSG:4326 🔻 🔧	options selected	/buffer-300m-dissolved.gpkg	
3 🖾 buffer-1km [EPSG:4326] 🔻 🔧	options selected	/buffer-1km-dissolved.gpkg	
4 🖻 buffer-10km [EPSG:4326 🔹 🔌	options selected	/buffer-10km-dissolved.gpkg	
2 2 Load layers on completion		3	
		0%	Cancel
Run as Single Process		5	Run Close Help

Figure 42: Dissolving 300 m, 1 km, and 10 km buffers

- 8. create spatial differences from previously created dissolved buffers to generate 300 1000 m and 1 10 km strips:
 - a. go to Vector ► Geoprocessing Tools ► Difference... and click on the Run as Batch Process button in the new dialog window (highlighted in Figure 43)
 - b. click once on the 🖶 button that is marked with 1 in Figure 44
 - c. if in dropdowns in the Input layer and Overlay layer columns you choose the same layers as in Figure 44 (marked with 2), the upper command will produce a 300 1000 m coastal strip, and lower a 1 10 km one
 - d. in the Difference column (③ in Figure 44), define names and storage location for each output layer by clicking on three-dot-buttons (name upper layer with *strip_300-1000m.gpkg* and lower with *strip_1-10km.gpkg*, choose GPKG as filetype)
 - e. tick the "Load layers on completion" option (4) in Figure 44)
 - f. finally, click the Run button to start the creation of the spatial difference layer (5 in Figure 44)



arameters Log	Difference		
put layer	This algorithm extracts features from the Input		
🛛 buffer-10km-dissolved [EPSG:4326] 🔹 🗘 🛄	layer that fall outside, or partially overlap, features		
Selected features only	in the Overlay layer. Input layer features that partially overlap feature(s) in the Overlay layer are		
verlay layer	split along those features' boundary and only the		
🛛 buffer-10km-dissolved [EPSG:4326] 🔹 🕇 🔧 🗔	portions outside the Overlay layer features are retained.		
Selected features only	Attributes are not modified, although properties		
ference	such as area or length of the features will be modified by the difference operation. If such		
reate temporary layer]	properties are stored as attributes, those		
Open output file after running algorithm	attributes will have to be manually updated.		
0%	Cancel		

Figure 43: Switching from single-processing to batch-processing spatial difference creation

Batch Processing - Difference Paraters Log E			×
Input layer	Overlay layer	Difference	
1 Autofil	Autofil	Autofil	
2 🗁 buffer-1km-dissolved [EPSG:4326] 🔹 🔧 📖	🖙 buffer-300m-dissolved [EPSG:4326] 🔹 🔧	/strip_300-1000m.gpkg	
	🖙 buffer-1km-dissolved [EPSG:4326] 🔹 🔧 📖	/strip_1-10km.gpkg	
✓ Load layers on completion		3	
4	0%		Cancel
Run as Single Process		5 Run Close	Help

Figure 44: Creating 300 – 1000 m and 1 – 10 km strips

- 9. merge two layers created in the previous step (*strip_300-1000m.gpkg* and *strip_1-10km.gpkg*) and dissolved 300 m buffer from step 7 (layer *buffer-300m-dissolved.gpkg*):
 - a. go to Vector ► Data Management Tools ► Merge vector layers...
 - b. in a new dialog window (Figure 45) click on the three-dots-button (marked with (1))
 - c. in a new window (Figure 46) tick three layers that have to be merged (strip_300-1000m.gpkg, strip_1-10km.gpkg, and buffer-300m-dissolved.gpkg, as is marked with (2) in Figure 46) and click the OK button (marked with (3) in Figure 46)

Q Merge Vector Layers	×
Parameters Log	Merge vector layers
Input layers 3 inputs selected	this algorithm combines multiple vector layers of
Destination CRS [optional] Merged	The attribute table of the resulting layer will contain the fields from all input layers. If fields with the same name but different types are found then the exported field will be
/coastal-strips.gpkg	found then the exported field will be matically converted into a string type field. fields storing the original layer name and source are also added.
☑ Open output file after running algorithm	If any input layers contain Z or M values, then the output layer will also contain these values. Similarly, if any of the input layers are multi-part, the output layer will also be a multi-part layer. Optionally, the destination coordinate reference system (CRS) for the merged layer can be set.
0%	Cancel
Run as Batch Process	5 Run Close Help

Figure 45: Merging 0 – 300 m, 300 – 1000 m, and 1 – 10 km strips into a single layer



- d. define a storage location and name for the output layer by clicking on the threedots-button marked with ④ on Figure 45 and choosing Save as File... (name it with coastal-strips.gpkg)
- e. finally, click the Run button to start merging layers (marked with **5** in Figure 45)

Parameters Log	Me	erge vector layers
Input layers		algorithm combines multiple vector layers o
✓ buffer-300m-dissolved [EPSG:4326]	Select All the	same geometry type into a single one.
✓ strip_1-10km [EPSG:4326] ✓ strip_300-1000m [EPSG:4326]		attribute table of the resulting layer will tain the fields from all input layers. If fields
aoi [EPSG:4326] buffer-10km [EPSG:4326]	Taggle Selection With	the same name but different types are ad then the exported field will be
buffer-10km-dissolved [EPSG:4326] buffer-1km [EPSG:4326]	Add File(s) auto	omatically converted into a string type field.
buffer-1km-dissolved [EPSG:4326]		I fields storing the original layer name and ree are also added.
buffer-300m [EPSG:4326] coastline-aoi [EPSG:4326]		ny inp <mark>ut</mark> layers contain Z or M values, then
coastline-aoi-densified [EPSG:4326] coastline-vertices [EPSG:4326]		output layer will also contain these values. larly, if any of the input layers are multi-part
lines [EPSG:4326]		output layer will also be a multi-part layer.
		ionally, the destination coordinate reference em (CRS) for the merged layer can be set.

Figure 46: Choosing layers that are going to be merged

10. import administrative units data downloaded from OSM-boundary (.geojson.gz file, the filename is starting with "OSMB") in QGIS by going to Layer ► Add Layer ► Add Vector Layer... and then follow the same steps as when importing coastline data (Figure 31), or just drag&drop downloaded file into QGIS (after importing administrative units, map view in QGIS should look like the one on Figure 47; if needed, draw order of different layers could be changed by changing layer's position (drag&drop) in the Layers panel – the first layer in the Layers panel will be on top of other layers in the QGIS map view)

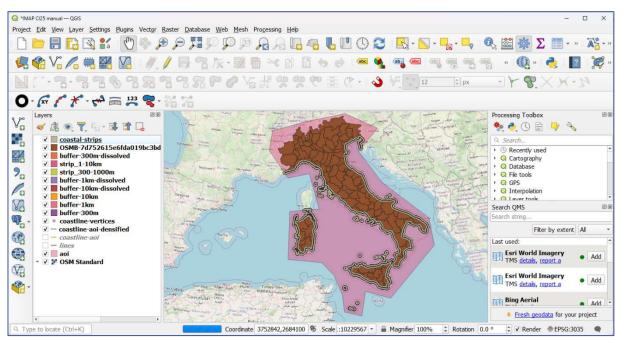


Figure 47: QGIS map view after importing OSM-boundary administrative units data (example for Italy, basemap: © OpenStreetMap contributors)



- 11. extract only administrative units that are intersecting previously created coastal strips (layer *coastal-strips.gpkg*):
 - a. go to Vector ► Research Tools ► Select by location...
 - b. in a new dialog window (Figure 48) in the Select features from dropdown choose the previously imported .geojson.gz file with administrative units data (1) on Figure 48)
 - c. tick only intersect geometric predicate (2) on Figure 48)
 - d. in the By comparing to the features from dropdown choose the coastal strips layer (coastal-strips.gpkg, ③ on Figure 48)
 - e. by clicking on the Run button (④ on Figure 48), select only those administrative units that intersect (i.e. have any point/part in common) this operation does not produce any new data (selected polygons are by default settings colored with yellow, as can been seen in Figure 49)

Q Select by location	×
Parameters Log Select features from OSMB-7ad3dae556df29aa76c6f1664c2b06009c6c6bc0.geojson [EPSG:4326] Where the features (geometric predicate) Intersect 2 n contain overlap disjoint are within equal cross	Select by location This algorithm creates a selection in a vector layer. The criteria for selecting features is based on the spatial relationship between each feature and the features in an additional layer.
By comparing to the features from Image: Coastal-strips [EPSG:4326] Image: Coastal-strips [EPSG:4326]	
Selected features only Modify current selection by	
creating new selection	
0%	Cancel
Run as Batch Process	4 Run Close Help

Figure 48: Performing a spatial query (select only administrative units that intersect coastal strips)

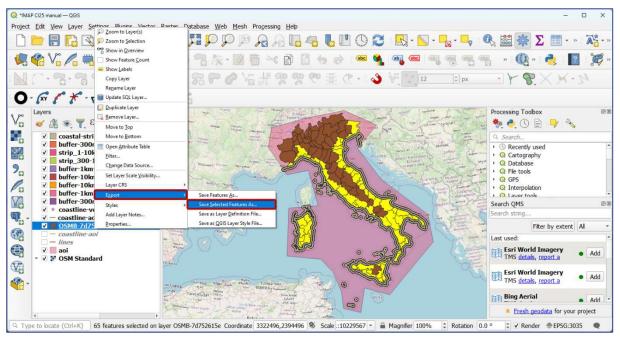


Figure 49: Extracting selected polygons (colored with yellow) from OSM-boundary administrative units data (basemap: © OpenStreetMap contributors)



- f. in the Layers panel, right-click on the imported .geojson.gz layer with administrative units in which administrative units that intersect coastal strips are selected and click on the Export ► Save Selected Features As... (Figure 49)
- g. in a new dialog window, under the Format dropdown choose "GeoPackage" (1) in Figure 50)
- h. click on the three-dots-button (**2** in Figure 50) and define a storage location and name for a new GeoPackage file (name file with *administrative-units.gpkg*)
- i. under Select fields to export and their export options untick all fields except "name", "local_name", and "name_en" (③ in Figure 50), and click on the OK button (④ in Figure 50)

Format	GeoPackage					
File name Layer name CRS	EPSG:4326		okg a 2			
Encoding ✓ Save only ▼ Select fi		UTF-8 atures Fort and their export options	•			
Name		Replace with displayed values	-			
bounda	ly Sully					
1. 10. 1. 10. 10.		r 🔲 Use Range				
1. 10. 1. 10. 10.	level Intege	r 🗌 Use Range				
admin_	level Intege	r 🗌 Use Range				
admin_	level Intege String String	Use Range				
□ admin_ □ parents ☑ name	level Intege String String ame String		•			

Figure 50: Exporting selected administrative units in the new GeoPackage file

- 12. create an intersection between coastal strips and administrative units produced in the previous step, which will produce reporting units:
 - a. go to Vector ► Geoprocessing Tools ► Intersection...
 - b. in the new dialog window (Figure 51) under the Input layer choose the layer with administrative units (*administrative-units.gpkg*, **1** on Figure 51)
 - c. under the Overlay layer choose the layer with coastal strips (coastal-strips.gpkg, 2) on Figure 51)
 - click on the three-dots-button under Intersection (3) on Figure 51), choose Save as File..., and define a storage location and name for a new GeoPackage file (name file with *reporting-units.gpkg*)
 - e. click the OK button (4) on Figure 51) to initiate the creation of reporting units
- 13. the final step is to clean attribute data in reporting units layer (*reporting-units.gpkg*):
 - a. open attribute table for the *reporting-units.gpkg* layer (right click on the *reporting-units.gpkg* layer name in the Layers panel and click on the Open Attribute Table)
 - b. enable layer editing by clicking on the 🥢 icon (marked with 🚺 in Figure 52)



2 Intersection	>
Parameters Log	Intersection
Input layer	This algorithm extracts the overlapping portions of
🖙 administrative-units [EPSG:4326] 🔹 🖏 🛄	features in the Input and Overlay layers. Features
Selected features only	in the output Intersection layer are assigned the attributes of the overlapping features from both
Overlay layer	the Input and Overlay layers.
🖙 coastal-strips [EPSG:4326] 🔹 🖒	
Selected features only	
Input fields to keep (leave empty to keep all fields) [optional]	
0 options selected	
Overlay fields to keep (leave empty to keep all fields) [optional]	
0 options selected	
Advanced Parameters	
Overlay fields prefix [optional]	
Intersection	
/reporting-units.gpkg 🚳 🛄	3
☑ Open output file after running algorithm	
0%	Cancel
Run as Batch Process	4 Run Close Help

Figure 51: Intersecting administrative units with coastal strips and thus producing reporting units

- c. create a new attribute with coastal strip names ("0 300 m", "300 1000 m", and "1 10 km") by clicking on the icon (marked with 2 in Figure 52), which will open the Field Calculator window (Figure 53):
 - i. make sure that the Create a new field option is ticked, and that the Only update # selected features option, if it is available, is unticked (marked with 1) in Figure 53)
 - ii. in the Output field name filed enter "strip", which will be the name for a new attribute (2) in Figure 53)
 - iii. in the Output field type dropdown select "Text" (3) in Figure 53)
 - iv. for the Output filed length filed enter "30" (4) in Figure 53)
 - v. in the Expression window (marked with **5** in Figure 53), paste the following expression:

```
CASE
WHEN "layer" = '<u>buffer-300m-dissolved</u>' THEN '0 - 300 m'
WHEN "layer" = '<u>strip 300-1000m</u>' THEN '300 - 1000 m'
WHEN "layer" = '<u>strip 1-10km</u>' THEN '1 - 10 km'
ELSE 'ERROR'
END
```

1 d	4	▼ = E 123							Update All Update Selected	
	hu	name	local_name	name_en	fid_2	vertex_index	3 2 vertex_part	vertex_part_index	distance	angle
. 1	63	Trieste	Trieste	Trieste	1	0	0	0	0	174.258492 buf
9	2	Trieste	Trieste	Trieste	2	0	0	0	0	174.258492 stri
1	3	Trieste	Trieste	Trieste	3	0	0	0	0	174.258492 stri
	4	Udine	Udine	NULL	1	0	0	0	0	174.258492 buf
i.	5	Udine	Udine	NULL	2	0	0	0	0	174.258492 stri
	6	Udine	Udine	NULL	3	0	0	0	0	174.258492 stri
5	7	Trapani	Trapani	NULL	1	0	0	0	0	174.258492 buf

Figure 52: Editing attribute data for a vector layer



- vi. in the area marked with 6 in Figure 53, look for "layer" item in the "Fields and Values" group, click on it, click on the All Unique button (marked with 7), and, if needed, replace underlined parts in the above expression with corresponding items from the list that was generated under the All Unique button (marked with 8)
- vii. click on the OK button (marked with 9 in Figure 53), which will close the Field Calculator window and after which a new attribute named "strip" will be created, and its values will be populated based on the above specified expression

Q reporting-units — Field Calculator				×
Only update 0 selected features				
Create virtual field Output field name strip Output field type Text (string) Output field length 30 Precision 3				*
Expression Function Editor	Q Search	Show Values	group field	•
CASE WHEN "layer" = 'buffer-300m-dissolved' THEN '0 - 300 m' WHEN "layer" = 'strip_300-1000m' THEN '300 - 1000 m' WHEN "layer" = 'strip_1-10km' THEN '1 - 10 km' ELSE 'ERROR' END 5 = + - / * ^ () '\n' Feature Aristanis/Oristano • • • • • • •	 Fields and Values NULL 123 fd =bc name =bc local_name =bc name_en 123 fd_2 123 vertex_index 123 vertex_part 123 vertex_part 124 distance 12 angle		Double-click to add field name to expression string. Right-Click on field name to Values Search Al Unique 10 Samples buffer-300m-dissolved strip_1-10km strip_300-1000m	
(i) You are editing information on this layer but the layer is currently not in	edit mode. If you dick OK, edit mode	will automatically	be turned on.	р

Figure 53: Creating a new "strip" attribute by defining expression in the Field Calculator window

- d. some attribute values in the "name_en" attribute/field are not specified, so they should be copied from the "name" or the "local_name" attribute/field:
 - i. again, open the Field Calculator window by clicking on the icon (marked with 2) in Figure 52)
 - ii. tick the Update existing field option (marked with 1) in Figure 54), and make sure that the Only update # selected features option (marked with 2) in Figure 54), if it is available, is unticked
 - iii. in a dropdown that is marked with (3) in Figure 54, choose "name_en"
 - iv. in the expression window (marked with (4)), enter the following expression:

if(
	"name_en" IS NOT NULL,
	"name_en",
	if(
	"name" IS NOT NULL
	"name",
	"local_name"
)
)

v. click on the OK button (marked with (5)), which will close the Field Calculator window and populate empty attribute values for the "name_en"



attribute with the attribute values from the "name", and "local_name" attribute, as specified in above expression

😡 reporting-units — Field Calculator	×
Only update 0 selected features Only update 0 selected features Create a new field Update existing field	
Create virtual field Output field name	
Output field type Whole number (integer) Output field length 0 Precision 3	
Expression Function Editor	
if("name_en", if("name", IS NOT NULL, "name", "local_name"))	Q. Search Show Help row_number • Aggregates • Arrays • Color • Conditionals • Conversions • Date and Time • Fields and Values • Fields and Values • Fieles and Paths • General • Geometry •
= + - / * ^ () '\n' Feature Aristanis/Oristano Preview: 'Aristanis/Oristano'	 Map Layers Maps Math Operators Rasters Record and Attributes
	5 OK Cancel Help

Figure 54: Updating the "local_name" attribute by defining expression in the Field Calculator window

- e. remove unnecessary attributes:
 - i. click on the 📗 icon (marked with 3 in Figure 52)
 - ii. in a new window (Figure 55) select attributes "fid_2", "vertex_index", vertex_part", "vertex_part_index", "distance", "angle", "layer", and "path" (as marked with 1)
 - iii. click on the OK button (marked with 2) in Figure 55) which will delete selected attributes and their values from the attribute table
- f. finally, click on the 🛃 icon (marked with ④ in Figure 52) to save all changes that have been done in the *reporting-units.gpkg* layer, and click on the 💋 icon (marked with ① in Figure 52) to disable layer editing

-			
	Delete Fields		×
11	fid		
	name		
11	local_name		
11	name_en		
	fid_2		
	vertex_index		
	vertex_part		
	vertex_part_index	1	
	distance		
	angle		
	layer		
	path		
	strip		
		2	Cancel

Figure 55: Selecting attributes that are about to be deleted

After this processing, the only layers that can be left in QGIS are: *aoi.gpkg*, *coastline-aoi.gpkg*, *administrative-units.gpkg*, *reporting-units.gpkg*, and basemap imported with the QuickMapServices plugin.



All other layers may be removed from the QGIS project by right-clicking on each of them in the Layers panel and then clicking on the Remove Layer... It is also recommended to save the QGIS project file (it has a QGZ extension) from time to time by going to File > Save... As already discussed, note that in the QGIS project file no raster or vector data is stored, it only stores locations of corresponding files that are stored in the computer storage. Always be sure to retain relative location on the computer storage between the QGIS project file and files that are imported into the QGIS project. All data that are not necessary for further processing can be deleted from the computer storage.

3.4 Preparing other data

Reporting units that are created in the previous chapter will be used for aggregating LC/LU and elevation data, and data on protected areas. In this chapter, these data will be prepared for their further processing and aggregation.

3.4.1 Preparing LC/LU data

All steps in this chapter, as opposed to steps in the previous chapter with the creation of reporting units, need to be done twice, for both years that are chosen for the indicator calculation.

Downloaded CGLS-LC100 GeoTIFF tiles can be imported in QGIS by going to Layer \triangleright Add Layer \triangleright Add Raster Layer... In the new dialog window (Figure 56) click on the three-dots-button (1) in Figure 56), locate and select the CGLS-LC100 GeoTIFF tile(s) that has to be imported, and finally import it by clicking the OK button (2) in Figure 56). Make sure you have imported (and previously downloaded) all CGLS-LC100 raster tiles that overlap with the AOI, that is, more specifically, with created reporting units. Also, make sure you have imported CGLS-LC100 tiles for both years that are chosen for the indicator calculation.

Q Data Source Manager Raster						×
🫅 Browser	Source Type					
Vector	💿 File 🔿 Protocol: HTTP	(S), cloud, etc.				
Raster						
Mesh	Source					
Paint Cloud	Raster dataset(s)	000N40_PROBAV_LC100_glo	bal_v3.0.1_2019-nrt_Discre	te-Classification-map_	EPSG-4326.tif	
🦜 Delimited Text	▼ Options					0
🙀 GeoPackage		age for detailed explanations	on options			
GPS	NUM_THREADS	-D-E-ikb				
🕖 SpatiaLite	GEOTIFF_KEYS_FLAVOR GEOREF_SOURCES					
PostgreSQL	SPARSE_OK	<default></default>				•
MSSQL					2	
📮 Oracle				Char		
	Y			Close	Add	Help

Figure 56: Importing CGLS-LC100 GeoTIFF tile in QGIS

If for each year only one raster tile is imported into QGIS, the following steps can be skipped. Otherwise, all imported rasters from each year should be merged (i.e. mosaicked) into one so that they can be processed jointly. Regular mosaicking (Raster ► Miscellaneous ► Merge...) creates a completely new raster which will, in this case, duplicate original data and unnecessarily take additional storage space. Another mosaicking approach is to create a so-called virtual raster. A virtual raster only points to the original raster data, it takes almost none of the storage space and is in QGIS treated as a regular raster. To create a virtual raster that consists of more CGLS-LC100 raster tiles, follow these steps (separately for each year):



- 1. go to Raster ► Miscellaneous ► Build virtual raster...
- 2. in a new dialog window (Figure 57), click on the three-dots-button under Input layers (marked with (1))
- 3. in a new window (Figure 58) tick all CGLS-LC100 raster tiles from one year (example for the year 2015 marked with (2))
- 4. click on the OK button (marked with **3** in Figure 58)
- 5. after clicking on the three-dots-button marked with ④ in Figure 57 and choosing Save as File..., define the storage location and name for the virtual raster that is about to be created (for name, use CGLS-LC100-<year>.vrt, replace <year> with the corresponding year)
- 6. click the Run button to initiate the creation of a virtual raster (**5** in Figure 57)

Build Virtual Raster	>
Parameters Log	
input layers	
2 inputs selected	U []
Resolution	
Average	~
Place each input file into a separate band	
Allow projection difference	
Advanced Parameters	
Add alpha mask band to VRT when source raster has none	
Override projection for the output file [optional]	
	-
Resampling algorithm	
Nearest Neighbour	*
Nodata value(s) for input bands (space separated) [optional]	
Additional command-line parameters [optional]	
/irtual //CGLS-LC100-2015,vrt	4
✓ Open output file after running algorithm 3DAL/OGR console call	
gdabuidvrt -overwrite -resolution average -r nearest -input_file_ist AppData/Local/Temp/processing_XuYRkR/b5f978af2f6640fdbaa188b2142236c3/ buidvrtInputFiles.txt /CGLS-LC100-2015.vrt	\bigcirc
0%	Cancel
tun as Batch Process 5 Run Close	Help

Figure 57: Merging all CGLS-LC100 tiles into one virtual raster

Q Build Virtual Raster Parameters Log Input layers			
V E000N40_PROBAV_LC100_global_v3.0.1_2015-base_Discrete-Classification-map_EPSG-4326 [EPSG:4326] 2 V E000N60_PROBAV_LC100_global_v3.0.1_2015-base_Discrete-Classification-map_EPSG-4326 [EPSG:4326] 2 E000N40_PROBAV_LC100_global_v3.0.1_2019-nrt_Discrete-Classification-map_EPSG-4326 (1) [EPSG:4326] 2 E000N60_PROBAV_LC100_global_v3.0.1_2019-nrt_Discrete-Classification-map_EPSG-4326 (5) [EPSG:4326] 2 OSM Standard [EPSG:3857] 2		Clear Togg Add	elect All r Selection le Selection d File(s) Directory OK 3
0%			Cancel
Run as Batch Process	Run	Close	Help

Figure 58: Selecting raster layers that will be merged into one virtual raster



To speed up processing in the next steps, we can create a new raster from previously imported CGLS-LC100 rasters or created virtual rasters in which all pixel values that are outside of reporting units will be removed, that is, set to appropriate "no data value". This procedure is in QGIS called clipping. We will also increase spatial resolution by 10 times to reduce errors in later calculations. We propose the following workflow (separately for each year):

- 1. to determine the resolution or pixel size of a CGLS-LC100 raster layer:
 - a. right click on one of the previously created virtual rasters in the Layers panel
 - b. click on Properties... in the dropdown menu
 - c. in the Information tab (on the left side), find the "Pixel Size" entry and copy one of the values (for CGLS-LC100, both values representing north-south and west-east pixel sizes should be the same, and to be sure about their correctness, these values could also be compared against values for original CGLS-LC100 rasters)

	Band 1	 STATISTICS_APPROXIMATE=YES STATISTICS_MAXIMUM=200 				
Information		 STATISTICS_MEAN=107.73234387043 				
Source		 STATISTICS_MINIMUM=20 STATISTICS_STDDEV=66.533128056586 				
Symbology		STATISTICS_VALID_PERCENT=100				
	More information					
Transparency	Dimensions	X: 20160 Y: 40320 Bands: 1				
Histogram	Origin	0.0000000000000,60.000000000000000				
mocogram	Pixel Size	0.0009920634920634887558,-0.0009920634920634887558				
Pondorina						
Rendering		_				
Rendering Temporal						
Temporal	Coordinate Re	ference System (CRS)				
Temporal	Coordinate Re	ference System (CRS) EPSG:4326 - WGS 84				
Temporal Pyramids Metadata	Name Units	With data states and the electronic state				
Temporal Pyramids	Name Units Method	EPSG:4326 - WGS 84 Geographic (uses latitude and longitude for coordinates) Lat/long (Geodetic alias)				
Temporal Pyramids Metadata Legend	Name Units Method Celestial body	EPSG:4326 - WGS 84 Geographic (uses latitude and longitude for coordinates) Lat/long (Geodetic alias) Earth				
Temporal Pyramids Metadata Legend	Name Units Method Celestial body Accuracy	EPSG:4326 - WGS 84 Geographic (uses latitude and longitude for coordinates) Lat/long (Geodetic alias) Earth Based on <i>World Geodetic System 1984 ensemble</i> (EPSG:6326), which has a	limited accura	cy of at be	est 2 meters.	
Temporal Pyramids Metadata	Name Units Method Celestial body	EPSG:4326 - WGS 84 Geographic (uses latitude and longitude for coordinates) Lat/long (Geodetic alias) Earth	limited accura	cy of at be	est 2 meters.	

Figure 59: Determining pixel dimensions (i.e. spatial resolution) for raster layers

- 2. go to Raster ► Extraction ► Clip Raster by Mask Layer...
- 3. in a new dialog window (Figure 60) under the Input layer dropdown (marked with 1) select imported CGLS-LC100 raster tile, if it is one for each year, or previously created virtual raster (CGLS-LC100-<year>.vrt)
- 4. in the Mask layer dropdown select reporting units vector layer (*reporting-units.gpkg*, marked with **2** on Figure 60)
- 5. ensure Match the extent of the clipped raster to the extent of the mask layer is ticked (3) on Figure 60)
- 6. tick the Set output file resolution option and paste 0.00009920634920634887558 in X Resolution to output bands and Y Resolution to output bands fields (marked with ⁶) on Figure 60) which will produce a raster with spatial resolution 10 times higher than the resolution of the original CGLS-LC100 raster layer (values in X Resolution to output bands and Y Resolution to output bands fields are after pasting shown rounded to six decimal places, but the calculation is done with more decimal places, so be sure to paste the whole number to avoid later raster misalignments, and also be sure to use the correct decimal separator)
- 7. in the Additional command-line parameters (6 on Figure 61) paste the following text (as suggested in [22]): -co COMPRESS=DEFLATE -wo CUTLINE_ALL_TOUCHED=TRUE
- 8. after clicking on the three-dots-button marked with **7** in Figure 61 and choosing Save as File..., define the storage location and name for the raster that is about to be created (for name, you can use **CGLS-LC100-<year>-clipped.tiff** (replace <*year>* with the corresponding year), choose TIF or TIFF as a storage format)
- 9. click the Run button to start the clipping algorithm (8) in Figure 61)



Q Clip Raster by Mask Layer		×
Parameters Log		
Input layer		-
F CGLS-LC100-2015 [EPSG:4326]		•
Mask layer	20 C	
Preporting-units [EPSG:4326]	- C	عم
Selected features only		
Source CRS [optional]		
		-
Target CRS [optional]		
		- 🔊 -
Assign a specified nodata value to output bands [optional]		
Not set		•
Create an output alpha band		
Match the extent of the clipped raster to the extent of the mask layer 3		
Keep resolution of input rast		
Set output file resolution		
X Resolution to output bands [optional]		
0.000099		€3 \$
Y Resolution to output bands [optional]		
0.000099		<
0%		Cancel
Run as Batch Process	Run Close	Help

Figure 60: Clipping virtual raster with CGLS-LC100 land cover data to reporting units (1)

Q Clip Raster by Mask Layer	×
Parameters Log	
	·
🖶 😑 Validate Help	
Output data type	
Use Input Layer Data Type	
Additional command-line parameters [optional]	
-co COMPRESS=DEFLATE -wo CUTLINE_ALL_TOUCHED=TRUE	
Cipped (mask)	
/CGLS-LC100-2015-clipped.tif	
☑ Open output file after running algorithm	
GDAL/OGR console call	
gdalwarp -overwrite -of GTiff -tr 9.920634920634888e-05 9.920634920634888e-05 -tap -cutine reporting-units -crop_to_cutine -co COMPRESS=DEFLATE -wo CUTLINE_ALL_TOUCHED=TRUE //CGLS-LC100-2015-cipped.tif	/reporting-units.gpkg -cl /CGLS-LC100-2015.vrt
	12
0%	Cancel
Run as Batch Process	8 Run Close Help

Figure 61: Clipping virtual raster with CGLS-LC100 land cover data to reporting units (2)

After clipping rasters to reporting units for both years, imported original CGLS-LC100 rasters can be removed from the QGIS project (right-click on the layer name in the Layers panel and click on the Remove Layer... in the dropdown menu), as well as virtual rasters, if they have been created. An example of a CGLS-LC100 raster after clipping to the reporting units is shown in Figure 62. Again, to change the draw order of different layers in the QGIS map view, drag&drop layers and change their order in the Layers panel.



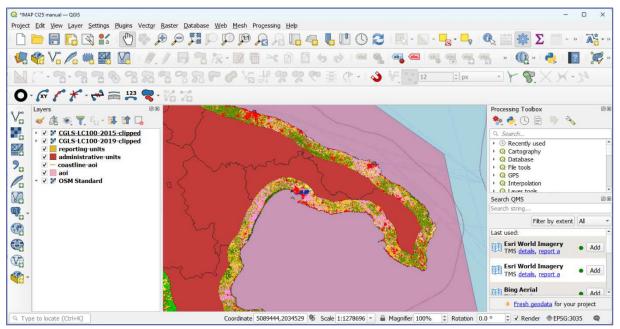


Figure 62: CGLS-LC100 layer after clipping to the reporting units (example for south Italy, basemap: © OpenStreetMap contributors)

Since the classification scheme of CGLS-LC100 data is not the same as the classification needed for CCI25, CGLS-LC100 raster data need to be reclassified to the CCI25 classification. To reclassify CGLS-LC100 raster tiles, follow these steps (separately for each year):

1. in the Processing Toolbox panel enter "r.reclass" in the search bar and then double click on the r.reclass item (Figure 63)

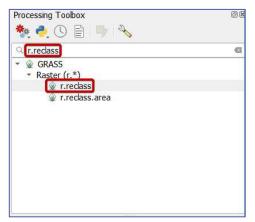


Figure 63: Accessing the r.reclass algorithm from the Processing Toolbox panel

- 2. in a new dialog window (Figure 64), under the Input raster layer dropdown select the clipped CGLS-LC100 raster tile (*CGLS-LC100-<year>-clipped.tif*, **1** in Figure 64)
- 3. under the Reclass rule text, paste the following text (2) in Figure 64):

50	= 1 Built-up
40	= 2 Agricultural
20 30 111 112 113 114 115 116 121 122 123 124 125 126 70 60 100	θ = 3 Forest and semi-natural land
90	= 4 Wetlands
80 200	= 5 Waterbodies

- 4. in the Output raster format options paste the following text: **COMPRESS=DEFLATE** (3) in Figure 64)
- 5. after clicking on the three-dots-button marked with ④ in Figure 64 and choosing Save as File..., define the storage location and name for the raster that is about to be created (for



name, use **CGLS-LC100-<year>-reclassified.tif** (replace <*year>* with the corresponding year), choose TIF or TIFF storage format)

6. click the Run button to initiate the creation of a reclassified raster (5) in Figure 64)

Q r.reclass			×
Parameters Log	r.reclass		
Input raster layer	Creates a new map laye	r whore catego	nuvalues
Y CGLS-LC100-2015-clipped [EPSG:4326]	are based upon a reclass	sification of the	
File containing reclass rules [optional]	in an existing raster map	layer.	
Reclass rules text (if rule file not used) [optional]			
50 = 1 Buit-up			
40 = 2 Agricultural 20 30 111 112 113 114 115 116 121 122 123 124 125 126 70 60 100 = 3 Forest and semi-natural land			
■ Advanced Parameters			
GRASS GIS 7 region extent [optional]			
Not set			
GRASS GIS 7 regine 3 lsize (leave 0 for default)			
Output Rasters format options (createopt) [optional]			
COMPRESS=DEFLATE			
Output Rasters format metadata options (metaopt) [optional]			
Reclassified			
/CGLS-LC100-2015-reclassified.tif,			
✓ Open output file after running algorithm			
0%			Cancel
Run as Batch Process	5 Run	Close	Help

Figure 64: Reclassifying CGLS-LC100 raster tiles to the CCI25 classification scheme

After this processing, only layers that can be left in QGIS are: *aoi.gpkg*, *coastline-aoi.gpkg*, *administrative-units.gpkg*, *reporting-units.gpkg*, *CGLS-LC100-<year1>-clipped.tif*, *CGLS-LC100-<year1>-reclassified.tif*, *CGLS-LC100-<year2>-reclassified.tif*, and basemap imported with the QuickMapServices plugin.

3.4.2 Preparing elevation data

As already mentioned, each downloaded FABDEM ZIP archive contains up to 100 1°×1° GeoTIFF tiles. From these tiles, the flooding zone needs to be extracted. We suggest the following workflow:

- 7. extract all tiles from the downloaded FABEDM ZIP archive (if multiple ZIP archives have been downloaded, move all tiles to the same folder) and remove metadata files that have an XML extension (do not import tiles into QGIS)
- 8. like with land cover CGLS-LC100 data, instead of making a "real" mosaic that unnecessarily takes storage space and duplicates original data, we can create a virtual raster:
 - a. go to Raster ► Miscellaneous ► Build virtual raster...
 - b. in a new dialog window (Figure 65), after clicking on the three-dots-button that is marked with **1**, a new dialog which is shown in Figure 66 opens
 - c. by clicking on the Add Directory... button (2) on Figure 66) and defining the location (i.e. path on the disc) of a directory where all FABDEM tiles have been extracted from downloaded ZIP files, we have an option to select raster data for creating virtual raster that has not been previously imported into QGIS
 - after defining a path to the folder with all FABDEM raster tiles, click the OK button (3) on Figure 66) to return to the previous window



Suild Virtual Raster	
Parameters Log	
Input layers	
325 inputs selected	
Resolution	
Highest	*
Place each pout file into a separate band	
Allow proje 4 difference	
Advanced Parameters	
Add alpha mask band to VRT when source raster has none	
Override projection for the output file [optional]	
	* 🍓
Resampling algorithm	
Nearest Neighbour	· •
Nodata value(s) for input bands (space separated) [optional]	
Additional command-line parameters [optional]	
Virtual	
/DEM.vrt	5
Open output file after running algorithm	
GDAL/OGR console call	
gdalbuildvrt -ovenvrite -resolution highest -r nearest -input_file_list buildvrtInputFiles.txt	/AppData/Local/Temp/processing_XuYRkR/49160ef5b9274a8cab00768a47fca54f/ /DEM.vrt
	0% Cancel
Dur an Date Durante	
Run as Batch Process	6 Run Close Help

Figure 65: Merging all FABDEM tiles into one virtual raster (1)

Build virtual raster		
Parameters Log Input layers		
CGLS-LC100-clipped [EPSG:4326] OpenStreetMap Standard aka Mapnik [EPSG:3857]	Se	elect All
GGLS-LC100-reclassified [EPSG:4326]	Clear	Selection
	Toggl	le Selection
	Add	File(s)
		Directory
	3	ОК
0%		Cance
un as Batch Process	Run Close	Help

Figure 66: Merging all FABDEM tiles into one virtual raster (2)

- e. in the Resolution dropdown choose "Highest" (4) in Figure 65)
- f. after clicking on the three-dots-button marked with (5) in Figure 65 and choosing Save as File..., define the storage location and name for the virtual raster that is about to be created (for name, you can use *DEM.vrt*)
- g. click the Run button to initiate the creation of a virtual raster (6 in Figure 65)
- 9. again, like with land cover CGLS-LC100 data, we should remove pixel values for all pixels in a previously created virtual raster that are outside of reporting units, and also ensure that the raster with elevation data is aligned (i.e. pixels in rasters perfectly overlap) with the raster with land cover CGLS-LC100 data (expect longer processing time for this step):
 - a. go to Raster ► Extraction ► Clip raster by mask layer...



- b. in a new dialog window (Figure 67) under the Input layer dropdown (marked with 1) select the previously created virtual raster with FABDEM elevation data (*DEM.vrt*)
- c. in the Mask layer dropdown select reporting units vector layer (*reporting-units.gpkg*, marked with **2** in Figure 67)
- d. ensure that the Match the extent of the clipped raster to the extent of the mask layer is ticked (3) in Figure 67)
- e. tick the Set output file resolution option and paste 0.00009920634920634887558 in X Resolution to output bands and Y Resolution to output bands fields (marked with 4 in Figure 67) which will, with the tick in the previous step, ensure that the raster with FABDEM elevation data and raster with CGLS-LC100 land cover data are aligned and have the same resolution (be sure to paste the whole number in X Resolution to output bands and Y Resolution to output bands fields)
- f. in the Additional command-line parameters (5 in Figure 68) paste the following text (as suggested in [22]): -co COMPRESS=DEFLATE -wo CUTLINE_ALL_TOUCHED=TRUE
- g. after clicking on the three-dots-button marked with 6 in Error! Reference source not found. and choosing Save as File..., define the storage location and name for the raster that is about to be created (for name, you can use *DEM-clipped.tif*, choose TIF or TIFF storage format)
- Q Clip raster by mask layer × Parameters Log Input layer DEM [EPSG:4326] Mask layer reporting-units [EPSG:4326] - 13 Selected features only 2 Source CRS [optional] - 🇠 Target CRS [optional] - 🏽 Assign a specified nodata value to output bands [optional] * Not set Create an output alpha band ✓ Match the extent of the clipped raster to the extent of the mask layer 3 Keep resolution of input raster Set output file resolution X Resolution to output bands [optional] 0.000099 63 \$ Y Resolution to output bands [optional] 0.000099 Advanced Parameters 4 Use multithreaded warping implementation Additional creation options [optional] Profile Ŧ 0% Cancel Run as Batch Process... Run Close Help
- h. click the Run button to start the clipping algorithm (7) in Figure 68)

Figure 67: Clipping virtual raster with FABDEM elevation data to reporting units (1)

- 10. to extract only pixels in the low elevation zone (LEZ) which is also a flooding zone, follow this workflow (expect a longer processing time for this step):
 - a. in the Processing Toolbox panel enter "Raster calculator" in the search bar and then double click on the Raster calculator item from the "GDAL" group (Figure 69)
 - b. in the new dialog window (Figure 70) in the Input layer A dropdown (marked with 1) select the previously created clipped elevation data layer (*DEM-clipped.tif*)



Clip Raster by Mask Layer	
Parameters Log	
🐵 📼 Validate Help	
Output data type 5	
Use Input Layer Data Type	· · · · · · · · · · · · · · · · · · ·
Additional command-line parameters [optional]	l l l l l l l l l l l l l l l l l l l
-co COMPRESS=DEFLATE -wo CUTLINE_ALL_TOUCHED=TRUE	
Clipped (mask)	
C:/Users/fglic/OneDrive/Desktop/manual-novo/DEM-clipped.tif	<u> </u>
✓ Open output file after running algorithm	
GDAL/OGR console call	
gdalwarp -ovenwrite -of GTiff -tr 9.920634920634888e-05 9.920634920634888e-05 -tap -cutline reporting-units -crop_to_cutline -co COMPRESS=DEFLATE -wo CUTLINE_ALL_TOUCHED=TRUE /DEM-clipped.tif	/reporting-units.gpkg -cl v/DEM.vrt
0%	Cancel

Figure 68: Clipping virtual raster with FABDEM elevation data to reporting units (2)

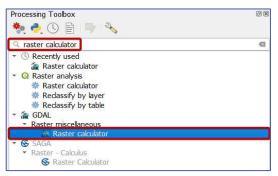


Figure 69: Accessing the GDAL's Raster calculator from the Processing Toolbox panel

- c. in the Calculation in gdalnumeric syntax field (2) in Figure 71) enter this logical formula: A <= 5 (in this case, 5 is entered because zone that is less than 5 m above sea level is defined as LEZ)
- d. in the Set output nodata value field enter **o** (**3** in Figure 71)
- e. in the Output raster type dropdown choose "Byte" (4) in Figure 71)
- f. in the Additional command-line parameters field enter: --co COMPRESS=DEFLATE (make sure to put two minuses at the beginning, as marked with (5) in Figure 71)
- g. after clicking on the three-dots-button marked with ⁽⁶⁾ in Figure 71 and choosing Save as File..., define the storage location and name for the raster that is about to be created (for name, you can use *LEZ.tif*, choose TIF or TIFF storage format)
- h. click the Run button to start raster creation based on the entered formula (7) in Figure 71)

Raster calculator	×
Parameters Log	
nput layer A	1 -
MDEM-clipped [EPSG:4326]	
Number of raster band for A	
Band 1 (Gray)	•
nput layer B [optional]	
· · · · · · · · · · · · · · · · · · ·	
Number of raster band for B [optional]	*
0%	Cancel
Run Close	Help

Figure 70: Extracting LEZ from FABDEM with GDAL's Raster Calculator (1)



Q Raster Calculator				×
Parameters Log				
Calculation in gdalnumeric syntax using +-/* or any numpy array functions (i.e. logical_and())				
A <= 5				
Set output nodata value [optional]				
				© \$
Output raster type				
Byte				
▼ Advanced Parameters				
Additional creation options [optional]				
Profile				•
Name			Valu	ie
👚 🥅 Validate Help				
Additional command-line parameters [optional]				
co COMPRESS=DEFLATE				
Calculated			-	
/LEZ.tif			6	.
✓ Open output file after running algorithm				
GDAL/OGR console call				
gdal_calc.batovenvritecalc "A <= 5 "format GTifftype ByteNoDataValue 0.0 -A	/1	DEM-clipped.	tifA_band	1co
COMPRESS=DEFLATEoutfle /LEZ.tif				
				•
0%	~)	Cancel
Run as Batch Process	1	Run	Close	Help

Figure 71: Extracting LEZ from FABDEM with GDAL's Raster Calculator (2)

11. to polygonize (convert raster layer to a vector one) raster created in the previous step with pixel values being 1, if logical formula A <= 5 is evaluated as true, or 0 if it is evaluated as false (in produced raster, pixels with value 1 are pixels from *DEM-clipped.tif* that have elevation less or equal to 5), follow this workflow:

Q Polygonize (Raster to Vector)		×
Parameters Log		
Input layer		
LEZ [EPSG:4326]		•][]
Band number		
Band 1 (Gray)		×.
Name of the field to create		
DN		
Use 8-connectedness 2		
 Advanced Parameters 		
Additional command-line parameters [optiona	n -	
		A
Vectorized	127 - 1	3
	/LEZ.gpkg	
✓ Open output file after running algorithm		
GDAL/OGR console call		
gdal_polygonize.bat -8	/LEZ.tif -b 1 -f "GPKG"	/LEZ.gpkg LEZ DN
<u>[L</u>		
	0%	Cancel
	070	
Run as Batch Process		4 Run Close Help

a. go to Raster ► Conversion ► Polygonize (Raster to Vector)...

Figure 72: Polygonizing raster layer with low elevation zone (LEZ)



- b. in the new dialog window (Figure 72), in the Input layer dropdown (marked with 1), choose the raster that is previously created with the Raster Calculator algorithm (*LEZ.tif*)
- c. tick the Use 8-connectedness option (marked with 2) in Figure 72)
- d. after clicking on the three-dots-button that is marked with ③ in Figure 72 and choosing Save as File..., define the storage location and name for the vector layer that is about to be created (for name, you can use *LEZ.gpkg*, and choose the GPKG storage format)
- e. click the Run button to start the polygonization algorithm (4) in Figure 72)
- 12. it is likely that the previously created vector layer (*LEZ.gpkg*) contains polygons that correspond to areas that have an elevation below 5 m ASL but are not contiguous to the coastline, and they should be removed:
 - a. go to Vector ► Research Tools ► Select by Location...
 - b. in a new dialog window (Figure 73), in the Select features from the dropdown (marked with 1) select a layer that was previously created by the polygonization algorithm (*LEZ.gpkg*)
 - c. make sure intersect option is the only one that is ticked under the Where the features (geometric predicate) (2 in Figure 73)
 - d. in the By comparing to the features from select vector layer with coastline data (*coastline-aoi.gpkg*, as marked with (3) in Figure 73)
 - e. make sure that in Modify current selection by "creating new selection" is the chosen option (4) in Figure 73)
 - f. click the Run button to start the algorithm that will select all polygons in the LEZ.gpkg vector layer that spatially have anything, even a single point in common with the coastline selected polygons are highlighted with yellow color in the QGIS map view, as is visible in Figure 75 (notice that this algorithm, as opposed to the most of the previous ones, does not produce any new data)

Q Select by Location	×
Parameters Log	Select by location
Select features from	This algorithm creates a selection in a vector layer.
□ LEZ [EPSG:4326]	The criteria for selecting features is based on the
Where the features (geometric predicate)	spatial relationship between each feature and the features in an additional layer.
✓ intersect □ touch <2	
🗆 contain 🗌 overlap	
disjoint are within	
equal cross	
By comparing to the features from	
🗸 coastine-aoi [EPSG:4326] 🔹 🖒	
Selected features only	
Modify current selection by	
creating new selection	
4	
0%	Cancel
Run as Batch Process	5 Run Close Help

Figure 73: Selecting polygons in the LEZ.gpkg layer that intersect with coastline

- g. open the attribute table for the LEZ.gpkg layer by right-clicking on the layer name ("LEZ") in the Layers panel and selecting Open Attribute Table (as highlighted in Figure 75)
- h. in the attribute table (Figure 74), click on the icon (1) to invert the selection (rows that correspond to the selected polygons/features are highlighted with blue color), enable layer editing by clicking on the icon (2), delete all selected



polygons/features by clicking on the \overline{m} icon (3), save edits by clicking on the \overline{m} icon (4), and finally click again on the $\sqrt{}$ icon (5) to disable layer editing

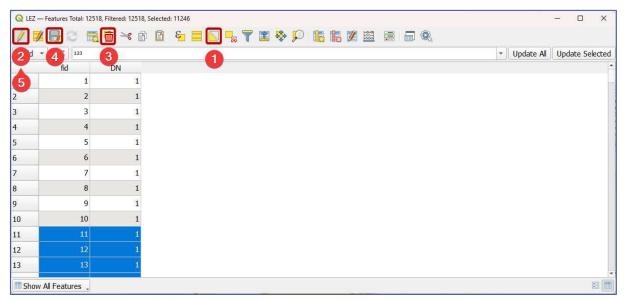


Figure 74: Removing features from the vector layer

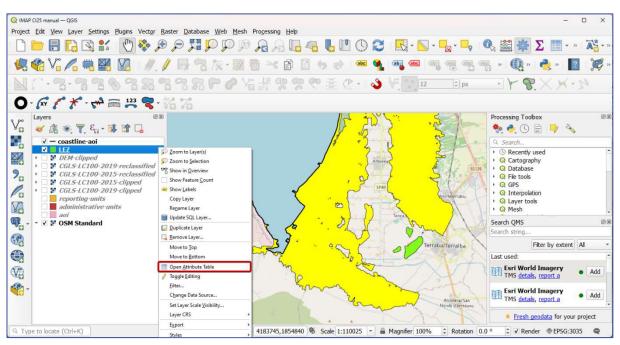


Figure 75: Selected polygons are highlighted with yellow color (by default settings) and all other remain in color assigned in corresponding layer settings – in this case, green (basemap: © OpenStreetMap contributors)

Some features/polygons in the generated *LEZ.gpkg* vector layer have topological errors, that will prevent some algorithms from making processing with them (this can be checked by going to Vector ► Geometry Tools ► Check Validity...). To fix those topological errors, you can use the Fix geometries algorithm. The Fix geometries algorithm can be accessed through the Processing Toolbox by entering "fix geometries" in the search bar, and double clicking on the "Fix geometries" item (Figure 76). After double-clicking, in a new dialog window (Figure 77):

1. under the Input layer dropdown choose the *LEZ.gpkg* layer (marked with **1** in Figure 77)



- 2. after clicking on the three-dots-button that is marked with **2** in Figure 77 and choosing Save as File..., define the storage location and name for the vector layer that is about to be created (for name, you can use *LEZ-fixed.gpkg*, and choose the GPKG storage format)
- 3. click the Run button (③ in Figure 77) to start the algorithm that will create a new *LEZ-fixed.gpkg* layer with fixed topological errors from the *LEZ.gpkg* layer

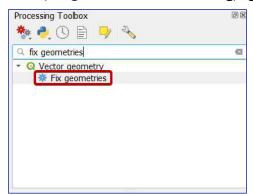


Figure 76: Accessing the Fix geometries algorithm from the Processing Toolbox panel

Q Fix Geometries		×
Parameters Log	Fix geometries	
Input layer	This algorithm attempts to create a valid	
🔎 LEZ [EPSG:4326] - 🕻 🖧 📖	representation of a given invalid geometry without	ut
Selected features only	losing any of the input vertices. Already-valid geometries are returned without further	
Fixed geometries	intervention. Always outputs multi-geometry lay	er.
/LEZ-fixed.gpkg	NOTE: M values will be dropped from the output	t.
0%	Canc	al
Run as Batch Process	3 Run Close Help	

Figure 77: Running the Fix geometries algorithm

To make some further calculations easier, remove *LEZ.gpkg* layer from the QGIS project, dissolve *LEZ-fixed.gpkg* layer by going to Vector \triangleright Geoprocessing Tools \triangleright Dissolve..., and name the output layer *LEZ.gpkg* (choose GPKG storage format and confirm the prompt that asks if you want to replace existing *LEZ.gpkg* layer).

3.4.3 Preparing data on protected areas

The downloaded ZIP archive with the WDPA data on protected areas firstly needs to be unzipped. In the unzipped folder, there is one or more (mostly three) ZIP archives with the Esri shapefiles. Combined data from all these ZIP archives contain all WDPA data for the area of interest. Each ZIP archive again needs to be unzipped. Only Esri shapefiles that have a name ending with "polygon" need to be further processed in QGIS since they contain polygonal vector layers. All polygonal vector layers need to be merged into one layer, and then two layers have to be generated out of the merged layer: one with polygons that correspond to protected areas that were established before the first year that is chosen for CCI25 calculation, and another one for areas that were established before the second chosen year. To merge multiple Esri shapefile polygon layers without firstly importing them in QGIS, follow these steps:



- 1. go to Vector ► Data Management Tools ► Merge Vector Layers...
- 2. in the new dialog window (Figure 78), click on the three-dots-button that is marked with (1)
- 3. in a new window (Figure 79), click on the Add File(s)... button (marked with 2), navigate to one of the folders created after unzipping ZIP archives, and select the file that ends with "...polygons.shp"

Q Merge Vector Layers	×
Parameters Log	Merge vector layers
Input layers 3 inputs selected	This algorithm combines multiple vector layers of the same geometry type into a single one.
Destination CRS [optional] Merged /protected-areas.gpkg	The attribute table of the resulting layer will contain the fields from all input layers. If fields with the same name but different types are found then the exported field will be automatically converted into a string type field. New fields storing the original layer name and source are also added.
☑ Open output file after running algorithm	If any input layers contain Z or M values, then the output layer will also contain these values. Similarly, if any of the input layers are multi-part, the output layer will also be a multi-part layer.
	Optionally, the destination coordinate reference system (CRS) for the merged layer can be set. If it is not set, the CRS will be taken from the first input layer. All layers will all be reprojected to match this CRS.
0%	Cancel
Run as Batch Process	6 Run Close Help

Figure 78: Merging multiple vector layers (1)

- 4. repeat the previous step for each unzipped ZIP archive
- make sure only previously selected files that end with "...polygons.shp" are ticked (in the example shown in Figure 79, three files ending with "...polygons.shp" are ticked, as marked with (3)
- 6. click the OK button (4) in Figure 79), which will again open the previous window
- 7. after clicking on the three-dots-button that is marked with ⁽⁵⁾ in Figure 78 and choosing Save as File..., define the storage location and name for the vector layer that is about to be created (for name, you can use *protected-areas.gpkg* and choose the GPKG storage format)
- 8. click the Run button to start merging vector layers algorithm (6) in Figure 78)

Merge Vector Layers Parameters Log	Merge vector layers
Input layers Input layers	Select Al Clear Selection Toggle Selection Add File(s) Add Directory OK Other instant of the instant of th
0%	Cancel
Run as Batch Process	Run Close Help

Figure 79: Merging multiple vector layers (2)

The next task would be extracting protected areas based on the year they have been established. Since some protected areas are spatially overlapping (e.g., the same zone can be protected on



different levels or different bases), we will also dissolve all protected areas. By dissolving the polygonal vector layer, all polygons that are overlapping will be flattened in a single polygon in the output layer. It is also important to know that each polygon/feature in the protected areas layer has an attribute "STATUS" that can have values: "Proposed", "Inscribed", "Adopted", "Designated", "Established", and "Not Reported". All polygons that have a value for the "STATUS" attribute either "Proposed" or "Not Reported" should not be used in further calculations. Follow these steps to take all this into account and make sure to go through them twice, for both years that are chosen for CCI25 calculation:

- 1. right click on the name of the previously created vector layer with merged protected areas (*protected-areas.gpkg*) in the Layers panel and click on Filter...
- in an opened Query Builder window (Figure 80) find "STATUS" within the Fields list (marked with 1), select it, and click the All button (marked with 2)
- 3. in the Values list check if there are values "Proposed" or "Not Reported", or some other unsuitable value (in Figure 80, only values "Adopted", "Designated" and "Inscribed" are present)
- 4. now define an expression under Provider Specific Filter Expression based on which data will be filtered (marked with ③ in Figure 80):
 - a. double click on the "STATUS_YR" in the Fields list, which will insert the "STATUS_YR" attribute name in the correct form in the Provider Specific Filter Expression filed
 - b. click on the <= button, which will again insert "<=" in the Provider Specific Filter Expression filed
 - c. manually enter a year in the Provider Specific Filter Expression filed (in Figure 80 it is "2015")
 - d. if there are no unsuitable values within the Values list for the "STATUS" attribute, the final expression would be "STATUS_YR" <= <year> (<year> should be replaced with the correct year), and if there are unsuitable values, then expression should be further expanded to take them into account, for example:
 - i. if there is a value "Proposed" within the Values list for the "STATUS" attribute, final expression should be: "STATUS_YR" <= <year> AND "STATUS" != 'Proposed'
 - ii. if there are values "Proposed" and "Not Reported", final expression should be: "STATUS_YR" <= <year> AND "STATUS" NOT IN ('Proposed', 'Not Reported')

et provider fi	ter on protect	ed-areas						
ields							Values	
GIS_AREA						*	Q Search	
NO_TAKE	FA					-	Adopted	
STATUS							Designated	2
STATUS_Y	R						Inscribed	· · · · · · · · · · · · · · · · · · ·
GOV_TYPE OWN_TYP							Sample	All
MANG_AUT	ГН							
MANG_PLA	N					*	Use unfiltered layer	
Operator	5						and and a second s	
=	<	>	LIKE	%	IN	NOT	IN	
<=	>=	!=	ILIKE	AND	OR	NC	Т	
	ocific Filtor	Expression						
rovider Sp	come rinter							
_	YR" <= 201	3						
"STATUS_		3						
_		3						

Figure 80: Filtering features in vector based on values of their attributes



- 5. after clicking on the OK button (marked with 4 in Figure 80) polygons/features will be filtered based on the defined expression, i.e., all features that do not fulfill conditions from the expression will remain stored within the layer, but will not be shown it the map view and will not be used in any processing with this layer, also, next to the layer name in the Layers panel, there will be shown a remain the remains the shown a remains th
- 6. to dissolve polygons in this layer, go to Vector ► Geoprocessing Tools ► Dissolve...
- 7. in a new dialog window (Figure 81), under the Input layer dropdown (marked with 1) choose the layer with protected areas that was previously filtered (*protected-areas.gpkg*)
- 8. after clicking on the three-dots-button that is marked with 2 in Figure 81 and choosing Save to File..., define the storage location and name for the vector layer that is about to be created (for name, you can use *protected-areas-<year>.gpkg*, replace *<year>* with the correct year (same that was used for filtering), and choose the GPKG storage format)
- 9. click the Run button to start the dissolving algorithm (marked with **3** in Figure 81)
- 10. open attribute table of the created vector layer (*protected-areas-<year>.gpkg*) and delete all attributes except "fid"

Q Dissolve		>
Parameters Log	Dissolve	
Input layer	This algorithm takes a vector layer and con	nbines
🖙 protected-areas [EPSG:4326] 🔹 🖒	their features into new features. One or mo attributes can be specified to dissolve feature	ore
Selected features only	belonging to the same class (having the sar	me
Dissolve field(s) [optional]	value for the specified attributes), alternativ features can be dissolved in a single one.	rely all
0 options selected	All output geometries will be converted to m	nulti
Dissolved /protected-areas-2015.gpkg	geometries. In case the input is a polygon l common boundaries of adjacent polygons b dissolved will get erased.	ayer,
☑ Open output file after running algorithm		
0%		Cancel
Run as Batch Process	3 Run Close	Help

Figure 81: Dissolving features in a vector layer

Q Layer Properties — protected-areas — S	ource X
Q	▼ Assigned Coordinate Reference System (CRS)
Information	EPSG:4326 - WGS 84
Source	Changing this option does not modify the original data source or perform any reprojection of features. Rather, it can be used to override the layer's CRS within this project if it could not be detected or has been incorrectly detected.
💜 Symbology	The Processing "Reproject Layer" tool should be used to reproject features and permanently change a data source's CRS.
(abc) Labels	▼ Geometry
abo Masks	Spatial Index Exists Update Extents
😚 3D View	
Magrams	Provider Feature Filter
[Fields	"STATUS_YR" <= 2015
🗄 Attributes Form	
Joins	
💼 Auxiliary Storage	
S Actions	4 D
🤛 Display	Query Builder
🞸 Rendering	Style * OK Cancel Apply Help

Figure 82: Accessing Query Builder through layer properties



Again, make sure to follow the previous steps twice, for both years that are chosen for CCI25 calculation. After finishing with dissolving protected areas for both years, the filer can be removed by deleting the filter expression in the Query Builder window. As already mentioned, the Query Builder window can be accessed by right-clicking on the layer name in the Layers panel and then clicking on the Filter..., but it can also be accessed through layer properties:

- 1. right click on the layer name in the Layers panel and then click on the Properties...
- 2. go to the Source tab on the left side
- 3. click on the Query Builder button (as highlighted in Figure 82)



4 CALCULATING INDICATOR PARAMETERS

After processing that is done in previous chapters, all layers that are needed for further processing should be prepared. In the QGIS project, layers that should be present are:

- aoi.gpkg
- coastline-aoi.gpkg
- administrative-units.gpkg
- reporting-units.gpkg
- CGLS-LC100-<year1>-clipped.tif
- CGLS-LC100-<year2>-clipped.tif
- CGLS-LC100-<year1>-reclassified.tif
- CGLS-LC100-<year2>-reclassified.tif
- DEM-clipped.tif
- LEZ.gpkg
- protected-areas.gpkg
- protected-areas-<year1>.gpkg
- protected-areas-<year2>.gpkg
- (and basemap imported with the QuickMapServices plugin)

All other layers that are not in the above list can be removed from the QGIS project and can also be deleted from the computer storage. Some of the layers mentioned above are not directly needed in further steps, but it is advised to keep them stored since they contain useful information that might be needed at some point, especially if some steps would have to be reprocessed. In the following sections, we will first overlay vector layers, and then raster layers with reporting units. After overlaying and area calculations, we will export data to spreadsheets and calculate indicator parameters.

4.1 Overlaying vector data with the reporting units

4.1.1 Overlaying data on protected areas with reporting units

To overlay two layers with data on protected areas with reporting units, go to Vector \blacktriangleright Geoprocessing Tools \blacktriangleright Intersection..., click on the Run as Batch Process...button, click once on the P button, and define options by following the example shown in Figure 83 (for names of the output layers, you can use *RU-protected-areas-<year1>.gpkg* and *RU-protected-areas-*

🏶 🕀 📼 🛅 🖪 Input layer		Overlay lay	er) keep (leave empt	y to l	o keep (leave emp	ty to	Intersection	
L Autofil		Autofil		_ Autofil		Autofil		Autofil	
protected-areas-2015 🔹	À	reporting-units 👻		0 options selected		0 options selected		/RU-protected-areas-2015	
protected-areas-2019 -	×	reporting-units 🔹	2	0 options selected	1.00	0 options selected		/RU-protected-areas-2019	
Load layers on completion									
2 Load layers on completion				0%					Cance

Figure 83: Intersecting layers with protected areas with reporting units



<year2>.gpkg, and choose GPKG storage format). Open the attribute table for both layers, open the Field Calculator window, and for both layers create a new attribute by following the options shown in Figure 84 and save edits done in an attribute table. Function \$area will calculate the area of each polygon in the vector layer on the surface of the ellipsoid that was defined in the project settings and will present those areas in the unit that was also defined in the project settings.

✓ Create a new field	Update existing field				
Create virtual field					
Output field name area_m2					
Output field type Decimal number (real)					
Output field length 0 Precision 3 2					
Expression Function Editor					
	Q	Search	Show Help		
\$area = + - / * ^ () '\n'	· A · A · C	ow_number ggregates rrays olor onditionals onversions ate and Time	•		
Feature Aristanis/Oristano	• F	ields and Values			
		les and Paths			
Preview: 139818440.2578969					

Figure 84: Defining a new attribute in the Field Calculator window

4.1.2 Overlaying LEZ with reporting units

Again, go to Vector \triangleright Geoprocessing Tools \triangleright Intersection... to overlay LEZ layer with reporting units layer. Define all options in the same way as in Figure 85, name the output layer with *RU*-LEZ.gpkg and choose the GPKG storage format. Open the attribute table and then in the Field

Q Intersection	>
Parameters Log	Intersection
Input layer	This algorithm extracts the overlapping portions of
🖙 LEZ [EPSG:4326]	features in the Input and Overlay layers. Features
Selected features only	in the output Intersection layer are assigned the attributes of the overlapping features from both
Overlay layer	the Input and Overlay layers.
🖙 reporting-units [EPSG:4326] 🔹 🗘 📖	
Selected features only	
Input fields to keep (leave empty to keep all fields) [optional]	
0 options selected	
Overlay fields to keep (leave empty to keep al fields) [optional]	
0 options selected	
Advanced Parameters	
Overlay fields prefix [optional]	
Intersection	
/RU-LEZ.gpkg @	
Open output file after running algorithm	
0%	Cancel
Run as Batch Process	Run Close Help

Figure 85: Intersecting LEZ layer with reporting units layer



Calculator window and create a new attribute with values that correspond to the area of each polygon (the same as in Figure 84). When finished, save edits done in the attribute table.

4.1.3 Calculating areas of reporting units

In reporting units layer, create a new attribute with values that correspond to the area of each polygon by opening the attribute table for the reporting units layer, and following settings in the Field Calculator window from Figure 86. When finished, save edits that are done in the attribute table.

reporting-units — Field Calculator Only update 0 selected features		×
✓ Create a new field	Update existing field	
Create virtual field		
Output field name area_m2		
Output field type Decimal number (real)		· · · ·
Output field length 0 Precision 3		
Expression Function Editor		
	Q Search Show Help	
\$area = + - / * ^ () \n' Feature Aristanis/Oristano Preview: 40832800.16819387	row_number Aggregates Arrays Color Conditionals Conversions Date and Time Fields and Values Files and Paths Fuzzy Matching General 	
		OK Cancel Help

Figure 86: Defining a new attribute in the Field Calculator window

4.2 Overlaying raster LC/LU data with the reporting units

We first need to calculate the area of each pixel in the LC/LU raster on the surface of the ellipsoid, then extract pixels that correspond to each LC/LU class, and sum their areas for each reporting unit. To calculate the area for each pixel, enter "r.mapcalc.simple" in the search bar of the Processing Toolbox panel and double-click on the r.mapcalc.simple item. In a new window (Figure 87), in the Raster layer A dropdown choose any of the CGLS-LC100 layers. In the Formula field enter area(), and in the Output Raster format options field enter COMPRESS=DEFLATE. For the name choose area.tif and click on the Run button to start the algorithm.

Now we will use the raster calculator to extract pixels from the *area.tif* raster that correspond to each LC/LU class and separately for each year that is chosen for CCl25 calculation. In the Processing Toolbox panel enter "Raster calculator" in the search bar and then double click on the Raster calculator item from the "GDAL" group (Figure 69). In the Input layer A choose reclassified CGLS-LC100 layer for one of the years that were chosen for CCl25 calculation (in the example in Figure 88 *CGLS-LC100-<year1>-reclassified.tif* was chosen). Under the Input layer B choose the previously created *area.tif* raster layer. In the Calculation in gdalnumeric syntax field enter (A==1)*B, in the Set output nodata value enter "O", in the Output raster type dropdown choose "Float32", in the Additional command-line parameters enter --co COMPRESS=DEFLATE, define the name of the output layer as *built-up-<year1>.tif*, and click on the Run button. The layer was named *built-up-<year1>.tif* because in reclassified CGLS-LC100-syear1>-reclassified CGLS-LC100-syear1>.tif because in reclassified CGLS-LC100-raster, pixels with value 1 match to built-up class, which corresponds to the defined expression (A==1)*B. This processing has to be done for additional nine times: the first four times with the *CGLS-LC100-<year1>-reclassified.tif* layer chosen under



r.mapcalc.simple		
Parameters Log	r.mapcalc.simple	
Formula	Calculate new raster map from a r.mapcak	C
area()	expression.	
 Advanced Parameters 		
GRASS GIS 7 region extent [optional]		
Not set		
GRASS GIS 7 region cellsize (leave 0 for default)		
0.000000	۰	
Output Rasters format options (createopt) [optional]		
COMPRESS=DEFLATE		
Output Rasters format metadata options (metaopt) [optional]		
alculated		
/area.tif	A A A A A A A A A A A A A A A	
🗹 Open output file after running algorithm	v	
0%		Cancel
un as Batch Process	Run Close	

Figure 87: Calculating area for each pixel in the CGLS-LC100 raster layers

the Input layer A dropdown, and five times with the *CGLS-LC100-<year1>-reclassified.tif* layer. Every time you need to change the expression in the Calculation in gdalnumeric syntax field and output layer name. When the expression is (A==2)*B, the output layer name should be *agricultural-*<*year#>.tif*, when the expression is (A==3)*B, it should be *forest-seminatural-year#>.tif*, when the expression is (A==3)*B, it should be *wetlands-year#>.tif*, and when the expression is (A==5)*B, it should be *waterbodies-year#>.tif*. After this processing, 10 new raster layers should be produced:

- built-up-<year1>.tif
- agricultural-<year1>.tif
- forest-seminatural-<year1>.tif
- wetlands-<year1>.tif
- waterbodies-<year1>.tif

- built-up-<year2>.tif
- agricultural-<year2>.tif
- forest-seminatural-<year2>.tif
- wetlands-<year2>.tif
- waterbodies-<year2>.tif

Pixel values in these rasters are areas of each pixel in square meters, but only pixels that correspond to the particular LC/LU class, and all other pixels have a value "O". We could not speed up this processing with the batch processing option, since batch processing does not allow defining all the necessary settings.

Q Raster Calculator		×
Parameters Log		
Input layer A		^
CGLS-LC100-2015-reclassified [EPSG:4326]		•
Number of raster band for A		
Band 1 (Palette)		-
Input layer B [optional]		
area [EPSG:4326]		•
0%		Cancel
Run as Batch Process	Run Close	Help

Figure 88: Using GDAL's Raster Calculator to extract pixels from the area.tif raster that correspond to a particular LC/LU class (1)



Q Raster Calculator		×
Parameters Log		
Calculation in gdalnumeric syntax using +-/* or any numpy array functions (i.e. logical_and())		*
(A==1)*B		
Set output nodata value [optional]		
0.000000		
Output raster type		
Float32		•
▼ Advanced Parameters		
Additional creation options [optional]		
Profile		•
Name Value		
🛞 📟 Validate Help		
Additional command-line parameters [optional]		
co COMPRESS=DEFLATE		
Calculated		
/buit-up-2015.tif		Ø,
☑ Open output file after running algorithm		
0%		Cancel
Run as Batch Process	Run Close	Help

Figure 90: Using GDAL's Raster Calculator to extract pixels from the area.tif raster that correspond to a particular LC/LU class (2)

We will now use the zonal statistics algorithm to sum all the pixel values from the previously created raster layers that fall within each reporting units polygon. Enter "Zonal statistics" in the Processing Toolbox panel and double-click on the Zonal statistics item. In a new dialog window click on the Run as Batch Process... button, and then press the
button nine times. Under the Input layer and Raster layer select the same layer as in the example in Figure 89. In the Statistics to calculate column, for each row click on the three-dots-button and tick only the "Sum" item. Name the output vector layers in the same way as in the example in Figure 91, make sure the Load layers on completion option is ticked, and click on the Run button.

4	📼 🚞 🗒 Input layer		Raster layer	Raster band	Output column prefix	Statistics to calculat	to	
1	Autofil		Autofil	Autofil	Autofil	Autofil	LC .	F
2	reporting-units [EPSG:4326] •	2	 F built-up-2015 [EPSG:4326]	 Band 1 (Gray) -		1 options selected		eC
3		Z	 * buit-up-2019 [EPSG:4326]	 Band 1 (Gray) -	^	1 options selected	l	1-
1		2	 agricultural-2015 [EPSG:4326]	 Band 1 (Gray) -	_	1 options selected		VE
5		2	 ₽ agricultural-2019 [EPSG:4326]	 Band 1 (Gray) -	_	1 options selected		Ve
5		R	 ✗ forest-seminatural-2015 [EPSG:432 ▼	 Band 1 (Gray) 🔹		1 options selected		kt
7		2	 Forest-seminatural-2019 [EPSG:432 -	 Band 1 (Gray) -	_	1 options selected		kt
8	reporting-units [EPSG:4326] *	Z	 ¥ wetlands-2015 [EPSG:4326] •	 Band 1 (Gray) *	_	1 options selected		Dri
9	reporting-units [EPSG:4326] 🔹	R	 ¥ wetlands-2019 [EPSG:4326] •	 Band 1 (Gray) 🔹		1 options selected][Dri
10	reporting-units [EPSG:4326] *	2	 waterbodies-2015 [EPSG:4326]	 Band 1 (Gray) *	_	1 options selected		e/
11	reporting-units [EPSG:4326] 🔹	2	 waterbodies-2019 [EPSG:4326]	 Band 1 (Gray) *	_	1 options selected][e/
4								,
1	Load layers on completion							

Figure 89: Using the Zonal statistics algorithm to sum areas of each LC/LU class within each reporting unit (1)



	ayer		Raster band	Output column prefix	Statistics to calcul	ate	Zonal Statistics	
1	l		Autofil	Autofil	Autofil	Ţ.	Autofil	
2	326] 🔹		Band 1 (Gray) 🔹	-	1 options selected		/buit-up-2015.gpkg	
3	326] 🔹		Band 1 (Gray) 🔹	<u></u>	1 options selected]	/buit-up-2019.gpkg	
4	G:4326] 🔹		Band 1 (Gray) *	_	1 options selected		/agricultural-2015.gpkg	
5	G:4326] *		Band 1 (Gray) *	_	1 options selected		/agricultural-2019.gpkg	
6	15 [EPSG:432 -		Band 1 (Gray) 🔹	_	1 options selected][]	/forest-seminatural-2015.gpkg	
7	19 [EPSG:432 -		Band 1 (Gray) *	_	1 options selected		/forest-seminatural-2019.gpkg	
8	4326] 🔹		Band 1 (Gray) *	_	1 options selected		/wetlands-2015.gpkg	
9	4326] *		Band 1 (Gray) 🔹	_	1 options selected		/wetlands-2019.gpkg	
10	SG:4326] •		Band 1 (Gray) +	_	1 options selected		/waterbodies-2015.gpkg	
11	SG:4326] •		Band 1 (Gray) *	_	1 options selected		/waterbodies-2019.gpkg	
• • •	Load layers on co	mple	tion					
					0%			Cance
2	n as Single Proces	c					Run Close	Help

Figure 91: Using the Zonal statistics algorithm to sum areas of each LC/LU class within each reporting unit (2)

The same processing that was done with the Zonal statistics algorithm needs to be done again, but this time within LEZ across reporting units. All settings should be the same as on Figure 89 and Figure 91, except that Input layer should be changed to *RU-LEZ.gpkg* in all rows and names of the output vector layers need to be changed. Names can be changed by just adding prefix "LEZ-" to already defined output layer names that are visible in Figure 91 (for example, name of the layer in the first row in Figure 91 should be changed to *LEZ-built-up-2015.gpkg*). This will produce another 10 new layers, so with Zonal statistics algorithm 20 new layers will overall be created.

4.3 Combining all calculated data in one table

After all processing that was done in the previous sections, all data that are required for final CCl25 calculation are prepared and stored in corresponding attribute tables, and they just need to be merged into one table. In the Layers panel, right click on the layer with original reporting units (*reporting-units-gpkg*), and click on the Properties... In the Layer Properties window, in the Joins tab (on the left side of the window) click on the end to be button. In a new window (visible in Figure 92) define settings for joining attribute data of two vector layers and repeat this step for every layer that was produced with the Intersection and the Zonal statistics algorithm. For joining data from the *RU-LEZ.gpkg* layer follow setting from the left screenshot in Figure 92, and for each of two layers produced with intersecting reporting units with protected areas (*RU-protected-areas-<year1>.gpkg*) and *RU-protected-areas-<year2>.gpkg*) follow settings from right screenshot. For each of the first 10 layers that were produced with the Zonal statistics algorithm (those layers that do not have a "LEZ-" prefix in their name), follow settings from the left screenshot in Figure 93, and for the second 10 created layers (those that have a "LEZ-" prefix in their name) use settings from right screenshot. After defining all these joins, the Joins tab of the *reporting-units.gpkg* layer should look like the one on Figure 94.



Q Add Vector Join		×	Q Add Vector Join		×
Join layer	🕅 RU-LEZ	-	Join layer	RU-protected-areas-20	015 -
Join field	123 fid_2	-	Join field	123 fid_2	•
Target field	123 fid	-	Target field	123 fid	•
✓ Cache join layer in memory			✓ Cache join layer in memory		
Create attribute index on join fie	łd		Create attribute index on join	field	
Dynamic form			Dynamic form		
▼ Edi <u>t</u> able join layer			🖝 🗌 Edi <u>t</u> able join layer		
Upsert on edit			Upsert on edit		
▼ ✓ Joined fields			▼ ✓ Joined fields		
fid DN fid_2 name local_name name_en strip ✔ area_m2			fid fid_2 name local_name name_en strip ✔ area_m2		
Custom field name prefix			Custom field name prefix RU-protected-areas-2015_	;	
	OK Cancel	Help		OK Cancel	Help

Figure 92: Joining data from attribute table of RU-LEZ.gpkg, and RU-protected-areas-2015.gpkg layers with data from attribute table of reporting-units.gpkg layer

Q Add Vector Join		×	Q Add Vector Join		×
Join layer	🔎 built-up-2015	*	Join layer	C LEZ-built-up-2015	•
Join field	123 fid	•	Join field	123 fid_2	•
Target field	123 fid	-	Target field	123 fid	•
✓ Cache join layer in memory			✓ Cache join layer in memory		
Create attribute index on join f	ield		Create attribute index on join f	field	
Dynamic form			Dynamic form		
Edi <u>t</u> able join layer			Edi <u>t</u> able join layer		
Upsert on edit			Upsert on edit		
Delete cascade			Delete cascade		
▼ ✓ Joined fields			▼ √ joined fields		
fid name local_name name_en strip area_m2 ✓			fid DN fid_2 name local_name name_en strip area_m2 ✓sum		
Custom field name prefix built-up-2015_			Custom field name prefix		
	OK Cancel	Help		OK Cancel	Help

Figure 93: Joining data from attribute table of built-up-2015.gpkg and LEZ-built-up-2015.gpkg layers with data from attribute table of reporting-units.gpkg layer



Q Layer Properties — reporting-units — .	loins					×
Q	Setting	Value				
-	> Join layer	RU-LEZ				
🥡 Information 👘		RU-protected-areas-2015				
	Join layer	RU-protected-areas-2019				
🍓 Source		built-up-2015				
	Join layer	built-up-2019				
🐳 Symbology		agricultural-2015				
		agricultural-2019				
(abo Labels		wetlands-2015				
		wetlands-2019				
DB Masks		waterbodies-2015				
~		waterbodies-2019				
🌱 3D View		forest-seminatural-2015				
		forest-seminatural-2019				
Magrams		LEZ-built-up-2015				
	Join layer	LEZ-built-up-2019				
Fields	Join layer	LEZ-agricultural-2015				
		LEZ-agricultural-2019				
🔚 Attributes Form		LEZ-forest-seminatural-2015				
		LEZ-forest-seminatural-2019				
• Joins		LEZ-wetlands-2015				
		LEZ-wetlands-2019				
auxiliary Storage		LEZ-waterbodies-2015				
S Actions	Join layer	LEZ-waterbodies-2019				
🤛 Display						
1	æ 😑 🥖					
🎸 Rendering	Style -		ОК	Cancel	Apply	
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Figure 94: Joins tab of the reporting-units.gpkg layer after defining all joins

After clicking on the OK button in the Layer Properties window (Figure 94), attribute table of the *reporting-units.gpkg* layer should be populated with all data that are needed for calculating CCI25 parameters. In the Layers panel, right click on the reporting units layer (*reporting-units.gpkg*), choose Export, and then Save Features As... In a new Save Vector Layer As... dialog window (Figure 95), in the Format dropdown choose XLSX, in the File name field define name and storage location of the output file (you can use *CCI25-calculation.xlsx* for name) and click on the OK button.

Format	MS Office Open XM	1L spreadsheet [XLSX]			
File name		N	CCI25-calculation.xlsx 🗠			
Layer name	CCI25-calculation					
CRS	EPSG:4326 - WGS 84					
Encoding	UTF-8			Ψ.		
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▼ Select field	111	d their export optio				
	e lds to export an Name	Туре	ns	1		
✓ fid	111	Type Integer64				
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Figure 95: Exporting data from attribute table in XLSX file



4.4 Calculating indicator parameters and representing results

XLSX file that was exported from QGIS contains all data that is necessary to calculate CCI25 parameters. We suggest that before conducting any other calculations, you divide all values in all cells in a spreadsheet that represent area with 1000000 so that results are expressed in km², instead of m². These are the parameters that have to be calculated for first monitoring:

- 1. km² of built-up area in coastal zone
- 2. % of built-up area in coastal zone
- 3. % of other land cover classes in coastal zone
- 4. % of built up area within coastal strips of different width compared to wider coastal units
- 5. % of other land cover classes within coastal strips of different width compared to wider coastal units
- 6. km² of protected areas within coastal strips of different width
- 7. km² of LEZ
- 8. km2 of built-up area within LEZ
- 9. % of built-up area within LEZ
- 10. % of built-up area within LEZ compared to coastal administrative unit
- 11. % of other land cover classes within LEZ
- 12. % of other land cover classes within LEZ compared to coastal administrative unit
- 13. km² of protected areas within LEZ in coastal zone

For the second monitoring, these parameters have to be calculated:

- 1. % of increase of built-up area, or land take
- 2. % of change of other land cover classes
- 3. % of change of protected areas
- 4. % of increase of built-up area, or land take within LEZ
- 5. % of change of other land cover classes within LEZ
- 6. % of change of protected areas within LEZ

All these parameters can be calculated by applying suitable filters and summing values in XLSX file or by creating pivot tables. We also suggest that you convert range with values (not empty cells) to table. In Microsoft Excel, to convert range to table, select one cell that is within the range, and then choose one of the predefined table styles after clicking on the Format as table in Styles group in the Home ribbon. After converting to table, spreadsheet should look similar to the one in Figure 96.

- 14	A B	С	D	E	F	G	Н	I
1 fid	💌 name	Iocal_name	name_en	💌 strip	💌 area_m2 🛛 💌	RU-LEZ_area_m2	RU-protected-areas-2015_area_n	RU-protected-areas-2019_area_n
2	1 Trieste	Trieste	Trieste	0 - 300 m	14,44094685	5,8103938	2,232523506	2,232523506
3	2 Trieste	Trieste	Trieste	1 - 10 km	168,5141639	1,609116633	88,06970819	88,06970819
4	3 Trieste	Trieste	Trieste	300 - 1000 m	29,13517235	1,922336253	6,93684203	6,93684203
5	4 Udine	Udine	Udine	0 - 300 m	5,389045508	4,675066961	2,876090623	2,876090623
6	5 Udine	Udine	Udine	1 - 10 km	261,446023	248,3850526	82,04528306	82,04528306
7	6 Udine	Udine	Udine	300 - 1000 m	11,51394894	9,321704533	6,812589291	6,812589291
8	7 Trapani	Trapani	Trapani	0 - 300 m	87,0941698	36,67230928	49,18298478	49,18298478
9	8 Trapani	Trapani	Trapani	1 - 10 km	1114,034148	21,65200315	205,628094	205,628094
10	9 Trapani	Trapani	Trapani	300 - 1000 m	155,1766104	29,26653241	67,01235032	67,01235032
11	10 Nord-Est Sa	rdegn Nord-Est Sard	degn Nord-Est Sa	rdegn 0 - 300 m	134,5117082	37,54668822	46,79671348	46,79671348
12	11 Nord-Est Sa	rdegn Nord-Est Sard	degn Nord-Est Sa	rdegn 1 - 10 km	1142,798075	13,53574137	4,663905612	4,663905612
13	12 Nord-Est Sa	rdegn Nord-Est Sard	degn Nord-Est Sar	rdegn 300 - 1000 m	181,5217638	17,00958596	32,01943506	32,01943506
14	13 Padova	Padova	Padova	1 - 10 km	14,84487667	14,84457324	14,39332751	14,39332751
15	14 Ragusa	Ragusa	Ragusa	0 - 300 m	25,28219956	13,66956124	2,397879188	2,397879188
16	15 Ragusa	Ragusa	Ragusa	1 - 10 km	619,2365414	11,83588323	32,08512504	32,08512504
17	16 Ragusa	Ragusa	Ragusa	300 - 1000 m	55,63983446	9,55907744	3,605773639	3,605773639
18	17 Foggia	Foggia	Foggia	0 - 300 m	54,63424066	29,03934671	41,13484714	41,13484714
19	18 Foggia	Foggia	Foggia	1 - 10 km	1394,714722	301,5581317	721,565292	721,565292
20	19 Foggia	Foggia	Foggia	300 - 1000 m	110,7891231	52,00006324	79,05238413	79,05238413
21	20 Frosinone	Frosinone	Frosinone	1 - 10 km	29,24503409	0	16,73924044	16,73924044
22	21 Messina	Messina	Messina	0 - 300 m	106,0084806	33,61608656	41,12672151	41,12672151

Figure 96: Spreadsheet after converting rage to table

In columns B, C, and D are the names of the administrative units, and in column E are the names of the coastal strips ("0 - 300 m", "300 - 1000 m", and "1 - 10 km"). In all other columns to the right of the column E are areas that are in example in Figure 96 already divided by 100000, so they



are expressed in km². To create a pivot table in Microsoft Excel, go to the Insert tab and click on the Pivot Table button and then by draging&dropping column/field names in Filters, Columns, Rows, and Values areas generate different pivot tables and calculate CCI25 parameters.

In tables and figures below, there are some examples and suggestions how can results of indicator calculation be visualizes in form of tables or graphs.

2015		Built- up areas	Agricultural land	Forest and semi-natural land	Wetlands	Water bodies	Total coastal zone
Albania	Area in km ²	166.52	1,289.57	1,712.20	36.11	197.56	3,401.96
	% in coastal zone	4.89	37.91	50.33	1.06	5.81	100.00
Durrës County	Area in km ²	55.73	215.13	152.08	2.29	7.64	432.86
	% in coastal zone	12.87	49.70	35.13	0.53	1.77	100.00
Fier County	Area in km ²	12.05	271.41	97.67	11.18	86.52	478.82
	% in coastal zone	2.52	56.68	20.40	2.33	18.07	100.00
Gjirokastër County	Area in km ²	0.00	0.22	8.68	0.00	0.00	8.89
	% in coastal zone	0.00	2.47	97.53	0.00	0.00	100.00
Lezhë County	Area in km ²	27.90	240.65	156.42	13.11	17.06	455.13
	% in coastal zone	6.13	52.87	34.37	2.88	3.75	100.00
Shkodër	Area in km ²	3.11	77.61	46.79	2.20	6.72	136.44
	% in coastal zone	2.28	56.89	34.30	1.61	4.93	100.00
Tirana County	Area in km ²	22.22	137.95	109.70	0.59	4.75	275.22
	% in coastal zone	8.08	50.13	39.86	0.21	1.73	100.00
Vlorë County	Area in km ²	45.50	346.60	1,140.88	6.74	74.88	1,614.60
	% in coastal zone	2.82	21.47	70.66	0.42	4.64	100.00

Table 1: Areas by CCI25 LC/LU classes in the coastal zone (0 – 10 km) and their percentage for Albania, year 2015

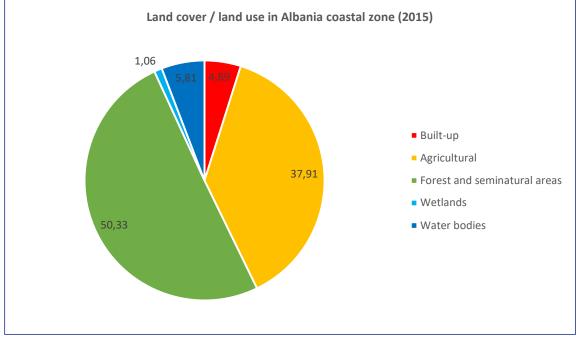


Figure 97: CCI25 LC/LU classes in Albanian coastal zone (0 – 10 km), year 2015



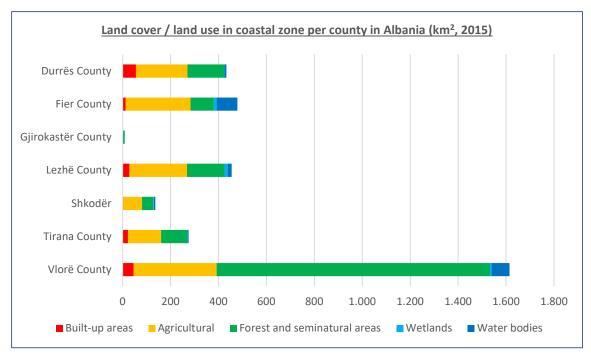


Figure 98: Areas of CCI25 LC/LU classes in Albanian coastal zone (0 – 10 km) per county, year 2015

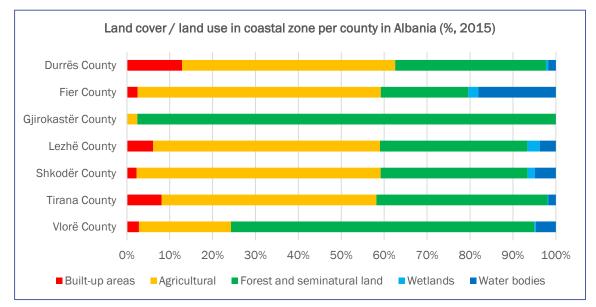


Figure 99: Percentages of CCI25 LC/LU classes in Albanian coastal zone (0 – 10 km) per county, year 2015



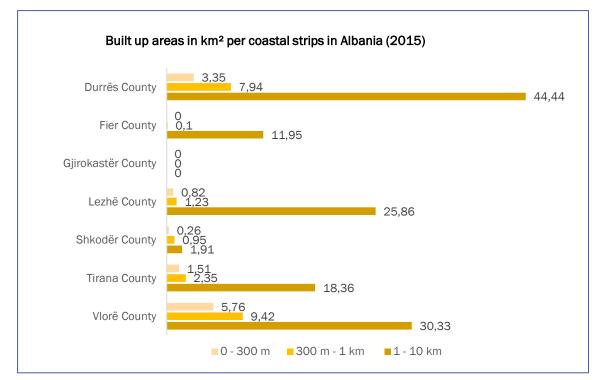


Figure 100: Built-up areas in Albanian coastal zone (0 – 10 km) per counties per coastal strips, year 2015

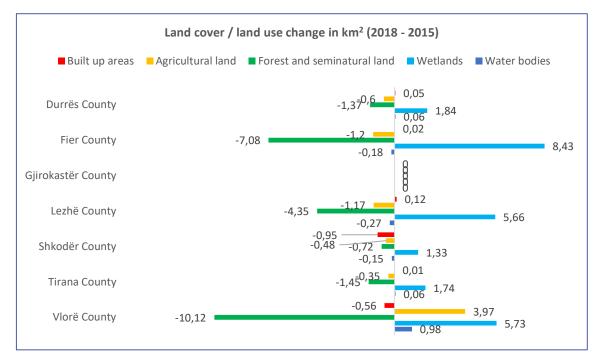


Figure 101: Change (in km²) in CCI25 LC/LU classes in Albanian coastal zone (0 – 10 km) per county, from 2015 to 2018



Table 2: LC/LU change from 2015 to 2018 in km² and percentages per Albanian counties,
per coastal strips

	Coastal strips		Coastal zone	с	oastal strip	DS	Coastal zone		
2018 - 2015	0 - 300 m	300 m -1 km	1 - 10 km	0 - 10 km	0 - 300 m	300 m - 1 km	1 - 10 km	0 - 10 km	
Built-up areas		Area	as in km²		Change	in percenta	age (2018-	2015)/2015	
Durrës County	0.02	0.00	0.03	0.05	0.60	0.00	0.07	0.09	
Fier County	0.00	0.00	0.02	0.02	0.00	0.00	0.17	0.17	
Gjirokastër County	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Lezhë County	0.05	0.00	0.07	0.12	6.10	0.00	0.27	0.43	
Shkodër County	0.00	-0.25	-0.70	-0.95	0.00	-26.32	-36.65	-30.45	
Tirana County	0.00	0.00	0.01	0.01	0.00	0.00	0.05	0.05	
Vlorë County	0.00	-0.40	-0.17	-0.57	0.00	-4.25	-0.56	-1.25	
Total	0.07	-0.65	-0.74	-1.32	0.60	-2.96	-0.56	-0.79	
Agricultural land		Area	as in km²		Change	in percenta	age (2018-	2015)/2015	
Durrës County	-0.17	-0.45	0.03	-0.59	-10.63	-4.51	0.01	-0.27	
Fier County	-0.04	-0.24	-0.93	-1.21	-26.67	-11.82	-0.35	-0.45	
Gjirokastër County	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Lezhë County	-0.17	-0.31	-0.69	-1.17	-16.83	-5.36	-0.30	-0.49	
Shkodër County	-0.09	-0.09	-0.30	-0.48	-39.13	-4.19	-0.40	-0.62	
Tirana County	-0.11	-0.11	-0.14	-0.36	-11.83	-1.25	-0.11	-0.26	
Vlorë County	-0.10	0.85	3.22	3.97	-4.85	10.81	0.96	1.15	
Total	-0.68	-0.35	1.19	0.16	-11.37	-0.96	0.10	0.01	
Forest and semi-natural land		Area	as in km²		Change in percentage (2018-2015)/2015				
Durrës County	-0.56	-0.14	-0.67	-1.37	-5.49	-0.70	-0.55	-0.90	
Fier County	-0.51	-1.38	-5.19	-7.08	-30.00	-14.10	-6.02	-7.25	
Gjirokastër County	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Lezhë County	-1.14	-1.38	-1.83	-4.35	-27.08	-10.92	-1.31	-2.78	
Shkodër County	-0.30	-0.16	-0.26	-0.72	-27.03	-3.11	-0.64	-1.54	
Tirana County	-0.38	-0.42	-0.65	-1.45	-7.85	-3.85	-0.69	-1.32	
Vlorë County	-1.16	-2.44	-6.52	-10.12	-2.08	-2.16	-0.67	-0.89	
Total	-4.05	-5.92	-15.12	-25.09	-5.20	-3.45	-1.03	-1.47	
Water bodies		Area	as in km²		Change in percentage (2018-2015)/2015				
Durrës County	0.00	-0.01	0.08	0.07	0.00	-1.64	3.10	0.92	
Fier County	0.18	-0.11	-0.24	-0.17	1.69	0.00	0.00	-0.20	
Gjirokastër County	0.00	0.00	0.00	0.00	0.00		0.00	0.00	
Lezhë County	-0.12	-0.17	0.01	-0.28	-1.73	-3.05	0.22	-1.64	
Shkodër County	-0.02	-0.03	-0.10	-0.15	-1.12	-3.70	-2.43	-2.23	
Tirana County	-0.01	0.00	0.07	0.06	-0.36	0.00	6.73	1.26	
Vlorë County	0.10	0.09	0.80	0.99	1.25	1.43	1.32	1.32	
Total	0.13	-0.23	0.62	0.52	0.38	-0.75	0.47	0.26	
Wetlands		Area	as in km²		Change in percentage (2018-2		2015)/2015		
Durrës County	0.71	0.60	0.53	1.84	94.67	68.97	79.10	80.35	
Fier County	0.37	1.72	6.34	8.43	25.52	46.74	104.79	75.40	
Gjirokastër County	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Lezhë County	1.38	1.85	2.44	5.67	40.12	42.73	45.78	43.28	
Shkodër County	0.41	0.26	0.67	1.34	53.25	49.06	74.44	60.91	
Tirana County	0.49	0.53	0.72	1.74	326.67	441.67	225.00	294.92	
Vlorë County	1.16	1.90	2.67	5.73	123.40	82.97	76.29	85.14	
Total	4.52	6.86	13.37	24.75	60.27	58.04	79.73	68.58	



Table 3: Areas in LEZ across LC/LU classes in Albanian coastal zone (0 -10 km) per counties

	Total	Total Built-	Built-up in different coastal strips [km²] 1			Total Agriculture	Total Forest and semi-	Total Wetlands	Total Waterbodies	
Administrative unit	flooding [km²]	up floodin [km²]	0 - 300 m	300 - 1000 m	1 - 10 km	flooding [km²]	natural flooding [km²]	flooding [km²]	flooding [km²]	
Albania	1052,63	43,30	6,84	8,81	27,65	256,57	466,20	181,52	105,04	
Durrës County	129,13	16,37	2,41	4,28	9,67	32,89	65,47	13,96	0,46	
Fier County	374,56	5,14	0,02	0,03	5,09	110,15	134,15	74,81	50,30	
Gjirokastër County	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	
Lezhë County	232,01	7,34	0,86	0,62	5,86	53,17	129,09	35,81	6,61	
Shkodër County	76,72	2,27	0,48	1,08	0,71	14,93	45,61	13,30	0,61	
Tirana County	40,81	1,64	0,58	0,68	0,38	13,42	16,14	8,14	1,47	
Vlorë County	199,39	10,54	2,48	2,11	5,95	32,01	75,75	35,50	45,59	

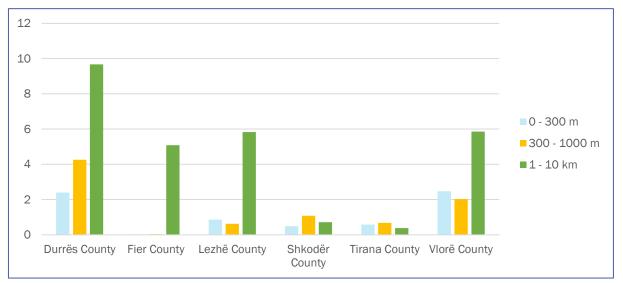


Figure 103: Area in km² of built-up LC/LU class in LEZ in different coastal strips, per counties in Albanian coastal zone (0 – 10 km)

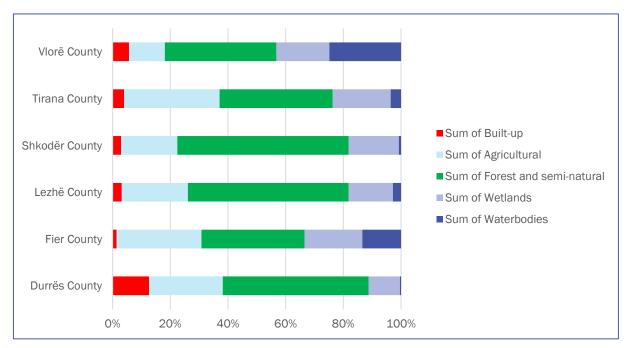


Figure 102: Percentages of areas in LEZ across LC/LU classes in Albanian coastal zone (0 -10 km) per counties



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