PAP/RAC of UNEP/MAP

Candidate Common Indicator 25 “Land cover change”

for Tunisia

Child Project 2.1

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Contents

1. Introduction

This report assesses the Common Candidate Indicator on land use change (CCI25) for Tunisia, highlighting urbanization as one of the main threats to coastal ecosystems. This indicator, an integral part of the Integrated Monitoring and Assessment Program (IMAP) and the Ecosystem Approach (EcAp), is part of the Mediterranean Strategy for Sustainable Development. It specifically contributes to the first strategic objective: ensuring sustainable development in marine and coastal areas.

This activity is carried out within the framework of the MedProgram project (Child Project 2.1), financed by the GEF and executed by UNEP/MAP via the Priority Actions Programme/Regional Activity Centre.

The LCC indicator aims to provide accurate and relevant data to support the implementation of the Protocol for Integrated Coastal Zone Management (ICZM) in the Mediterranean. It is designed to support the understanding of risks affecting coastal zones, the preservation of coastal open spaces, the securing of retreat zones, the prevention of urban sprawl by limiting the linear extension of urban development, including transport infrastructures along the coast, the guarantee of a balanced distribution of uses and the health of ecosystems. These objectives are among the most important in the ICZM protocol.

As a candidate common indicator, the land use indicator is still in the testing phase. As part of MedProgram PC 2.1, the PAP/RAC team of experts reviewed and updated the initial methodology for this indicator originally developed in 2017 and included elevation data in order to adapt this indicator to the rapid identification of coastal flooding risks. This study focuses on the Tunisian coastal zone, but logically, the CCI25 should be replicable across the entire Mediterranean coastal zone, enabling the comparison of equivalent parameters between different coastal countries.

This survey analyzes land use in the Tunisian coastal zone in 2021 and assesses the changes observed between 2015 and 2020, applying the updated methodology of the candidate Common Indicator on Land Use Change (CCI25) and relying on recent, open remote sensing data, thus ensuring high accuracy and reliability of the analyses.

This report is structured into four main sections to detail the analysis and results of the CCI25 indicator applied to the Tunisian coastal zone. After an introduction to the context and objectives of the CCI25 indicator, the second section presents the project area; the Tunisian coastal zone as defined for the

CCI25 indicator covering its natural, geographical, and socio-economic characteristics, with an emphasis on key environmental pressures. The third section indicates the most important determinants of CCI 25 and the methodological framework, explaining the selection of source data and the tools used for the geospatial and statistical analyses and the workflow for The CCI25 indicator parameters calculation and presents the calculated CCI25 parameters, distinguishing between current values (2021) and changes observed over the 2015-2020 period, in order to document land use trends. interprets the results of the analysis. The fourth section is devoted to a discussion of the results obtained. It offers a critical analysis of the methods used, in particular questioning the current proportional approach and highlighting the disparities found between different sources of land use data.

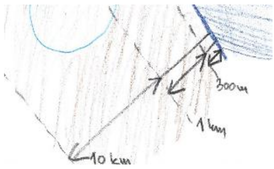
2. Project area

The project area in Tunisia, as defined in the CCI25 calculation manual, corresponds to a coastal strip 10 kilometers deep, measured from the Tunisian coastline inland. This zone, which we shall refer to simply as the "coastal zone" in the remainder of this report, extends over a simplified general length of around 1,000 kilometers. Considering all continental and island shores, as well as those of lagoons located outside administrative zones, the total coastal length reaches 2,290 kilometers.

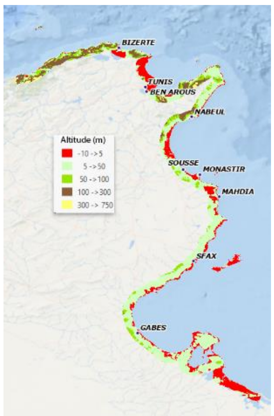
The coastal zone covers a total surface area of **10,673 km²** and crosses **14 governorates**, stretching from the Algerian border in the north-west to the Libyan border in the south-east: **Jendouba, Béja, Bizerte, Ariana, Tunis, Ben Arous, Nabeul, Zaghouan, Sousse, Monastir, Mahdia, Sfax, Gabès and Médenine**.

Of these **14 governorates, 10 have their administrative center located in the coastal zone**. This zone is also home to the country's main urban areas, notably **Tunis**, the capital, **Sfax**, the country's second-largest city, and **Sousse**, the third-largest city.

The coastal zone is divided into three coastal strips:



- **0 -300 meters :** from the coastline inland immediate zone in contact with the coastline.
- **300 meters - 1 km** : intermediate strip influenced by coastal dynamics.
- **1 km - 10 km** : extended area of influence.



The coastal zone is characterized by significant geomorphological diversity. It consists of two distinct facades - northern and eastern - with their natural boundary located at the tip of the Cap Bon peninsula. This coastal zone presents remarkable altitude variations, extending from the northern high plateaus, where Jbal Harbouna (Jendouba Governorate) reaches 750 meters, to the depressions of the eastern coast, notably the Sebkhat of Moknine (Monastir Governorate) which descends to 10 meters below sea level.

The **Low Elevation Coastal Zones (LECZ)**, as defined in the **CCI25 indicator analysis**, refer to **coastal areas located less than 5 meters above sea level**. These zones cover a total area of **2,532 km²**, representing **24% of the coastal zone (10 673 km²)**.

The coastal zone is home to **752 km² of protected areas**, including sites of international and national importance that stand out for their ecosystem diversity. Ramsar-listed wetlands include the Lagunes du Cap Bon Oriental, the Salines de Thyna, and Bahiret El Bibane - the latter covering 264,770 hectares and constituting the largest area. These sites are essential for the preservation of migratory birds and aquatic ecosystems.

Under the Barcelona Convention, the La Galite Archipelago and the Zembra and Zembretta islands are designated as specially protected marine areas of Mediterranean importance, ensuring the conservation of marine and coastal biodiversity. The Ain Baccouch, M'hibeus and Dar Chichou wildlife reserves contribute to the protection of endemic fauna by preserving their natural habitats. The network of protected areas also includes the Boukornine national park and the Kneiss Islands nature reserve.

This mosaic of protected areas, encompassing lagoons, mountainous areas and islands, reflects the ecological richness of the territory and underlines the importance of efforts to conserve biodiversity and natural habitats.

2.1. Natural-geographic features

The coastal zone is characterized by a remarkable natural diversity, resulting from the interaction between relief, climate, hydrography and geology. These characteristics create clear contrasts between the different parts of the coast, making it an area rich in varied ecosystems but vulnerable to environmental pressures.

Climat : The climate is Mediterranean with marked variations between the humid north and the arid south. The north (Bizerte, Tunis, Cap Bon) enjoys a sub-humid to humid climate, with annual rainfall exceeding 600 mm and mild winters. The center (Sousse, Monastir, Mahdia, Sfax) has a semi-arid climate, with annual rainfall between 200 and 400 mm and dry summers. The south (Gabès, Médenine) is arid, with less than 200 mm rainfall per year and high evaporation rates, leading to soil salinization. Sea winds play a key role in coastal erosion and dune formation.

Geology : The coastal geology is varied, marked by a distinction between the mountainous north

(Tunisian Tell) and the south-central region, characterized by sedimentary basins and coastal plains. The north is dominated by Mesozoic and Cenozoic limestone and marl, while the center and south are made up of recent sedimentary deposits, including sandy-clay formations and coastal dunes. Low-lying areas (sebkhas, lagoons) are the result of Quaternary alluvial and marine accumulations.

Hydrography : The hydrographic network is irregular, consisting mainly of temporary watercourses. The oued Medjerda, the only permanent watercourse, is an essential source of freshwater and sediment for the Gulf of Tunis. Other intermittent wadis, such as Wadi Miliane and Wadi Zeroud, contribute seasonally to coastal dynamics. Lagoons and sebkhas (Ghar El Melh, Sebkha de Sijoumi) play a crucial ecological role as transition zones between terrestrial and marine environments.

Soils : Soils vary according to climate and geology. In the north, ferruginous and clay-limestone soils are fertile and suitable for agriculture. In the center and Sahel, sandy, calcimagnesian soils are susceptible to wind erosion. In the south, saline and hydromorphic soils dominate, particularly in the sebkhas, where evaporation and marine intrusions accentuate salinization.

Vegetation : Vegetation reflects climatic and geomorphological diversity. The north is home to Mediterranean forests (Aleppo pine, cork oak) and maquis. The center and south are characterized by garrigues, shrub steppes and halophilous formations (tamarisk, samphire). Coastal wetlands are home to flora adapted to saline environments, playing a key role in soil stabilization and biodiversity.

Bathymetry and marine dynamics : Bathymetry shows marked contrasts. The northern coast has deep waters close to shore, with isobaths of 10 m and 50 m often close to the coast. Conversely, the eastern coast, particularly in the Gulf of Gabès, has an extensive continental shelf, with shallow waters and a more pronounced tide, sometimes reaching 2 m in amplitude at equinoxes.

2.2. Socio-economic features

The coastal zone, which represents only around 7% of Tunisia's total surface area, is nevertheless home to 47% of the national population, or more than 5 million inhabitants, according to the 2014 General Census of Population and Housing. This high demographic concentration underlines the central role of the coastline in the country's socio-economic development. This population is mainly concentrated in six major metropolises: Tunis, Sfax Sousse, Nabeul, Bizerte, Gabes, which constitute major urban hubs attracting inhabitants thanks to their economic opportunities and developed infrastructure.

The region's economic activity is based on three main sectors.

- Industry and commerce have a strong presence in the industrial zones of Tunis, Bizerte, Sousse, Sfax and Gabès. These industrial clusters are diversified, covering fields such as textiles, food processing, chemicals and shipbuilding. Commercial ports play a crucial role in international trade.
- Tourism is a major economic pillar, contributing around 14% of the national GDP. The main tourist destinations are Hammamet, Sousse, Monastir, Mahdia, Djerba and Zarzis. This sector generates many direct and indirect jobs, although it faces environmental challenges such as coastal erosion and rising sea levels.
- agriculture and fishing play an important role. Coastal agriculture is characterized by market gardening, arboriculture and olive growing, particularly developed in the Cap Bon, Sahel and Gabès regions. Fishing, concentrated around Sfax, Mahdia, Monastir and Bizerte, remains a vital activity despite the problems of overexploitation of marine resources and pollution.

However, this demographic and economic concentration brings with it major challenges. Rapid and often poorly controlled urbanization is exerting considerable pressure on coastal ecosystems. On the one hand, water resources are becoming increasingly limited, a situation exacerbated by climate change and overexploitation. Pollution, both industrial and domestic, is significantly affecting the quality of marine and coastal waters. On the other hand, this situation accentuates the country's socio-economic vulnerability to growing environmental risks: coastal erosion, rising sea levels and extreme climatic phenomena threaten the region's infrastructures and economic activities.

2.3. Main pressures and threats to the coastal environment

The Tunisian coastal zone is under increasing environmental pressure from urbanization, climate change, pollution, and overexploitation of natural resources. These challenges are intensified by demographic and economic growth, making coastal management crucial for sustainable development.

Urbanization and Land Use Changes: Rapid urbanization, particularly in cities like Tunis, Sfax, and Sousse, results in land artificialization and encroachment on natural ecosystems. Mass tourism further contributes to this by converting natural land into tourist zones and generating waste that pollutes coastal areas. Chemical industries in Gabès and Skhira release pollutants into the sea, affecting marine ecosystems and public health.

Climate Change and Sea-Level Rise

Rising temperatures, prolonged droughts and more intense storms are exacerbating coastal risks in Tunisia. Over the past decade, the country has experienced six years of drought. One of the most severe periods of drought in its recent history, drastically reducing water availability and straining coastal agricultural areas, and increasing dependence on irrigation, raising the threat of saltwater intrusion into coastal aquifers.

At the same time, intense rainfall triggered devastating coastal flooding. Since 2015, several coastal cities have been hit by major floods, including Nabeul in 2018, where record rainfall submerged entire neighborhoods, causing significant damage to infrastructure and livelihoods. These extreme weather events, compounded by sea-level rise - estimated at 50 cm by 2100 - pose a growing threat to low-lying coastal areas, wetlands and fragile coastal ecosystems. Saline intrusion, erosion and the gradual submergence of natural habitats are likely to have a lasting impact on the biodiversity and ecological balance of these environments. Without effective adaptation strategies, these cumulative pressures could accelerate coastal erosion, displace communities, weaken ecosystems and disrupt economic activities all along the Tunisian coastline.

Pollution and Water Quality Degradation: Industrial, agricultural, and domestic pollution contaminate the coastal environment. Industrial hubs release chemical waste, while agricultural runoff carries fertilizers and pesticides. Untreated sewage and plastic waste degrade water quality, posing risks to marine biodiversity and public health.

Overexploitation of Natural Resources: Unsustainable exploitation of coastal ecosystems threatens their long-term viability. Overfishing leads to declining fish stocks, and sand extraction accelerates coastal erosion. Intensive groundwater use depletes aquifers, exacerbating saltwater intrusion.

Loss of Biodiversity and Habitat Degradation: Habitat destruction due to urbanization, pollution, and climate change leads to a decline in biodiversity. Wetlands and sebkhas, which provide natural flood and erosion protection, are being converted for development. Invasive species and illegal fishing practices disrupt marine ecosystems.

Effective coastal zone management is essential to mitigate these pressures and preserve the natural and economic value of Tunisia’s coastline. Integrated and sustainable coastal planning strategies are needed to address these challenges and ensure the resilience of coastal communities.

3. Common Indicator 25 “Land cover change”

The Candidate Common Indicator 25 (CCI 25) "Land cover change" constitutes a fundamental framework for monitoring and evaluating land cover dynamics in Mediterranean coastal regions. This indicator is comprehensively defined in the UNEP/MAP WG.549/5 document through multiple interconnected dimensions.

The ecological foundation of CCI 25 rests on maintaining the natural dynamics of coastal ecosystems, with particular emphasis on preserving landscape integrity and ecosystem functionality. This objective is intrinsically linked to the Good Environmental Status (GES) definition, which advocates for controlled coastal development and promotes mixed land-use patterns in anthropized coastal landscapes.

The operational implementation of CCI 25 focuses on safeguarding the integrity of coastal ecosystems and their geomorphological characteristics. This manifests through specific targets aimed at restricting construction in vulnerable coastal zones, mitigating urban dominance in coastal areas, and enhancing landscape diversity. These objectives necessitate careful adaptation to regional specificities, incorporating socio-economic, cultural, and historical considerations.

The underlying rationale of CCI 25 acknowledges land cover change, particularly urbanization, as a critical driver of coastal transformation. Such changes often result in irreversible impacts on habitat connectivity, ecosystem functions, and climate resilience. The indicator particularly emphasizes the vulnerabilities of low-lying coastal zones to climate-induced risks, including flooding, erosion, and salinization.

The measurement framework of CCI 25 encompasses various parameters, including built-up land proportions, land take percentages, and changes in natural and protected areas. These metrics are quantified through specific units, initially establishing baseline data in square kilometers and percentages, followed by monitoring change rates in subsequent assessments. This comprehensive measurement approach enables systematic evaluation of coastal land cover dynamics, facilitating informed decision-making in coastal zone management.

3.1. Methodology

The methodology for calculating Candidate Common Indicator 25 (CCI 25) "Land Cover Change" is designed to systematically assess changes in land cover, particularly in coastal areas. It relies on a combination of remote sensing data, Geographic Information Systems (GIS), and standardized classification systems to ensure a consistent and reproducible approach.

The first step involves data compilation. Land cover classes are mapped using remote sensing data, typically through supervised digital image classification or in situ monitoring. These classes follow the Land Cover Classification System (LCCS) developed by the United Nations Food and Agriculture Organization (FAO). This system provides a standardized framework for categorizing land cover types, ensuring consistency across different regions and datasets. The land cover classes considered include artificial surfaces (built-up areas), agricultural land, forests and semi-natural areas, wetlands, water bodies, and protected areas.

Next, the data is pre-processed to ensure uniformity. Land cover data may be available in vector (polygons) or raster (grid) formats. The first step is to convert all data into a raster format with a resolution of 1 hectare (ha) or less. This conversion is typically done using GIS software, with the "maximum area" criterion being the standard method for rasterization. Once the data is converted, different layers are combined to create a comprehensive dataset. These layers include baseline land cover data (initial time period, 2015), land cover change data (between 2015 and 2020), the delineation of coastal zones and strips, administrative units (e.g., NUTS3 or equivalent), and the delineation of the Low Elevation Coastal Zone (LECZ).

The result of this processing is a data table that includes a unique identifier for each grid cell, along with information on the cell's location (coastal zone, coastal strip, administrative unit, or LECZ) and the land cover class at the initial time period (2015).

Once the data is combined, the next step is to extract the statistics needed to calculate the indicators. This analysis is performed using spreadsheet software or GIS tools. The parameters calculated include the percentage of artificial surfaces in the coastal zone or specific coastal strips, the percentage of other land cover classes (such as forests or wetlands), and land take (increase in built-up areas) as a percentage of the initial urban area. Other parameters, such as changes in forests and semi-natural areas, changes in wetlands, and changes in protected areas, are also calculated.

The document provides detailed instructions for each calculation, including filtering data by land cover class, counting grid cells, and calculating percentages or area changes. The indicator units vary depending on whether it is the initial monitoring or subsequent monitoring. For the initial monitoring, the units include square kilometers of artificial surfaces in the coastal zone, the percentage of artificial surfaces, and the percentage of other land cover classes. For subsequent monitoring, additional units are considered, such as the percentage increase in artificial surfaces (land take) and the percentage change in other land cover classes.

In addition to the main parameters, additional analytical units can be considered to refine the analysis. For example, setback zones (where development is restricted) can be analyzed separately to assess land take in these sensitive areas. Similarly, the coastal zone can be divided into elevation classes (e.g., 5-10 m, 10-50 m, 50-100 m) to better understand the relationship between land cover changes and habitat distribution. A pivot table can also be created to show which land cover classes have been converted into artificial surfaces, providing insights into losses due to urbanization.

The expected outputs include digital maps showing land cover classes for the coastal zone, in accordance with the classification in Table 2 of the document. These maps should be in GeoTIFF format with a resolution of 1 ha and include metadata such as the title, geographic reference, area covered, coordinate system, reference period, and responsible organization. A spreadsheet containing the calculated indicators (e.g., percentage of artificial surfaces, land take, changes in forests and wetlands) is also expected. Starting from the second monitoring, additional maps indicating areas of land take (new urbanization) should be provided, following the same specifications as the land cover maps.

3.2. Data

Spatial data required for the CCI25 calculation include data on land cover and land use (LC/LU), elevation, coastline, administrative units and protected areas. Procedures for the creation of coastal strips and reporting units, and the specific preparation of each type of data (LC/LU, elevation, protected areas) have been carried out in line with the “UNEP/MED WG.522/4 Manual for IMAP Candidate Common Indicator 25 Land cover change calculation”. These preparation stages involved the management and processing of spatial data in QGIS software.

3.2.1. Data acquisition and preparation

3.2.1.1. Land use/land cover data

This section details the procedure for acquiring and preparing Land Cover/Land Use (LC/LU) data for quantifying the CCI25 indicator in the coastal zone. The specific aim of this study is to establish the CCI25 parameters in order to carry out a diachronic analysis of land use in the Tunisian coastal region, with the year 2021 as the reference period, as well as an assessment of the spatial dynamics observed during the interval 2015-2020. The analytical approach is based on the use of recent open source remote sensing data.

Notwithstanding the recommendations of the UNEP/MED WG.522/4 manual, which recommends the use of Copernicus Global Land Service (CGLS) Land Cover 100m (CGLS-LC100) data for quantifying the CCI25 indicator, the limited temporal coverage of this dataset, extending only from 2015 to 2019, proved inadequate for the objectives of the present study. Indeed, the analytical requirements of examining land use for the reference year 2021, as well as assessing territorial mutations between 2015 and 2020, led to the search for alternative data sources.

In this context, and in line with PAP/RAC recommendations, the GLC_FCS30D product (Global 30m Land-Cover Dynamics Monitoring Product with a Fine Classification System), published in 2023, has been identified as a suitable data source for diachronic analysis. For land cover characterization in 2021, the European Space Agency's (ESA) WorldCover 2021 product was chosen, with its optimal spatial resolution of 10 meters.

GLC_FCS30D:

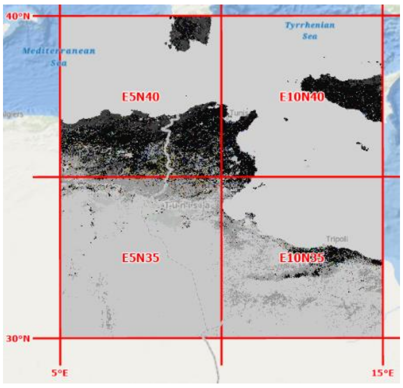
This data was produced by the Chinese Academy of Sciences (CAS). Specifically, the product was developed by the Center for Geographic Information Science (GIS) and the Center for Earth Data Research for Sustainable Development (CBAS), both of which are entities within the Chinese Academy of Sciences.

Key Characteristics of GLC_FCS30D data: the data are derived from Landsat archives, It has a Spatial Resolution of 30 meters and is geometrically referenced to the EPSG:4326 WGS84 geographic coordinate system. It covers the period from 1985 to 2022. It features a Fine Classification, with 35 land cover classes, including categories such as urban areas, agricultural land, forests, and water bodies.

The fine classification system containing 35 land-cover

LC id	Classification System				
10	Rainfed cropland	91	Open mixed leaf forest (broadleaved and needle-leaved)	183	Flooded flat
11	Herbaceous cover cropland	92	Closed mixed leaf forest (broadleaved and needle-leaved)	184	Saline
12	Tree or shrub cover (Orchard) cropland	120	Shrubland	185	Mangrove
20	Irrigated cropland	121	Evergreen shrubland	186	Salt marsh
51	Open evergreen broadleaved forest	122	Deciduous shrubland	187	Tidal flat
52	Closed evergreen broadleaved forest	130	Grassland	190	Impervious surfaces
61	Open deciduous broadleaved forest (0.15<fc<0.4)	140	Lichens and mosses	200	Bare areas
62	Closed deciduous broadleaved forest (fc>0.4)	150	Sparse vegetation (fc<0.15)	201	Consolidated bare areas
71	Open evergreen needle-leaved forest (0.15< fc <0.4)	152	Sparse shrubland (fc<0.15)	202	Unconsolidated bare areas
72	Closed evergreen needle-leaved forest (fc >0.4)	153	Sparse herbaceous (fc<0.15)	210	Water body
81	Open deciduous needle-leaved forest (0.15< fc <0.4)	181	Swamp	220	Permanent ice and snow
82	Closed deciduous needle-leaved forest (fc >0.4)	182	Marsh	0, 250	Filled value

Data is acquired via open-access platforms, notably Zenodo (https://zenodo.org/records/8239305), where data is structured into archives corresponding to 10° longitude zones, segmented into 5°x5° tiles. Data is distributed in GeoTIFF format. Each tile is made up of two separate files: the first, entitled "GLC_FCS30D_19851995_5years_E**N**", comprises three bands representing land-use maps for the years 1985, 1990 and 1995. The second file, "GLC_FCS30D_20002022_E**N**", comprises 23 bands corresponding to annual land-use maps from 2000 to 2022.



For this study, four tiles covering a geographical area between 5° and 15° East, and between 30° and 40° North were selected to cover the coastal zone under study: E5N35, E10N35, E5N40 and E10N40. Data extraction focused on the second file "GLC_FCS30D_20002022_E**N**", specifically on band 16 for the year 2015 and band 21 for the year 2020. The preparation protocol involved the extraction of eight separate files (two per tile and per study year), followed by a mosaicking operation for each reference year. The final delimitation of the data was achieved by applying a vector polygon mask corresponding to the boundaries of the coastal zone. The GLC_FCS30D data feature a detailed nomenclature with 35 thematic classes, a finer granularity than that required for calculating the ICC25 indicator, which requires only 5 classes. A reclassification procedure was therefore implemented to aggregate the original classes according to the indicator's target nomenclature.

GLC_FCS30D LC ID	CCI 25 LC ID	Land cover Classes
190	1	Built-up
10, 11, 12, 20	2	Agriculture
50, 51, 52, 60, 61, 62, 70, 71, 72, 80, 81, 82, 90, 91, 92, 120, 121, 122, 130, 140, 150, 152, 153, 200, 201, 202	3	Forest and semi-natural
180, 181, 182, 183, 184, 186, 187	4	Wetlands
210, 220	5	Waterbodies

WorldCover 2021 of the European Space Agency (ESA)

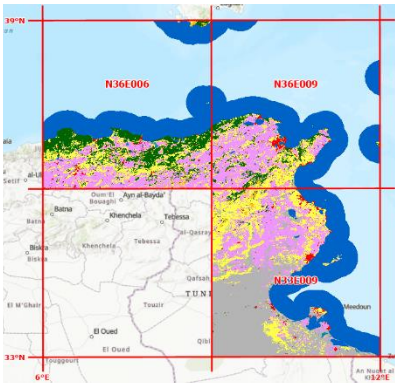
WorldCover 2021 land cover data is a mapping product developed under the aegis of the European Space Agency (ESA). The origin of this initiative dates back to the 2017 WorldCover conference, jointly organized by ESA, the Group on Earth Observation (GEO), the Food and Agriculture Organization of the United Nations (FAO) and the European Union (EU). This conference served as a catalyst for the establishment of the WorldCover project, whose main objective is to produce a comprehensive map of land cover on a global scale. The project's efforts have culminated in the production of two successive global maps, covering the years 2020 and 2021 respectively, making a significant contribution to our understanding of global land cover dynamics. The WorldCover project has produced two versions. The first version (v100), offers a validated global accuracy of 74.4%. An improved version, (v200), achieving a global accuracy of 76.7%. We have chosen to use version 2021 because of its improved accuracy.

Cartographic production is based on data from the Sentinel-1 and Sentinel-2 satellites of the Copernicus program. These data have a spatial resolution of 10 meters and are georeferenced using the WGS84 geographic coordinate system (EPSG:4326). Worldcover data are classified into 11 classes, using the Land Cover Classification System (LCCS).

Map code	Land Cover Class
10	Tree cover
20	Shrubland
30	Grassland
40	Cropland
50	Built-up
60	Bare / sparse vegetation
70	Snow and Ice
80	Permanent water bodies
90	Herbaceous wetland
95	Mangroves
100	Moss and lichen

Access to these cartographic products is provided via open-access distribution platforms, notably the official WorldCover portal (https://worldcover2021.esa.int/downloader) and the Zenodo platform (https://zenodo.org/records/7254221).

The distributed data structure is organized according to a two-level hierarchy: 60 degree by 60 degree macro tiles, subdivided into 3 degree by 3 degree elementary tiles. Data are encoded in Cloud Optimized GeoTIFF (COG) format, optimizing their integration and manipulation within geographic information systems (GIS) and geospatial processing environments. File naming follows a standardized convention based on the model "ESA_WorldCover_10m_2021_V200_N**E***_Map.tif", where N** and E*** designate the geographic coordinates of the tile's point of origin (lower left corner). In the context of the present study, an exhaustive coverage of the coastal zone of interest was obtained by assembling three adjacent tiles.



The preparation procedure for the WorldCover 2021 data case involved the extraction of three files, followed by a mosaicking operation. The final delimitation of the data was achieved by applying the vector polygon mask corresponding to the boundaries of the coastal zone. The classification of the data

Worldcover LC ID	CCI 25 LC ID	Land cover Classes
50	1	Built-up
40	2	Agriculture
10 20 30 60 70 100	3	Forest and semi-natural
90 95	4	Wetlands
80	5	Waterbodies

differs from that required to calculate the ICC25 indicator. A reclassification procedure was therefore implemented in order to aggregate the original classes according to the indicator's target nomenclature.

3.2.1.2. Coastline

The coastline data used to calculate CCI25 comes from OpenStreetMap (OSM), a collaborative platform providing free and open access geospatial data. OSM's coastline data is recognized for its reliability and regular updating, making it a suitable source for coastal zone analysis. The data is available as vector data (linestring) and is georeferenced in the WGS84 coordinate system (EPSG:4326). The use of coastline data from OSM offers a reliable solution for delineating coastal zones. The open source nature of the data guarantees the transparency and reproducibility of the analysis, which is essential for calculating the CCI25 indicator.

Download: The coastline data were downloaded from the official OSM website (https://osmdata.openstreetmap.de/data/coastlines.html). They are available in two formats, according to the WGS84 (EPSG:4326) and Web Mercator (EPSG:3857) coordinate systems. For this analysis, the WGS84 version was selected to ensure consistency with the other datasets used in the project.

Data downloaded in Esri's shapefile format were imported into QGIS, a free, open-source geographic information system (GIS) software package. The data were then sliced according to area of interest (AOI) using a polygonal layer to retain only those coastal segments relevant to the analysis.

The methodology used to delineate coastal zones is based on a rigorous sequential procedure. First, vertex extraction is carried out from the densified coastline, enabling a layer of reference points to be established. Buffer zones are created using the Shape Tools module, with the application of three distance thresholds (300 meters, 1,000 meters and 10,000 meters) around the previously extracted vertices. The buffer zones generated are then dissolved, resulting in the formation of continuous polygons representative of each coastal strip. The next step consists of an analysis of the spatial differences between the bands, enabling the three study areas to be precisely isolated. The robustness of this delimitation is finally validated by comparison with reference cartographic data and satellite images.

This methodology provides a precise and coherent segmentation of the coastal space, constituting a rigorous spatial framework for the analysis of coastal dynamics.

3.2.1.3. Elevation data

In this section, we describe the methodology used to acquire and process altimetry data for the analysis of low-lying coastal areas. The altimetry data mobilized for the assessment of Common Indicator Candidate 25 (CCI25) on land use change come from FABDEM (Forest And Buildings removed Copernicus DEM). This global digital elevation model, developed by the University of Bristol, stands out for its optimized accuracy compared with other open-access DEMs. It is particularly useful for identifying Low Elevation Coastal Zones (LECZ), areas that are particularly vulnerable to flooding and rising sea levels.

Data specifications FABDEM features a spatial resolution of one arcsecond (approx. 30 meters), in WGS84 (EPSG:4326) projection. The data, in GeoTIFF format, is freely available for non-commercial use under a Creative Commons Attribution-NonCommercial-ShareAlike 4.0 license. The increased accuracy of FABDEM results from the elimination of artifacts related to building heights and forest cover, enabling a more faithful representation of natural topography.

Acquisition and pre-processing protocol Data acquisition was carried out via the University of Bristol portal, using a 1°x1° tile organization. Tiles relevant to the Tunisian coastal zone were selected according to their geographical coordinates. Initial processing was carried out in QGIS, with the creation of a virtual raster (VRT) enabling tiles to be aggregated without duplicating source data. This mosaic was then cut according to area of interest (AOI), reprojected and resampled to 30 meters to ensure consistency with the project's other geographic information layers.

Delineation and characterization of the Low elevation coastal zone LECZ. The definition of low elevation coastal zones was based on an elevation threshold of 5 meters above sea level. These zones were extracted using a conditional analysis in Raster Calculator, generating a binary raster which was subsequently vectorized. A topological cleaning process eliminated artifacts and ensured spatial continuity with the coastline. The results were validated by comparison with satellite imagery and available cartographic references.

Integration into the CCI25 analysis The LECZs delineated in this way provide a spatial framework for analyzing land-use dynamics in a vulnerable coastal context. Particular attention has been paid to the evolution of artificial surfaces within these zones, enabling us to assess exposure to flood risks and the potential impacts of climate change.

3.2.1.4. Administrative units

CCI25's spatial analysis is based on an administrative breakdown that enables relevant territorial aggregation of results. In the Tunisian context, the adoption of NUTS 3 (Nomenclature des Unités Territoriales Statistiques) level administrative units. NUTS 3 regions typically have between 150,000 and 800,000 inhabitants. Their national equivalent is the governorate, the spatial frame of reference for analyzing coastal dynamics.

Characteristics and sources of administrative data: The administrative data used come from the OpenStreetMap (OSM) database, a collaborative geographic data infrastructure. These vector data, available in polygonal format in WGS84 projection (EPSG:4326), are distributed under Open Database License (ODbL). The granularity of the breakdown, integrating governorate and municipality levels, enables a detailed analysis of coastal territories.

Acquisition and processing protocol Data extraction was carried out via the OSM Boundaries platform, specifically selecting the administrative level equivalent to NUTS 3, corresponding to the Tunisian governorates. This harmonization with European standards facilitates regional comparative analyses. The data, imported in GeoJSON format into the QGIS environment, underwent a series of spatial processing operations.

Methodology for preparing spatial units for analysis The data preparation process involved several stages: A spatial division operation was used to isolate the administrative units intersecting the 10-kilometer coastal strip, An intersection with the different coastal bands (0-300 m, 300-1,000 m, 1-10 km) generated specific reporting units, A topological cleaning process was applied to eliminate artifacts and optimize feature geometry, A thorough visual validation, based on satellite imagery and available cartographic references, confirmed the consistency of the resulting division.

Application to CCI25 analysis: Spatial units defined in this way provide the framework for aggregating the results of land-use change analysis. This territorial structuring makes it possible to establish robust inter-regional comparisons and to identify coastal sectors subject to significant anthropic pressures, particularly in terms of artificialisation.

3.2.1.5. Protected area

This section deals with the integration of protected areas into the analysis of coastal land-use dynamics and the methodology used to prepare the data. The CCI25 analysis is based on data from the World Database on Protected Areas (WDPA), a reference data infrastructure jointly managed by the United Nations Environment Programme and the International Union for Conservation of Nature (IUCN). This database is an essential tool for assessing anthropogenic pressures on protected coastal ecosystems.

Data characteristics and structure: The WDPA distributes vector data (polygon and point formats) in WGS84 projection (EPSG:4326), available under a Creative Commons Attribution 4.0 International license. Monthly updating of the database guarantees the temporal relevance of information on terrestrial and marine protected areas worldwide.

Acquisition and processing protocol: Data extraction focused on the Tunisian territory via the Protected Planet portal, with selection in Shapefile format. Data processing in QGIS followed a multi-stage procedure:

a spatial filtering operation was used to isolate protected areas located within the 10-kilometre coastal strip, excluding marine areas and areas with "Proposed" or "Not Reported" status. A dissolution procedure was applied to resolve spatial overlaps resulting from different levels of protection or administrative overlaps, resulting in a unified vector layer. An intersection with predefined coastline bands (0-300 m, 300-1,000 m, 1-10 km) was used to analyze the spatial distribution of protected areas and their exposure to artificialisation dynamics.

Although the CCI25 protocol calls for a diachronic analysis between 2015 and 2020, the lack of evolution in the Tunisian protected area network over this period led to the use of a single layer for both reference dates. This methodological peculiarity does not affect the relevance of the analysis of anthropogenic pressures on these areas.

The inclusion of protected areas in the CCI25 analysis makes it possible to assess the impact of land-use changes on these sensitive areas, despite the temporal stability of the Tunisian protected area network over the study period.

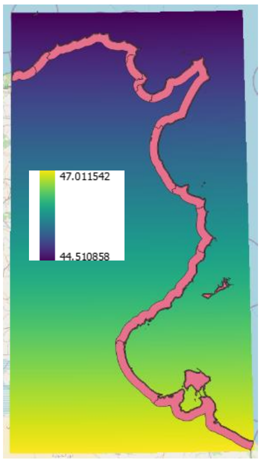
3.2.2. Data preprocessing

Data pre-processing is a fundamental methodological step in the development of spatial analyses and the calculation of territorial indicators. This operational phase aims to structure and standardize source data through a sequence of operations to manipulate, clean and transform raw geographic information. The central objective is to establish a robust analytical framework, in particular by defining reference spatial units (Reporting Units - RU) and linking them to the associated thematic layers. This harmonization of geospatial information sources optimizes the consistency of analyses, while guaranteeing the efficiency of subsequent computational processing.

Coordinate system harmonization (CRS): All spatial data used in the analysis must be referenced in the same coordinate system to ensure spatial alignment. Particular attention has been paid to harmonizing spatial reference systems: all geographic information layers have been validated and standardized in WGS84 (EPSG:4326) projection. **Geometric calculations were carried out on the WGS84 ellipsoid, while cartographic visualization was based on the projected WGS84/UTM zone 32N coordinate system (EPSG:32632),** thus guaranteeing measurement accuracy and cartographic representation adapted to the regional context.

Harmonizing spatial resolution of raster data is a fundamental methodological requirement. In line with the recommendations of the "Manual for CCI25 calculation", which recommends oversampling CGLS_100m data by a factor of 10 (from 0.00099206349° to 0.00009920635° resolution), our protocol was adapted to the specificities of FCS30D data. For the latter, with a native resolution of 0.00026949459°, we opted for oversampling by a factor of 4, resulting in a final resolution of 0.00006737250°. This methodological choice meets a dual requirement: on the one hand, to obtain a resolution close to and finer than that recommended in the manual, while maintaining a manageable data volume, and on the other, to use an oversampling factor corresponding to a power of 2, thus optimizing algorithmic computation times.

Calculation of area image per pixel : As the actual pixel area varies with latitude due to the map projection used, a correction is necessary to ensure accurate measurements. A pixel area map is generated by assigning to each pixel the value corresponding to its actual area in square meters. This operation relies on a conversion function based on the earth's curvature and raster resolution, applied to the entire image. This correction factor is then incorporated into area calculations to adjust measurements of changes in land use.



Creation of the Reporting Units (RU) layer is based on the cross-referencing of two fundamental data sets: Coastal Strips and administrative boundaries. The aim is to subdivide the study area into homogeneous analysis units, reflecting both territorial organization and the spatial dynamics of land-use change. These two layers are superimposed via a spatial intersection operation, generating unique geographical units corresponding to the portions of each governorate present in each of the three coastal strips. Each resulting polygon is assigned a unique identifier and contains the attributes associated with the administrative units and coastal strips.

Crossing of the RU layer with low-altitude zones (LECZ) : Low Elevation Coastal Zones (LECZ), defined as areas less than 5 meters above sea level, represent a major challenge in assessing the risks associated with sea-level rise and coastal flooding. RU and LECZ are superimposed via a second spatial intersection operation, resulting in a fine segmentation of Reporting Units according to their total or partial inclusion in low-lying areas. A binary classification is applied to each resulting unit, indicating whether or not it belongs to a low-altitude zone. This differentiation is essential for the analysis of land use changes in relation to coastal vulnerability. To assess the impact of territorial transformations on sensitive natural areas, the RU layer is also cross-referenced with protected areas. The intersection between the RU layer and protected areas enables us to identify territorial units containing areas subject to conservation measures.

Decomposition of the land cover image into thematic layers : Land use analysis is based on a thematic classification of several land use categories. To facilitate calculations, the land cover raster image is broken down into five distinct binary layers, each representing a specific class: Built-up, Agriculture,Forest and seminatural, Wetlands and Water bodies. This separation is achieved by categorical filtering, where each class is extracted and converted into a binary raster (values 1 for the class concerned, 0 for the rest). This method facilitates the analysis of the spatial distribution of different land use types within the RU and their evolution over time.

Vector layer generation for thematic polygons : The final stage of data pre-processing involves vectorizing the thematic raster layers and calculating polygon areas for each land use class. This conversion produces precise spatial entities, facilitating analysis and visualization of territorial evolution dynamics. Each land-use class is processed separately, giving rise to a vector layer containing homogeneous polygons, to which information is attributed on their surface area and membership of the RUs. These data serve as the basis for CCI25 indicator calculations, enabling a quantitative and spatial assessment of land use trends within reporting units.

Thanks to these various pre-processing steps, the data used to calculate the CCI25 indicator parameters are homogenized, reliable and suitable for geospatial analysis. This approach guarantees methodological consistency, facilitating the interpretation of results and decision-making for coastal zone management.

3.3. Calculation of indicator parameters

The calculation of the CCI25 indicator parameters involves a structured workflow that integrates various geospatial operations, including overlay analysis, statistical aggregation, and data structuring. The process ensures that land cover/land use (LC/LU) changes are accurately quantified within the defined Reporting Units (RU), while also assessing the impact of changes in Low Elevation Coastal Zones (LECZ) and protected areas. This section outlines the step-by-step methodology used to compute indicator parameters, highlighting the distinction between first monitoring indicators (single-year assessment) and second monitoring indicators (change detection over time). Additionally, the methods used for tabular and graphical representation of results are detailed, ensuring clarity and consistency in data presentation.

Overlaying Raster LC/LU Data with the Reporting Units (RU)

The primary step in indicator calculation is the **spatial overlay** between **land cover/land use (LC/LU) raster data** and the **Reporting Units (RU)**. Since LC/LU datasets are raster-based, each pixel represents a specific land cover class at a given resolution. To extract land cover statistics at the RU level, raster datasets are clipped using the RU vector boundaries and then processed to calculate the proportion of each land cover class within each unit.

For the **first monitoring period**, WorldCover 2021 dataset is overlaid with the RU layer to determine the distribution of land cover classes. For the **second monitoring period**, two FCS30D datasets for years 2015 and 2020 are used to assess changes over time. The overlay process is repeated for both years. The key parameters extracted at this stage include **Total area (m^2) covered by each LC/LU class per RU.**

Overlaying LC/LU Data with LECZ

A refined analysis is conducted to assess land cover changes specifically within **Low Elevation Coastal Zones (LECZ)**. Since LECZ represents areas vulnerable to **sea-level rise and coastal flooding**, tracking land use dynamics in these zones is crucial for risk assessment.

To achieve this, the previously generated **LECZ layer** is used to clip the LC/LU data for each year. The same calculations as in the RU analysis are performed, but restricted to pixels within the LECZ extent. The outputs include **Land cover composition within LECZ for the first monitoring period 2021 and the two monitoring periods 2015 2020.**

The differentiation between **RU analysis** and **RU-LECZ analysis** allows for **a comparative assessment of land cover trends within and outside vulnerable coastal areas**, helping identify patterns of high-risk development.

Aggregating Data into a Unified Table

Once all spatial overlay calculations are completed, results are compiled into a **structured table** that consolidates all indicator values for each RU. The table includes:

- **RU identifier**
- **RU area (m^2)**
- **RU-LECZ area (m^2)**
- **RU-Protected-areas-2015 area (m^2)**
- **RU-LECZ-protected-areas-2015 area (m^2)**
- **Land cover area (m^2) per RU per year area (15 values)**
- **Land cover LECZ area (m^2) per year area (15 values)**

The resulting table forms an essential basis for calculating the various parameters of the CCI25 indicator. By centralizing land use data for each Reporting Unit (RU), as well as their intersections with Low Elevation Coastal Zones (LECZ) and protected areas, this structured dataset enables a coherent comparative analysis between different coastal segments. It thus facilitates the calculation of the

CCI25 parameters. For the **first monitoring**, the calculated indicator units represent the base line from which changes will be calculated. First monitoring **indicator units** are the following:

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.

Additional seven parameters are defined for the first monitoring:

7. km2 of LECZ;
8. km2 of built-up area within LECZ;
9. % of built-up area within LECZ;
10. % of built-up area within LECZ compared to coastal administrative unit;
11. % of other land cover classes within LECZ;
12. % of other land cover classes within LECZ compared to coastal administrative unit;
13. km2 of protected areas within LECZ in coastal zone.

For the **second monitoring**, in addition to the indicator units defined for the first monitoring, the following units are 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.

By introduction of LECZ, additional three parameters are defined for the second monitoring:

4. % of increase of built-up area, or land take within LECZ;
5. % of change of other land cover classes within LECZ;
6. % of change of protected areas within LECZ.

Aggregate views on the calculated CI25 parameters are presented in the following paragraphs.

3.3.1. Land cover assessment for 2021 (based on ESA WorldCover data)

In 2021, the most represented land use class in Tunisia's 10 km coastal zone was Forest and semi-natural land (61.5%), agricultural land (22.0 %), followed by built-up areas (9.6 %), water bodies (5.1 %) and finally wetlands (1.8 %). (Fig1)

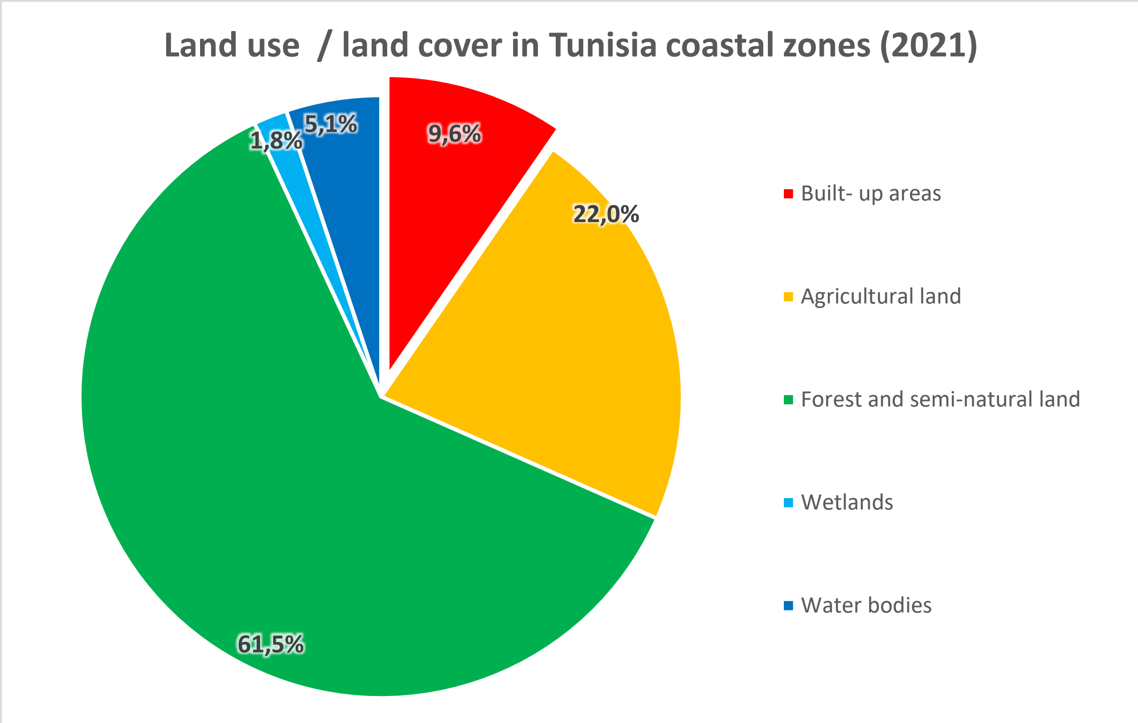


Figure 1 : LU/LC in Tunisia coastal zones (ESA WorldCover 2021)

Built-up Areas: Spatial analysis reveals significant heterogeneity in coastal urbanization dynamics at the governorate level. In terms of absolute surface area, Sfax exhibits the largest extent of built-up areas (197.09 km²), followed by Medenine (142.68 km²) and Nabeul (135.13 km²). However, relative analysis, expressed as a percentage of the governorate's coastal area, highlights the predominance of Tunis, where built-up areas occupy 50.32% of the coastal area, followed by Ben Arous with an urbanization rate of 31.27%.

Agricultural Land: The distribution of agricultural land is concentrated in three main governorates: Nabeul (552.80 km²), Sfax (468.16 km²), and Medenine (430.37 km²). Relatively, agricultural land is most prominent in Mahdia, accounting for 40.67%, and in Ariana, with 38.78% of the governorate's coastal zone.

Forest and Semi-Natural land: The spatial analysis of forest and semi-natural areas reveals contrasting territorial distributions. Medenine has the largest absolute surface area of natural areas (1,441.43

km²), followed by Nabeul (1,007.45 km²) and Sfax (979.16 km²). In relative terms, these areas are most prevalent in Zaghouan (95.57% of the coastal zone), Jendouba (92.90%), and Béja (90.64%).

Wetlands: Wetland distribution is significantly concentrated in Medenine, with 48.15 km², followed by Ariana with 32.39 km². Relatively, Ariana has the highest proportion of wetlands, reaching 11.32% of its coastal zone.

Water bodies: Medenine exhibits a predominance of water surface areas (el Bibane lagoon), accounting for 239.31 km², followed by Bizerte with 125.19 km² (lake of Bizerte and Ghar el Melh Lagoon). In relative terms, Tunis stands out with water surfaces representing 19.62% of its coastal zone (lake of Tunis).

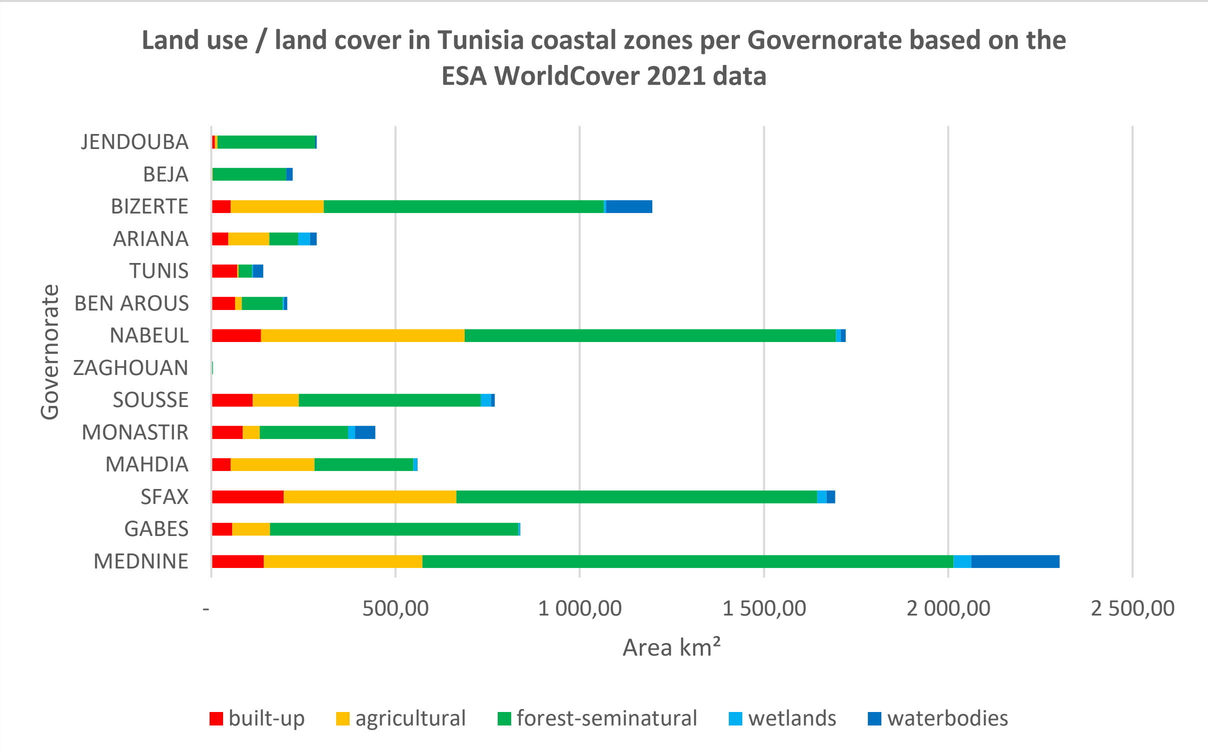


Figure 2 Land use / land cover in Tunisia coastal zones per Governorate base on the ESA WorldCover 2021

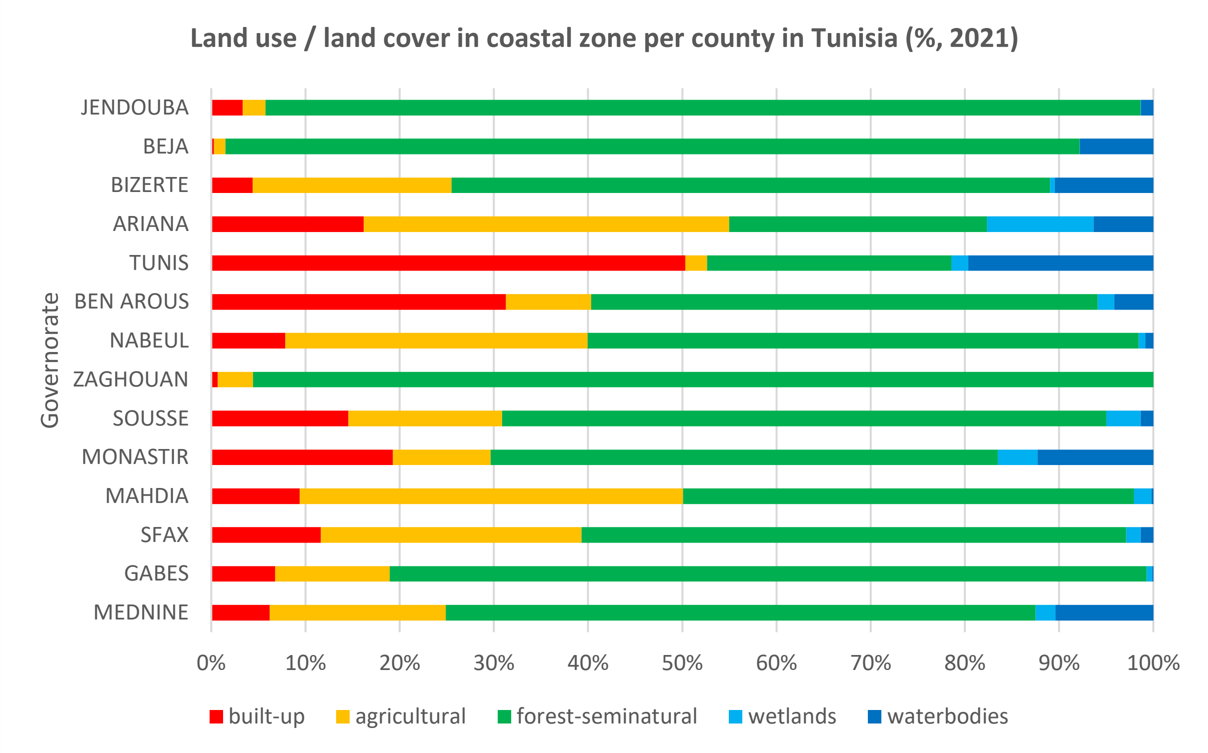


Figure 3 Percentage Land use / land cover in Tunisia coastal zones per Governorate base on the ESA WorldCover 2021

Table 1 Areas of CCI 25 land use classes in the coastal zones and their percentage, year 2021.
CCI25 parameters 1 (km2 of built-up area in coastal zone),
2 (% of built-up area in coastal zone)
and 3 (% of other land cover classes in coastal zone)

2021		Built- up areas	Agricultural land	Forest and semi-natural land	Wetlands	Water bodies	Total coastal zone
Tunisia	Area in km ^{2}	1 027.20	2 348.29	6 560.45	192.96	544.14	10 673.06
	% in coastal zone	*9.62*	*22.00*	*61.47*	*1.81*	*5.10*	*100.00*
JENDOUBA	Area in km ^{2}	9.60	6.83	265.60	0.16	3.71	285.90
	% in coastal zone	*3.36*	*2.39*	*92.90*	*0.06*	*1.30*	*100.00*
BEJA	Area in km ^{2}	0.66	2.71	200.40	0.04	17.28	221.08
	% in coastal zone	*0.30*	*1.22*	*90.64*	*0.02*	*7.82*	*100.00*
BIZERTE	Area in km ^{2}	52.59	252.81	760.36	6.17	125.19	1 197.14
	% in coastal zone	*4.39*	*21.12*	*63.51*	*0.52*	*10.46*	*100.00*
ARIANA	Area in km ^{2}	46.35	110.95	78.24	32.39	18.17	286.09
	% in coastal zone	*16.20*	*38.78*	*27.35*	*11.32*	*6.35*	*100.00*
TUNIS	Area in km ^{2}	71.08	3.27	36.61	2.57	27.72	141.26
	% in coastal zone	*50.32*	*2.32*	*25.92*	*1.82*	*19.62*	*100.00*
BEN AROUS	Area in km ^{2}	64.48	18.68	110.88	3.68	8.49	206.22
	% in coastal zone	*31.27*	*9.06*	*53.77*	*1.78*	*4.12*	*100.00*
NABEUL	Area in km ^{2}	135.13	552.80	1 007.45	12.06	14.44	1 721.89
	% in coastal zone	*7.85*	*32.10*	*58.51*	*0.70*	*0.84*	*100.00*
ZAGHOUAN	Area in km ^{2}	0.03	0.18	4.72	-	-	4.94
	% in coastal zone	*0.70*	*3.73*	*95.57*	*0.00*	*0.00*	*100.00*
SOUSSE	Area in km ^{2}	112.08	125.54	493.70	27.85	10.38	769.54
	% in coastal zone	*14.56*	*16.31*	*64.16*	*3.62*	*1.35*	*100.00*
MONASTIR	Area in km ^{2}	85.84	46.10	239.51	18.75	54.68	444.89
	% in coastal zone	*19.29*	*10.36*	*53.84*	*4.21*	*12.29*	*100.00*
MAHDIA	Area in km ^{2}	52.64	227.79	268.15	10.44	1.05	560.07
	% in coastal zone	*9.40*	*40.67*	*47.88*	*1.86*	*0.19*	*100.00*
SFAX	Area in km ^{2}	197.09	468.16	979.16	25.60	22.83	1 692.85
	% in coastal zone	*11.64*	*27.66*	*57.84*	*1.51*	*1.35*	*100.00*
GABES	Area in km ^{2}	56.95	102.10	674.24	5.09	0.88	839.26
	% in coastal zone	*6.79*	*12.17*	*80.34*	*0.61*	*0.10*	*100.00*
MEDNINE	Area in km ^{2}	142.68	430.37	1 441.43	48.15	239.31	2 301.94
	% in coastal zone	*6.20*	*18.70*	*62.62*	*2.09*	*10.40*	*100.00*

The Specific Case of Zaghouan Governorate : It is important to highlight that within the coastal zone, **Zaghouan Governorate** occupies a very small area of approximately **5 km²**, located exclusively within the **1 - 10 km strip**. This area represents only **0.05% of the total coastal zone studied (10,673 km²)**.

This particularity results in the **systematic absence** of Zaghouan in the first coastal strips (**0 - 300 m and 300 - 1,000 m**) and, conversely, in extreme values when it appears in the **1 - 10 km strip**. Such a low representation can introduce **statistical bias**, affecting overall averages and causing imbalances in the interpretation of regional trends.

While one might be tempted to consider this unit as **statistical noise** and exclude it from the analysis to prevent distortions, it is crucial to ensure **methodological consistency**, especially when comparing data across different countries. To avoid arbitrary inclusion or exclusion of administrative units and to maintain a **comprehensive and transparent analysis**, **Zaghouan Governorate is retained in the study**, despite its minimal influence on overall results.

3.3.1.1. Built-up area in coastal zone

The primary objective of this analysis is to evaluate CCI25 Parameter 4, which measures the proportion of urbanized areas within each band to identify urbanization trends relative to the coastline. Table 2 details the distribution of built-up areas in the Tunisian coastal zone for 2021, categorized by coastal bands (0-300 m, 300-1,000 m, and 1-10 km). The table highlights both the surface area (in km²) and the percentage of built-up areas in each band relative to the built-up areas of the entire governorate coastal zone (0-10 km). This allows for analysis of the concentration of built-up areas across the different coastal strips and identification of the governorates most impacted by urbanization.

Spatial analysis of built-up area land in the littoral zone: Examination of the spatial distribution of built-up area in the coastal zone (0-10 km) reveals a total urban footprint of 1,027.20 km². Analysis of the spatial distribution reveals a preponderant concentration of urbanized areas in the retro-littoral strip (1-10 km), which totals 819.45 km² of artificialized space, or 79.78% of the total built-up area observed. Sectors in the immediate vicinity of the coastline show more moderate rates of urbanization: the strictly coastal strip (0-300 m) accounts for only 6.55% of built-up areas, while the intermediate zone (300-1000 m) represents 13.68% of the total built-up area.

Territorial disparities in the artificialization of coastal areas: Data analysis reveals a marked heterogeneity in the spatial distribution of built-up areas at governorate level. The areas with the highest value are the governorates of Sfax (197.09 km²), Médenine (142.68 km²), Nabeul (135.13 km²) and Sousse (112.08 km²). On the other hand, some governorates are characterized by a very small urban footprint in the coastal zone, as illustrated by the cases of Béja (0.66 km²), Zaghouan (0.03 km²) and Jendouba (9.60 km²).

Tableau 2 Built-up area for year 2021 in km2 and percentage for coastal strips. CCI25 parameter 4 (% of built up area within coastal strips of different width compared to wider coastal units)

	Coastal strips			Coastal zone	*Coastal strips*			*Coastal zone*
2021_FCS30D	**0 - 300 m**	**300 - 1000 m**	**1 - 10 km**	**0-10 km**	***0 - 300 m***	***300 - 1000 m***	***1 - 10 km***	**0-10 km Control column**
Governorate	**Areas in km²**				***% of c. strips within c. zone (0m - 10 km)***			
JENDOUBA	0.83	1.72	7.04	9.60	8.68%	17.94%	73.37%	100.00%
BEJA	0.04	0.01	0.60	0.66	6.47%	1.28%	92.25%	100.00%
BIZERTE	4.10	8.06	40.43	52.59	7.79%	15.33%	76.88%	100.00%
ARIANA	0.50	0.85	45.00	46.35	1.08%	1.84%	97.08%	100.00%
TUNIS	4.64	7.53	58.92	71.08	6.52%	10.59%	82.88%	100.00%
BEN AROUS	3.81	8.61	52.06	64.48	5.91%	13.35%	80.74%	100.00%
NABEUL	10.50	25.50	99.13	135.13	7.77%	18.87%	73.36%	100.00%
ZAGHOUAN			0.03	0.03	0.00%	0.00%	100.00%	100.00%
SOUSSE	6.35	13.02	92.71	112.08	5.66%	11.62%	82.72%	100.00%
MONASTIR	7.36	16.47	62.01	85.84	8.57%	19.19%	72.24%	100.00%
MAHDIA	6.28	10.75	35.60	52.64	11.94%	20.43%	67.64%	100.00%
SFAX	9.41	18.09	169.59	197.09	4.77%	9.18%	86.05%	100.00%
GABES	2.47	6.60	47.89	56.95	4.33%	11.59%	84.08%	100.00%
MEDNINE	10.96	23.27	108.45	142.68	7.68%	16.31%	76.00%	100.00%
Total	**67.24**	**140.50**	**819.45**	**1027.20**	6.55%	13.68%	79.78%	100.00%

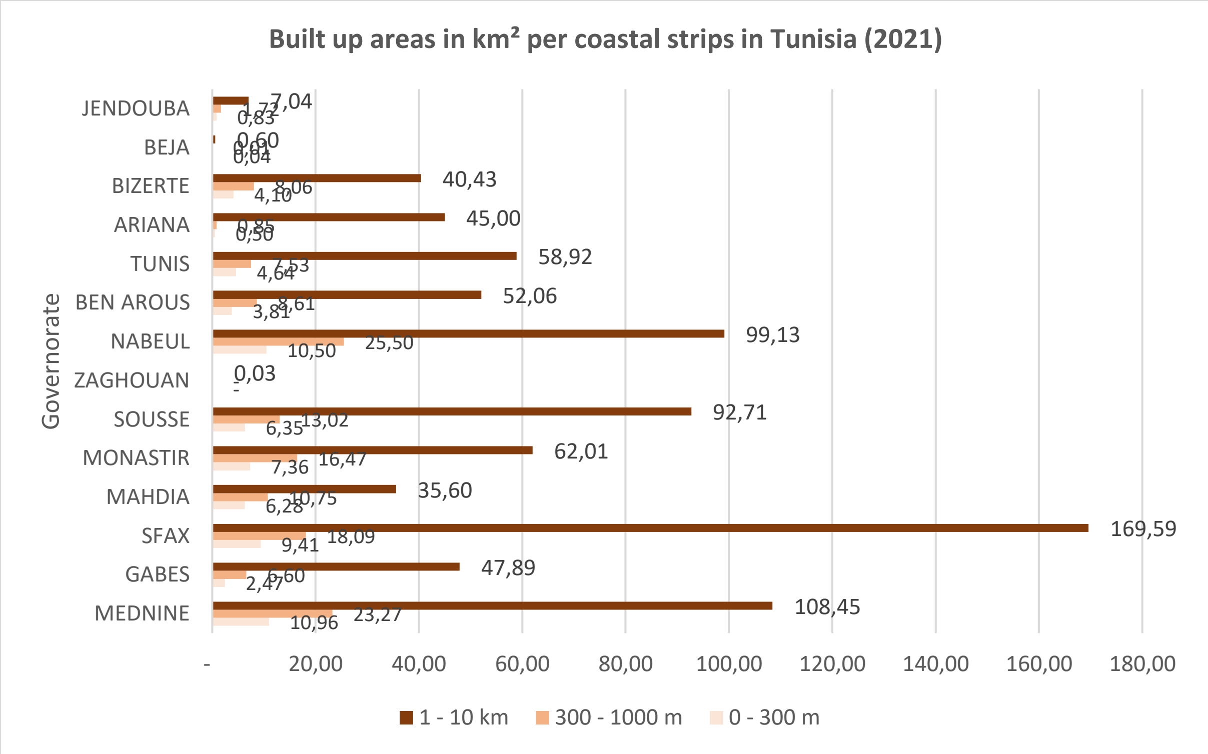


Figure 4 Built-up areas in Tunisia coastal zones per coastal strips base on CBAS World Cover data, 2021

3.3.1.2. Other land cover classes in coastal zone

Dans la bande côtière 1-10km, on observe les concentrations maximales pour toutes les classes d'occupation des sols, que ce soit en valeurs ou en proportions relatives aux gouvernorats. Plus précisément l'occupation des sols atteint ses pics dans les gouvernorats suivants : Built-up areas : Ariana avec 97,08%, Agricultural land : Béja avec 99,89%, Forest and semi-natural land : Ben Arous avec 93,80%, Wetlands : Beja avec 91.66%, Water bodies : Beja avec 98.27%.

Tableau 3 Land use/cover classes for year 2021 in km2 and percentage for coastal strips. CCI25 parameter 5 (% of other land cover classes within coastal strips of different width compared to wider coastal units)

	Coastal strips			Coastal zone	*Coastal strips*			*Coastal zone*
2021	**0 - 300 m**	**300 m– 1km**	**1 - 10 km**	**0-10 km**	**0 - 300 m**	**300 m – 1km**	**1 - 10 km**	**0-10 km Control column**
Built-up areas	**Areas in km2**				**% of c. strips within c. zone (0m - 10 km)**			
JENDOUBA	0.83	1.72	7.04	9.60	8.68%	17.94%	73.37%	*100*
BEJA	0.04	0.01	0.60	0.66	6.47%	1.28%	92.25%	*100*
BIZERTE	4.10	8.06	40.43	52.59	7.79%	15.33%	76.88%	*100*
ARIANA	0.50	0.85	45.00	46.35	1.08%	1.84%	**97.08%**	*100*
TUNIS	4.64	7.53	58.92	71.08	6.52%	10.59%	82.88%	*100*
BEN AROUS	3.81	8.61	52.06	64.48	5.91%	13.35%	80.74%	*100*

NABEUL	10.50	25.50	99.13	135.13	7.77%	18.87%	73.36%	*100*
ZAGHOUAN			0.03	0.03	0.00%	0.00%	100.00%	*100*
SOUSSE	6.35	13.02	92.71	112.08	5.66%	11.62%	82.72%	*100*
MONASTIR	7.36	16.47	62.01	85.84	8.57%	19.19%	72.24%	*100*
MAHDIA	6.28	10.75	35.60	52.64	11.94%	20.43%	67.64%	*100*
SFAX	9.41	18.09	**169.59**	197.09	4.77%	9.18%	86.05%	*100*
GABES	2.47	6.60	47.89	56.95	4.33%	11.59%	84.08%	*100*
MEDNINE	10.96	23.27	108.45	142.68	7.68%	16.31%	76.00%	*100*
Total	**67.24**	**140.50**	**819.45**	**1 027.20**	6.55%	13.68%	79.78%	**100**
Agricultural land	**Areas in km2**				**% of c. strips within c. zone (0m - 10 km)**			
JENDOUBA	0.00	0.30	6.53	6.83	0.05%	4.44%	95.51%	*100*
BEJA	0.00	0.00	2.70	2.71	0.04%	0.06%	**99.89%**	*100*
BIZERTE	1.26	4.51	247.05	252.81	0.50%	1.78%	97.72%	*100*
ARIANA	0.02	1.33	109.60	110.95	0.02%	1.20%	98.78%	*100*
TUNIS	0.00	0.38	2.89	3.27	0.14%	11.59%	88.28%	*100*
BEN AROUS	0.05	0.22	18.41	18.68	0.28%	1.16%	98.56%	*100*
NABEUL	3.75	26.14	**522.90**	552.80	0.68%	4.73%	94.59%	*100*
ZAGHOUAN			0.18	0.18	0.00%	0.00%	100.00%	*100*
SOUSSE	0.28	1.72	123.54	125.54	0.22%	1.37%	98.41%	*100*
MONASTIR	0.25	2.88	42.98	46.10	0.54%	6.24%	93.23%	*100*
MAHDIA	1.17	9.99	216.63	227.79	0.51%	4.39%	95.10%	*100*
SFAX	2.75	13.26	452.16	468.16	0.59%	2.83%	96.58%	*100*
GABES	0.83	5.80	95.47	102.10	0.81%	5.68%	93.51%	*100*
MEDNINE	3.74	25.14	401.49	430.37	0.87%	5.84%	93.29%	*100*
Total	**14.10**	**91.66**	**2 242.53**	**2 348.29**	0.60%	3.90%	95.50%	*100*
Forest and semi-natural land	**Areas in km2**				**% of c. strips within c. zone (0m - 10 km)**			
JENDOUBA	7.39	16.08	242.13	265.60	2.78%	6.05%	91.17%	*100*
BEJA	7.72	17.53	175.15	200.40	3.85%	8.75%	87.40%	*100*
BIZERTE	42.55	80.53	637.28	760.36	5.60%	10.59%	83.81%	*100*
ARIANA	3.42	4.85	69.96	78.24	4.37%	6.20%	89.42%	*100*
TUNIS	3.26	5.82	27.53	36.61	8.90%	15.90%	75.20%	*100*
BEN AROUS	2.58	4.29	104.01	110.88	2.33%	3.87%	**93.80%**	*100*
NABEUL	45.15	77.82	884.48	1 007.45	4.48%	7.72%	87.79%	*100*
ZAGHOUAN			4.72	4.72	0.00%	0.00%	100.00%	*100*
SOUSSE	12.34	28.36	453.00	493.70	2.50%	5.74%	91.76%	*100*
MONASTIR	10.15	17.29	212.08	239.51	4.24%	7.22%	88.55%	*100*
MAHDIA	13.06	23.98	231.11	268.15	4.87%	8.94%	86.19%	*100*
SFAX	67.20	126.38	785.59	979.16	6.86%	12.91%	80.23%	*100*
GABES	20.07	45.33	608.84	674.24	2.98%	6.72%	90.30%	*100*
MEDNINE	84.13	155.95	**1 201.36**	1 441.43	5.84%	10.82%	83.34%	*100*
Total	**319.01**	**604.21**	**5 637.23**	**6 560.45**	4.86%	9.21%	85.93%	*100*
Wetlands	**Areas in km2**				**% of c. strips within c. zone (0m - 10 km)**			
JENDOUBA	0.00	0.12	0.04	0.16	1.88%	76.09%	22.04%	*100*
BEJA	-	0.00	0.04	0.04	0.00%	8.34%	**91.66%**	*100*
BIZERTE	0.38	0.38	5.41	6.17	6.22%	6.12%	87.66%	*100*
ARIANA	2.29	7.80	22.30	32.39	7.07%	24.09%	68.84%	*100*
TUNIS	0.05	0.68	1.85	2.57	1.77%	26.35%	71.89%	*100*
BEN AROUS	0.23	0.32	3.12	3.68	6.38%	8.83%	84.79%	*100*
NABEUL	2.83	3.08	6.15	12.06	23.47%	25.57%	50.96%	*100*
ZAGHOUAN			-	-				
SOUSSE	2.59	5.36	19.90	27.85	9.31%	19.24%	71.45%	*100*
MONASTIR	1.70	0.37	16.68	18.75	9.06%	1.98%	88.97%	*100*
MAHDIA	1.08	0.65	8.72	10.44	10.30%	6.24%	83.46%	*100*
SFAX	15.00	7.65	2.95	25.60	58.59%	29.90%	11.51%	*100*
GABES	3.37	1.36	0.36	5.09	66.16%	26.71%	7.14%	*100*
MEDNINE	12.98	8.38	**26.79**	48.15	26.97%	17.39%	55.64%	*100*
Total	**42.51**	**36.16**	**114.29**	**192.96**	22.03%	18.74%	59.23%	100.00

Water bodies	Areas in km2				% of c. strips within c. zone (0m - 10 km)			
JENDOUBA	0.23	0.03	3.45	3.71	6.23%	0.83%	92.94%	*100*
BEJA	0.19	0.11	16.99	17.28	1.08%	0.65%	**98.27%**	*100*
BIZERTE	2.75	5.85	116.59	125.19	2.19%	4.67%	93.13%	*100*
ARIANA	1.05	1.33	15.79	18.17	5.77%	7.34%	86.89%	*100*
TUNIS	0.20	1.35	26.17	27.72	0.71%	4.88%	94.40%	*100*
BEN AROUS	0.33	1.02	7.15	8.49	3.86%	11.96%	84.18%	*100*
NABEUL	2.19	2.88	9.37	14.44	15.19%	19.96%	64.85%	*100*
ZAGHOUAN			-	-				
SOUSSE	0.45	2.44	7.49	10.38	4.30%	23.51%	72.19%	*100*
MONASTIR	1.29	2.40	50.99	54.68	2.36%	4.39%	93.24%	*100*
MAHDIA	0.34	0.26	0.45	1.05	32.16%	24.69%	43.14%	*100*
SFAX	6.01	10.89	5.94	22.83	26.32%	47.68%	25.99%	*100*
GABES	0.65	0.14	0.08	0.88	74.41%	16.01%	9.58%	*100*
MEDNINE	4.55	13.45	**221.31**	239.31	1.90%	5.62%	92.48%	*100*
Total	**20.22**	**42.16**	**481.76**	**544.14**	3.72%	7.75%	88.54%	*100*

3.3.1.3. protected areas within coastal strips of different width

CCI25 parameter 6 reveals a specific distribution of protected areas along the Tunisian costal zone, with significant variations between governorates and different coastal strips.

Spatial distribution of protection zones

The total surface area of coastal protected areas is 751.98 km² (7.05%). Most of this protection is concentrated in the 1-10 km band (593.42 km²), representing 79% of all protected areas. Closer-to-shore strips are much less well represented, with 96.64 km² (12.8%) in the 300-1000 m zone and only 61.92 km² (8.2%) in the immediate coastal fringe (0-300 m).

Marked territorial disparities

Analysis by governorate reveals significant contrasts:

- Médenine stands out with 352.15 km² of protected areas, including 288.35 km² in the coastal hinterland (1-10 km), thanks in particular to the Bhiret el Bibane lagoon.
- Béja ranks second with 123.71 km² of protected areas, mainly in the 1-10 km band (107.02 km²).
- Bizerte (71.12 km²), Sfax (52.80 km²) and Nabeul (49.13 km²) also have significant areas, with a more balanced distribution in Sfax, which has 13.33 km² in the 0-300 m band.

On the other hand, some governorates show a worrying lack of protected areas. Ariana and Mahdia have no listed protected areas, while Jendouba has only a symbolic 0.37 km² in the 1-10 km band.

Table 4 Protected areas in Tunisia and in governorates in year 2015.

2015		Protected areas	Non protected areas	Total coastal zone
Tunisia	Area in km ²	751.98	9 921.08	10 673.06
	% in coastal zone	*7.05%*	*92.95%*	*100.00%*
JENDOUBA	Area in km ²	0.37	285.53	285.90
	% in coastal zone	*0.13%*	*99.87%*	*100.00%*
BEJA	Area in km ²	123.71	97.38	221.08
	% in coastal zone	*55.96%*	*44.04%*	*100.00%*
BIZERTE	Area in km ²	71.12	1 126.01	1 197.14
	% in coastal zone	*5.94%*	*94.06%*	*100.00%*
ARIANA	Area in km ²	-	286.09	286.09
	% in coastal zone	*0.00%*	*100.00%*	*100.00%*
TUNIS	Area in km ²	26.88	114.37	141.26
	% in coastal zone	*19.03%*	*80.97%*	*100.00%*
BEN AROUS	Area in km ²	27.67	178.54	206.22
	% in coastal zone	*13.42%*	*86.58%*	*100.00%*
NABEUL	Area in km ²	49.13	1 672.76	1 721.89
	% in coastal zone	*2.85%*	*97.15%*	*100.00%*
ZAGHOUAN	Area in km ²	-	4.94	4.94
	% in coastal zone	*0.00%*	*100.00%*	*100.00%*
SOUSSE	Area in km ²	10.64	758.90	769.54
	% in coastal zone	*1.38%*	*98.62%*	*100.00%*
MONASTIR	Area in km ²	9.46	435.43	444.89
	% in coastal zone	*2.13%*	*97.87%*	*100.00%*
MAHDIA	Area in km ²	-	560.07	560.07
	% in coastal zone	*0.00%*	*100.00%*	*100.00%*
SFAX	Area in km ²	52.80	1 640.05	1 692.85
	% in coastal zone	*3.12%*	*96.88%*	*100.00%*
GABES	Area in km ²	28.04	811.22	839.26
	% in coastal zone	*3.34%*	*96.66%*	*100.00%*
MEDNINE	Area in km ²	352.15	1 949.79	2 301.94
	% in coastal zone	*15.30%*	*84.70%*	*100.00%*

in the most sensitive zones (0-300 m and 300-1000 m), only 61.92 km² (8.23%) are protected in the 0 - 300 m band, reflecting poor conservation of immediate coastal areas. The governorates with most protection in this band are Médenine (27.32 km²), Sfax (13.33 km²), Béja (5.19 km²) and Gabès (4.35 km²). Médenine stands out as the governorate with the strongest protection of the immediate coastline, while Tunis, Sousse and Monastir have virtually no protected areas in this critical strip.

Tableau 5 Protected areas in km2 and percentages in the coastal strips per year 2015.
CCI25 parameter 6 (km2 of protected areas within coastal strips of different width)

	Coastal strips	**Coastal**	***Coastal strips***	***Coastal***

				zone				zone
Protected areas	**0 - 300 m**	**300 – 1km**	**1 - 10 km**	**0-10 km**	**0 - 300 m**	**300 – 1km**	**1 - 10 km**	**0-10 km Control column**
	Areas in km2				**% of c. strips within c. zone (0m - 10 km)**			
Tunisia	**61.92**	**96.64**	**593.42**	**751.98**	8.23%	12.85%	78.91%	100.00%
JENDOUBA	-	-	0.37	0.37	0.00%	0.00%	100.00%	100.00%
BEJA	5.19	11.50	107.02	123.71	4.20%	9.29%	86.51%	100.00%
BIZERTE	6.83	10.69	53.61	71.12	9.60%	15.03%	75.37%	100.00%
ARIANA	-	-	-	-				
TUNIS	0.05	1.21	25.62	26.88	0.17%	4.51%	95.31%	100.00%
BEN AROUS	0.14	1.12	26.41	27.67	0.52%	4.06%	95.42%	100.00%
NABEUL	4.68	5.16	39.29	49.13	9.53%	10.50%	79.97%	100.00%
ZAGHOUAN			-	-				
SOUSSE	0.03	2.22	8.39	10.64	0.32%	20.83%	78.85%	100.00%
MONASTIR	-	1.06	8.40	9.46	0.00%	11.21%	88.79%	100.00%
MAHDIA	-	-	-	-				
SFAX	13.33	19.79	19.69	52.80	25.24%	37.47%	37.29%	100.00%
GABES	4.35	7.42	16.27	28.04	15.52%	26.45%	58.03%	100.00%
MEDNINE	27.32	36.48	288.35	352.15	7.76%	10.36%	81.88%	100.00%

3.3.1.3. Low elevation coastal zones

This table shows the surface area of low elevation coastal zones (LECZ) in each coastal governorate, as well as their proportion of the total coastal zone (0-10 km). LECZs are defined as areas less than 5 meters above sea level, making them particularly vulnerable to sea-level rise, coastal flooding and saline intrusion.

The total area of LECZs in the coastal zone studied is 2,532.49 km², representing 23.73% of the total coastal zone (10,673.06 km²). This proportion indicates that around a quarter of the Tunisian coastline is directly exposed to coastal hazards, underlining the need for appropriate management of these sensitive areas.

Some governorates have a very high proportion of LECZ, making them particularly vulnerable to the impacts of climate change:

- Ariana (80.22%) and Tunis (61.56%): These heavily urbanized areas have a large part of their coastal area at low altitude, which exposes them directly to flood risks.
- Médenine (38.38%), Monastir (35.25%) and Sousse (26.76%): These governorates have significant low-lying areas, often occupied by tourist infrastructures and expanding urban areas.
- Sfax (22.91%) and Mahdia (23.77%): The proportion of LECZ is also significant here, which poses challenges in terms of land use planning.

Some governorates have a low proportion of LECZ in their coastal zone, which means they are less directly exposed to the risks associated with sea-level rise:

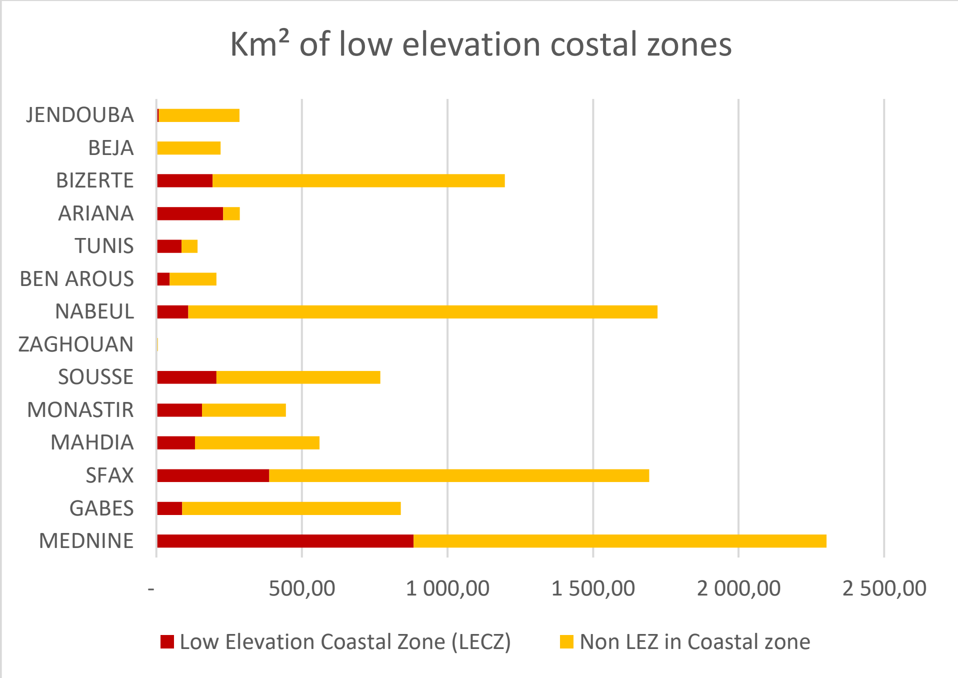
- Béja (1.16%) and Jendouba (3.06%): These regions have a higher relief and are therefore less affected by coastal flooding issues.
- Nabeul (6.37%) and Gabès (10.54%): Although these coastal areas are largely urbanized or agricultural, their exposure to the LECZ remains moderate compared with other regions.

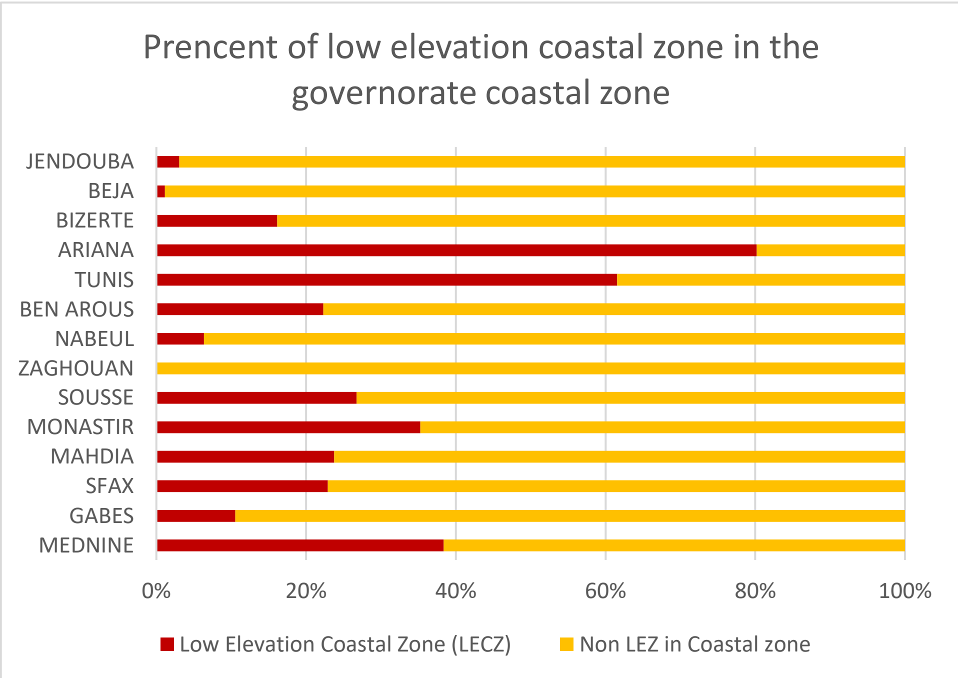
Correlation with urbanization and economic activities

- The governorates with the highest proportions of LECZ (Ariana, Tunis, Monastir, Sousse, Médenine) are also those with major urban and industrial areas, meaning that critical infrastructures (ports, roads, residential and industrial buildings) could be threatened by extreme coastal phenomena.
- Regions with high tourist activity, such as Monastir, Sousse and Médenine (Djerba), are particularly vulnerable, as many hotels and infrastructures are built in close proximity to the coast.
- Agricultural areas, particularly in the plains of Sfax and Gabès, are also at risk of saline intrusion into the water table, which could affect the productivity of arable land.

Table 1 LEZ areas in different administrative units and their percentages within the 10 km coastal zone CCI25 parameter 7 (km2 of LEZ)

Governorate	Low Elevation Coastal Zone (LECZ) [km^2]	Non LEZ in coastal zone [km^2]	Coastal zone (CZ) - 0-10 km [km^2]	Percentage of LECZ within CZ
JENDOUBA	8.76	277.14	285.90	3.06%
BEJA	2.56	218.53	221.08	1.16%
BIZERTE	193.43	1 003.71	1 197.14	16.16%
ARIANA	229.50	56.60	286.09	80.22%
TUNIS	86.96	54.30	141.26	61.56%
BEN AROUS	46.01	160.21	206.22	22.31%
NABEUL	109.72	1 612.16	1 721.89	6.37%
ZAGHOUAN	-	4.94	4.94	0.00%
SOUSSE	205.94	563.60	769.54	26.76%
MONASTIR	156.82	288.07	444.89	35.25%
MAHDIA	133.11	426.96	560.07	23.77%
SFAX	387.83	1 305.01	1 692.85	22.91%
GABES	88.47	750.79	839.26	10.54%
MEDNINE	883.39	1 418.55	2 301.94	38.38%
Total	**2 532.49**	**8 140.57**	**10 673.06**	**23.73%**


Km² of low elevation costal zones
JENDOUBA
BEJA
BIZERTE
ARIANA
TUNIS
BEN AROUS
NABEUL
ZAGHOUAN
SOUSSE
MONASTIR
MAHDIA
SFAX
GABES
MEDNINE
-
500,00
1 000,00
1 500,00
2 000,00
2 500,00
Low Elevation Coastal Zone (LECZ)
Non LEZ in Coastal zone


Prencent of low elevation coastal zone in the governorate coastal zone
JENDOUBA
BEJA
BIZERTE
ARIANA
TUNIS
BEN AROUS
NABEUL
ZAGHOUAN
SOUSSE
MONASTIR
MAHDIA
SFAX
GABES
MEDNINE
0%
20%
40%
60%
80%
100%
Low Elevation Coastal Zone (LECZ)
Non LEZ in Coastal zone

Built-up area in low elevation coastal zone

CCI25 parameters 8, 9 and 10 allow us to assess the distribution of urbanization in low-lying areas, which are particularly vulnerable to coastal hazards such as sea-level rise, erosion and flooding.

The total surface area of built-up areas in the LECZ is 228.75 km². Most of the urbanization is in the 1 - 10 km band (117.23 km², 51% of the total), followed by the 300 - 1000 m band (61.52 km², 26.9%) and finally the 0 - 300 m band (50 km², 21.8%). This confirms a trend in which urbanization is more marked behind the immediate coastline, although there are variations from region to region.

Some governorates stand out for their strong presence of built-up areas in the LECZ. Sfax (37.56 km²) is the most urbanized governorate in the LECZ, with a high concentration in the 300 - 1000 m and 1 - 10 km band. Tunis (34.07 km²) and Ariana (27.69 km²) follow, with marked urbanization in the 1 - 10 km band, a sign of the gradual extension of towns beyond the immediate shoreline. Médenine (25.87 km²) and Ben Arous (21.10 km²) are also heavily urbanized in the LECZ.

Some governorates show significant urbanization in the 0 - 300 m band, indicating high vulnerability to coastal hazards. Médenine (8.78 km²), Sfax (8.75 km²) and Nabeul (7.35 km²) are the most urbanized in this band, making them more vulnerable to erosion and marine submersion. Monastir (4.81 km²) and Sousse (4.58 km²) also have high levels of erosion, probably as a result of tourist urbanization. Tunis and Bizerte, although highly urbanized in general, show urbanization further back from the coastline.

Some governorates show very limited urbanization in the LECZ. Béja (0.01 km²) and Jendouba (1.09 km²) are practically undeveloped in the LECZ, which may be linked to the geographical configuration (presence of relief, forests or wetlands). Gabès (5.52 km²) and Mahdia (14.93 km²) also have moderate built-up areas in the LECZ, despite the presence of industrial and tourist activities. Zaghouan has no built-up areas in the LECZ, which is logical given its limited access to the coast.

Table 6 Built-up areas [km²] within LECZ by coastal strips and Governorates.
CCI25 parameters 8 (km2 of built-up area within LEZ),
9 (% of built-up area within LEZ)
and 10 (% of built-up area within LEZ compared to coastal administrative unit)

Governorate	built-up area within LEZ [km^2]	Low Elevation Coastal Zone [km^2]	Coastal zone - 0-10 km [km^2]	% of built-up area within LEZ	% of built-up area within LEZ compared to CZ
JENDOUBA	1.09	8.76	285.90	12.48%	0.38%
BEJA	0.01	2.56	221.08	0.41%	0.00%
BIZERTE	9.09	193.43	1 197.14	4.70%	0.76%
ARIANA	27.69	229.50	286.09	12.07%	9.68%
TUNIS	34.07	86.96	141.26	39.18%	24.12%
BEN AROUS	21.10	46.01	206.22	45.86%	10.23%
NABEUL	19.86	109.72	1 721.89	18.10%	1.15%
ZAGHOUAN	-	-	4.94	-	0.00%
SOUSSE	13.31	205.94	769.54	6.47%	1.73%
MONASTIR	18.64	156.82	444.89	11.88%	4.19%
MAHDIA	14.93	133.11	560.07	11.21%	2.67%
SFAX	37.56	387.83	1 692.85	9.69%	2.22%
GABES	5.52	88.47	839.26	6.24%	0.66%
MEDNINE	25.87	883.39	2 301.94	2.93%	1.12%
Total	**228.75**	**2 532.49**	**10 673.06**	**9.03%**	**2.14%**

Table 2 Built-up areas [km²] within LECZ by coastal strips and governorates

	Built-up in different coastal strips in LECZ [km^2]			
Governorate	**0 - 300 m**	**300 - 1000 m**	**1 - 10 km**	**Built-up in LECZ [km^2]**
JENDOUBA	0.36	0.36	0.37	1.09
BEJA	0.01	0.00	0.00	0.01
BIZERTE	2.05	1.59	5.45	9.09
ARIANA	0.50	0.85	26.34	27.69
TUNIS	2.51	2.70	28.86	34.07
BEN AROUS	3.80	7.65	9.65	21.10
NABEUL	7.35	9.10	3.41	19.86
ZAGHOUAN			-	-
SOUSSE	4.58	3.15	5.59	13.31
MONASTIR	4.81	4.26	9.57	18.64
MAHDIA	4.50	5.99	4.43	14.93
SFAX	8.75	13.96	14.86	37.56
GABES	1.99	2.94	0.59	5.52
MEDNINE	8.78	8.98	8.10	25.87
Total	**50.00**	**61.52**	**117.23**	**228.75**

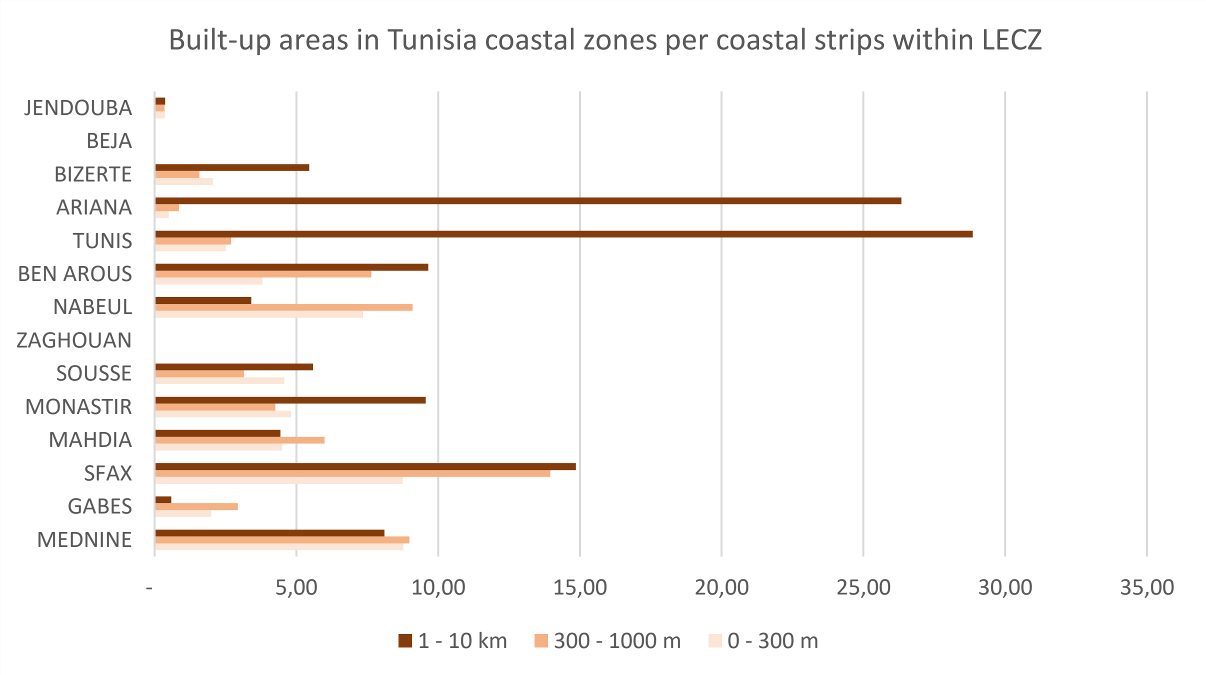


Figure 5 Built-up areas in Tunisia coastal zones per coastal strips within LECZ

Tableau 7 Land use / land cover classes in the LECZ

Governorate	Built-up [km²]	Agriculture [km²]	Forest & semi-natural [km²]	Wetlands [km²]	Waterbodies [km²]	Total [km²]
JENDOUBA	1.09	1.21	6.15	0.14	0.16	8.76
BEJA	0.01	-	2.21	0.00	0.34	2.56
BIZERTE	9.09	38.84	27.28	6.10	112.10	193.41
ARIANA	27.69	93.55	57.72	32.39	18.15	229.50
TUNIS	34.07	1.94	20.70	2.57	27.68	86.96
BEN AROUS	21.10	0.76	12.02	3.67	8.45	46.01
NABEUL	19.86	18.28	54.52	10.49	6.57	109.72
ZAGHOUAN	-	-	-	-	-	-
SOUSSE	13.31	20.91	134.50	27.44	9.77	205.94
MONASTIR	18.64	6.01	59.40	18.14	54.63	156.82
MAHDIA	14.93	34.83	71.91	10.40	1.04	133.11
SFAX	37.56	22.59	279.44	25.50	22.73	387.83
GABES	5.52	7.98	69.01	5.08	0.87	88.47
MEDNINE	25.87	43.08	527.37	48.01	239.07	883.39
Total	**228.75**	**289.99**	**1 322.23**	**189.94**	**501.57**	**2 532.48**

This table shows the distribution of different land use classes in the Low Elevation Coastal Zones (LECZ) of Tunisia's coastal governorates. It enables us to identify the dynamics of land use in these areas, which are particularly vulnerable to the effects of climate change and urbanization.

The overall distribution of land use classes in the LECZs shows a breakdown between five main categories:

- Forest & Semi-Natural Land: 1,322.23 km² (52.2% of total)
- Agricultural Land: 289.99 km² (11.4%)
- Built-up areas: 228.75 km² (9.0%)
- Wetlands: 189.94 km² (7.5%)
- Water bodies: 501.57 km² (19.8%)

Médenine (883.39 km²) has the largest low-lying coastal area, dominated by the Forest & Semi-Natural Land class (527.37 km², or 59.7%), followed by water bodies (239.07 km², or 27.1%). Urbanization is also significant (25.87 km²). Sfax (387.83 km²) is characterized by a predominance of forests and semi-natural environments (279.44 km², or 72.1%) and relatively high urbanization (37.56 km²).

Sousse (205.94 km²), Bizerte (193.41 km²) and Monastir (156.82 km²) also have large areas of LECZ, with a more balanced distribution between agriculture, natural environments and urbanization.

Agriculture covers only 11.4% of the LECZ (289.99 km²). Ariana (93.55 km²), Médenine (43.08 km²) and Bizerte (38.84 km²) have the largest agricultural areas in LECZ.

The "Forest & Semi-Natural Land" class represents 52.2% of the LECZ, or 1,322.23 km². Médenine (527.37 km²), Sfax (279.44 km²) and Mahdia (71.91 km²) have the largest areas in this category.

Wetlands account for 189.94 km² (7.5%), concentrated in Médenine (48.01 km²), Sousse (27.44 km²) and Sfax (25.50 km²).

Water bodies cover 501.57 km² (19.8%), with particularly large areas in Bizerte (112.10 km²), Médenine (239.07 km²) and Monastir (54.63 km²).

Other land cover classes in low elevation coastal zone

Tableau 8 CCI25 parameters 11 (% of other land cover classes within LECZ) and 12 (% of other land cover classes within LEZ compared to coastal administrative unit)

Governorate	agricultural land within LECZ [km^2]	Low Elevation Coastal Zone (LECZ) [km^2]	Coastal zone (CZ) [km^2]	% of agricultural area within LECZ	% of agricultural area within LECZ compared to coastal zone
JENDOUBA	1.21	8.76	285.90	13.80%	0.42%
BEJA	-	2.56	221.08	0.00%	0.00%
BIZERTE	38.84	193.43	1 197.14	20.08%	3.24%
ARIANA	93.55	229.50	286.09	40.76%	32.70%

TUNIS	1.94	86.96	141.26	2.24%	1.38%
BEN AROUS	0.76	46.01	206.22	1.66%	0.37%
NABEUL	18.28	109.72	1 721.89	16.66%	1.06%
ZAGHOUAN	-	-	4.94	-	0.00%
SOUSSE	20.91	205.94	769.54	10.15%	2.72%
MONASTIR	6.01	156.82	444.89	3.83%	1.35%
MAHDIA	34.83	133.11	560.07	26.16%	6.22%
SFAX	22.59	387.83	1 692.85	5.83%	1.33%
GABES	7.98	88.47	839.26	9.03%	0.95%
MEDNINE	43.08	883.39	2 301.94	4.88%	1.87%
Total général	**289.99**	**2 532.49**	**10 673.06**	**11.45%**	**2.72%**
Governorate	forest-seminaturalwithin LECZ [km^2]	Low Elevation Coastal Zone (LECZ) [km^2]	Coastal zone (CZ) [km^2]	% of forest-seminatural area within LECZ	% of forest-seminatural area within LECZ compared to coastal zone
JENDOUBA	6.15	8.76	285.90	70.22%	2.15%
BEJA	2.21	2.56	221.08	86.25%	1.00%
BIZERTE	27.28	193.43	1 197.14	14.10%	2.28%
ARIANA	57.72	229.50	286.09	25.15%	20.18%
TUNIS	20.70	86.96	141.26	23.80%	14.65%
BEN AROUS	12.02	46.01	206.22	26.13%	5.83%
NABEUL	54.52	109.72	1 721.89	49.69%	3.17%
ZAGHOUAN	-	-	4.94	-	0.00%
SOUSSE	134.50	205.94	769.54	65.31%	17.48%
MONASTIR	59.40	156.82	444.89	37.88%	13.35%
MAHDIA	71.91	133.11	560.07	54.02%	12.84%
SFAX	279.44	387.83	1 692.85	72.05%	16.51%
GABES	69.01	88.47	839.26	78.00%	8.22%
MEDNINE	527.37	883.39	2 301.94	59.70%	22.91%
Total général	**1 322.23**	**2 532.49**	**10 673.06**	**52.21%**	**12.39%**
Governorate	wetlands within LECZ [km^2]	Low Elevation Coastal Zone (LECZ) [km^2]	Coastal zone (CZ) [km^2]	% of wetlands area within LECZ	% of wetlands area within LECZ compared to coastal zone
JENDOUBA	0.14	8.76	285.90	1.62%	0.05%
BEJA	0.00	2.56	221.08	0.14%	0.00%
BIZERTE	6.10	193.43	1197.14	3.15%	0.51%
ARIANA	32.39	229.50	286.09	14.11%	11.32%
TUNIS	2.57	86.96	141.26	2.96%	1.82%
BEN AROUS	3.67	46.01	206.22	7.98%	1.78%
NABEUL	10.49	109.72	1 721.89	9.56%	0.61%
ZAGHOUAN	-	-	4.94	-	0.00%
SOUSSE	27.44	205.94	769.54	13.32%	3.57%
MONASTIR	18.14	156.82	444.89	11.57%	4.08%
MAHDIA	10.40	133.11	560.07	7.81%	1.86%
SFAX	25.50	387.83	1 692.85	6.58%	1.51%

GABES	5.08	88.47	839.26	5.75%	0.61%
MEDNINE	48.01	883.39	2301.94	5.43%	2.09%
Total général	**189.94**	**2 532.49**	**10 673.06**	**7.50%**	**1.78%**
Governorate	waterbodies land within LECZ [km²]	Low Elevation Coastal Zone (LECZ) [km²]	Coastal zone (CZ) [km²]	% of waterbodies area within LECZ	% of waterbodies area within LECZ compared to coastal zone
JENDOUBA	0.16	8.76	285.90	1.87%	0.06%
BEJA	0.34	2.56	221.08	13.20%	0.15%
BIZERTE	112.10	193.43	1 197.14	57.96%	9.36%
ARIANA	18.15	229.50	286.09	7.91%	6.34%
TUNIS	27.68	86.96	141.26	31.83%	19.59%
BEN AROUS	8.45	46.01	206.22	18.37%	4.10%
NABEUL	6.57	109.72	1 721.89	5.99%	0.38%
ZAGHOUAN	-	-	4.94	-	0.00%
SOUSSE	9.77	205.94	769.54	4.75%	1.27%
MONASTIR	54.63	156.82	444.89	34.84%	12.28%
MAHDIA	1.04	133.11	560.07	0.78%	0.19%
SFAX	22.73	387.83	1 692.85	5.86%	1.34%
GABES	0.87	88.47	839.26	0.98%	0.10%
MEDNINE	239.07	883.39	2301.94	27.06%	10.39%
Total général	**501.57**	**2 532.49**	**10 673.06**	**19.81%**	**4.70%**

3.3.1.4. Protected areas in coastal zone

This table shows the surface areas of protected zones in the LECZs, broken down by governorate and coastal strip (0-300 m, 300-1000 m, 1-10 km). A few key observations stand out:

General distribution of protected areas in LECZ:

- The total surface area of LECZ protected areas in Tunisia reaches 500.60 km², with a greater concentration in the 1-10 km band (373.62 km², or 75% of the total).
- The 0-300 m band represents 49.04 km², showing a low proportion of protected areas at very low elevations, probably due to urban pressures and coastal erosion.
- The 300-1000 m band accounts for 77.94 km², an intermediate zone where protection seems more present than in the very first few hundred meters.

Some governorates stand out for their high levels of protected area:

- Medenine has the largest protected area in the LECZ (331.66 km², including 267.90 km² in the 1-10 km band).

- Sfax has a fairly balanced distribution (49.45 km²), with notable protection even in the first coastal strips (0-300 m and 300-1000 m).
- Bizerte and Tunis also enjoy significant protected coverage (38.66 km² and 26.66 km² respectively), although most of this is located beyond the first kilometer.

Tableau 9 Protected areas within LECZ in km2 and percentages in the coastal strips per year 2015. CCI25 parameter 13 (km2 of protected areas within LEZ in coastal zone)

	Coastal strips			Coastal zone	*Coastal strips*			*Coastal zone*
Protected areas	**0 - 300 m**	**300 – 1km**	**1 - 10 km**	**0-10 km**	**0 - 300 m**	**300 – 1km**	**1 - 10 km**	**0-10 km Control column**
	Areas in km2				**% of c. strips within c. zone (0m - 10 km)**			
Tunisia	**49.04**	**77.94**	**373.62**	**500.60**	9.80%	15.57%	74.63%	100.00%
JENDOUBA	-	-	-	-				
BEJA	0.07	-	-	0.07	100.00%	0.00%	0.00%	100.00%
BIZERTE	1.54	5.53	31.59	38.66	3.98%	14.31%	81.71%	100.00%
ARIANA	-	-	-	-				
TUNIS	0.05	1.21	25.40	26.66	0.18%	4.55%	95.27%	100.00%
BEN AROUS	0.14	0.99	7.11	8.24	1.75%	11.97%	86.28%	100.00%
NABEUL	2.24	3.35	2.55	8.14	27.56%	41.15%	31.28%	100.00%
ZAGHOUAN			-	-				
SOUSSE	0.03	2.22	8.39	10.64	0.32%	20.83%	78.85%	100.00%
MONASTIR	-	1.06	8.40	9.46	0.00%	11.21%	88.79%	100.00%
MAHDIA	-	-	-	-				
SFAX	13.33	19.79	16.34	49.45	26.95%	40.01%	33.05%	100.00%
GABES	4.35	7.33	5.94	17.62	24.69%	41.59%	33.73%	100.00%
MEDNINE	27.30	36.47	267.90	331.66	8.23%	10.99%	80.78%	100.00%

3.3.2. Land cover change assessment for 2015-2020 (based on GLC_FCS30D data)

3.3.2.1. Increase of built-up area (land take)

This table highlights the variations in built-up area in Tunisia's coastal governorates between 2015 and 2020, with an overall increase of 1.73%. However, this trend conceals major disparities between regions.

Some governorates show marked growth in urbanization. Nabeul recorded the highest increase (+5.22%), rising from 134.32 km² to 141.34 km². This growth can be attributed to the extension of residential areas. Ariana follows with +3.80%. Sfax also showed significant expansion (+3.37%), reflecting growing urban pressure. Jendouba (+2.35%) and Ben Arous (+1.57%) recorded moderate but significant increases.

These increases suggest sustained urban development in these governorates, possibly linked to the expansion of infrastructure, tourism and demographic pressure.

Moderate increase nationwide: The total increase in built-up area in coastal zones (1.73%) remains relatively low, which could indicate saturation of existing urban spaces and/or stricter regulations on coastal development. Nevertheless, some governorates (Nabeul, Ariana, Sfax) continue to grow strongly, indicating an urban expansion that could pose challenges in terms of land and environmental management.

Tableau 10 increase of built-up area in the coastal zones between 2015 and 2020

Governorate	built-up area 2015	built-up area 2020	% of increase of built-up area
JENDOUBA	9.02	9.23	2.35%
BEJA	1.32	1.24	-6.62%
BIZERTE	58.46	59.08	1.06%
ARIANA	52.37	54.35	3.80%
TUNIS	82.06	81.76	-0.37%
BEN AROUS	76.28	77.48	1.57%
NABEUL	134.32	141.34	5.22%
ZAGHOUAN	0.03	0.03	-8.66%
SOUSSE	116.30	117.59	1.11%
MONASTIR	96.34	95.75	-0.62%
MAHDIA	52.22	52.62	0.75%
SFAX	210.76	217.86	3.37%
GABES	69.67	70.44	1.10%
MEDNINE	174.59	174.63	0.02%
Total	**1 133.76**	**1 153.39**	**1.73%**

Tableau 11 increase of built-up area in the coastal zones between 2015 and 2020 in the diffrent coastal strips

	Coastal strip			
Governorate	**0 - 300 m**	**300 - 1 km**	**1 - 10 km**	**Total**
JENDOUBA	-2.63%	15.15%	9.59%	5.01%
BEJA	3.76%	36.05%	-31.94%	3.47%
BIZERTE	-4.51%	0.51%	-1.55%	-2.45%
ARIANA	1.61%	-0.42%	5.86%	5.44%
TUNIS	-0.70%	-1.09%	-0.33%	-0.43%
BEN AROUS	-0.86%	0.96%	-2.70%	-1.36%
NABEUL	0.06%	4.25%	3.72%	1.89%
ZAGHOUAN	-	-	-	-
SOUSSE	-0.44%	1.20%	1.20%	0.47%
MONASTIR	0.40%	-0.45%	-2.17%	-1.06%
MAHDIA	-0.93%	-0.64%	-3.56%	-1.55%
SFAX	3.91%	1.51%	1.22%	2.04%
GABES	3.92%	1.50%	1.13%	2.80%
MEDNINE	1.86%	0.94%	-1.50%	0.53%
Total	**0.78%**	**1.24%**	**0.60%**	

This table shows the relative variations in surface area by governorate in three coastal bands (0 - 300 m, 300 m - 1 km and 1 - 10 km), as well as the total variation for each governorate. It enables us to identify trends in the spatial evolution of land use according to coastal zones, and to assess regional disparities.

General analysis shows an average variation in the total coastal zone of +0.60%. The strongest change is in the 300 m - 1 km band (+1.24%), followed by the 0 - 300 m band (+0.78%). The 1 - 10 km band is progressing more slowly (+0.60%), suggesting a slowdown in the pace of change as one moves away from the immediate coastline.

Some governorates recorded significant increases, notably Béja (+3.47% overall), with particularly marked growth in the 300 m - 1 km band (+36.05%), but a significant decrease in the 1 - 10 km band (-31.94%). Gabès (+2.80%) and Sfax (+2.04%), where growth is relatively balanced between bands. Ariana (+5.44%), with significant growth in the 1 - 10 km band (+5.86%).

Conversely, some governorates saw a reduction in surface area. Tunis (-0.43%) and Ben Arous (-1.36%), where the decrease was uniform across the three coastal strips. Monastir (-1.06%) and Mahdia (-1.55%), with negative trends, particularly in the 1 - 10 km band. Bizerte (-2.45%), which showed a general decline, particularly in the 0 - 300 m band (-4.51%).

Regional disparities and notable trends

- The northern governorates (Bizerte, Tunis, Ben Arous, Monastir, Mahdia) are tending to see their surface areas shrink, while those in the center and south (Sfax, Gabès, Médenine) are seeing increases.

- The greatest variations are observed in the 300 m - 1 km band, which may indicate a shift in urban and agricultural dynamics towards this intermediate zone, under the effect of land pressure or regulations limiting expansion in the 0 - 300 m band.

3.3.2.2. Change of other land cover classes

The percentage evolution of the different land use classes in Tunisian coastal areas between 2015 and 2020 enables us to assess the dynamics of coastal landscape transformation, particularly with regard to urbanization, agriculture, natural environments and wetlands.

The overall evolution of land use classes shows an increase in urbanized areas (+1.73%): a confirmed trend, albeit moderate, indicating a progression of urbanization on the coast. Stagnation of agricultural land (+0.02%): This figure is stable overall, but masks significant local variations. Decrease in forests and semi-natural environments (-0.52%): A slight reduction, but a cause for concern in certain regions. Regression of wetlands (-3.84%): A significant loss which may have major environmental implications. Increase in water bodies (+3.15%).

Tableau 12 increase of other land cover classes in the coastal zones between 2015 and 2020

Governorate	% of increase of built-up area	% of increase of agricultural land	% of increase of forest and semi natural area	% of increase of wetland	% of increase of waterbodies
JENDOUBA	2.35%	-1.83%	0.40%	-67.96%	127.66%
BEJA	-6.62%	-3.89%	1.22%	82.60%	-5.58%
BIZERTE	1.06%	-1.15%	0.70%	1.54%	3.42%
ARIANA	3.80%	-2.29%	51.97%	-0.88%	39.39%
TUNIS	-0.37%	-0.46%	17.98%	-6.01%	1.19%
BEN AROUS	1.57%	-2.64%	8.33%	2.06%	1.00%
NABEUL	5.22%	-1.07%	6.52%	2.18%	13.08%
ZAGHOUAN	-8.66%	-1.44%	26.52%	-	-
SOUSSE	1.11%	0.49%	0.46%	-10.20%	90.81%
MONASTIR	-0.62%	0.91%	10.93%	-5.76%	29.27%
MAHDIA	0.75%	-0.01%	-4.31%	-15.34%	69.70%
SFAX	3.37%	-2.57%	1.67%	-2.78%	0.05%
GABES	1.10%	11.48%	-4.46%	3.25%	4.58%
MEDNINE	0.02%	8.51%	-1.63%	-2.86%	1.99%
Total	**1.73%**	**0.02%**	**-0.52%**	**-3.84%**	**3.15%**

In terms of urbanization and land artificialisation, the governorates with the highest increase in built-up area were Nabeul (+5.22%), Ariana (+3.80%), Sfax (+3.37%) and Jendouba (+2.35%). Conversely, Zaghouan (-8.66%) and Béja (-6.62%) posted a decline.

In terms of agricultural dynamics, there was overall stability, but local variations. Gabès (+11.48%) and Médenine (+8.51%) recorded a sharp increase in farmland, suggesting an intensification of cultivation in coastal areas. Conversely, the majority of governorates recorded a decline in agricultural land, notably Ben Arous (-2.64%), Ariana (-2.29%) and Sfax (-2.57%).

Forests and semi-natural environments showed an overall decline (-0.52%), but some governorates showed contrasting trends. Ariana (+51.97%) and Zaghouan (+26.52%) show a significant increase. Gabès (-4.46%), Médenine (-1.63%) and Mahdia (-4.31%) showed a reduction.

As for wetlands, we note an alarming loss (-3.84%). Jendouba (-67.96%) and Mahdia (-15.34%) show worrying decreases in wetlands. The reduction in wetlands is a cause for concern, as they play a major ecological role in regulating coastal waters and protecting against erosion and flooding.

We note an expansion of water bodies (+3.15%). Jendouba (+127.66%), Sousse (+90.81%) and Mahdia (+69.70%) recorded marked increases. Béja (-5.58%) and Tunis (+1.19%) showed moderate variations.

	built-up area		
Governorate	**2015 (km²)**	**2020 (km²)**	**% of increase**
JENDOUBA	9.02	9.23	2.35%
BEJA	1.32	1.24	-6.62%
BIZERTE	58.46	59.08	1.06%
ARIANA	52.37	54.35	3.80%
TUNIS	82.06	81.76	-0.37%
BEN AROUS	76.28	77.48	1.57%
NABEUL	134.32	141.34	5.22%
ZAGHOUAN	0.03	0.03	-8.66%
SOUSSE	116.30	117.59	1.11%
MONASTIR	96.34	95.75	-0.62%
MAHDIA	52.22	52.62	0.75%
SFAX	210.76	217.86	3.37%
GABES	69.67	70.44	1.10%
MEDNINE	174.59	174.63	0.02%
Total	**1133.76**	**1153.39**	**1.73%**
	agricultural land		
Governorate	**2015 (km²)**	**2020 (km²)**	**% of increase**
JENDOUBA	71.71	70.40	-1.83%
BEJA	42.93	41.26	-3.89%
BIZERTE	627.49	620.25	-1.15%
ARIANA	193.78	189.33	-2.29%
TUNIS	28.91	28.77	-0.46%
BEN AROUS	103.26	100.54	-2.64%
NABEUL	1457.91	1442.25	-1.07%
ZAGHOUAN	4.65	4.58	-1.44%
SOUSSE	568.06	570.84	0.49%
MONASTIR	270.84	273.30	0.91%
MAHDIA	500.19	500.13	-0.01%
SFAX	682.52	665.01	-2.57%
GABES	206.09	229.75	11.48%
MEDNINE	270.77	293.82	8.51%
Total	**5029.10**	**5030.24**	**0.02%**
	forest-seminatural		
Governorate	**2015 (km²)**	**2020 (km²)**	**% of increase**
JENDOUBA	201.81	202.63	0.40%
BEJA	159.28	161.22	1.22%
BIZERTE	388.03	390.74	0.70%
ARIANA	3.74	5.69	51.97%
TUNIS	1.78	2.10	17.98%
BEN AROUS	16.97	18.38	8.33%
NABEUL	111.39	118.65	6.52%
ZAGHOUAN	0.26	0.33	26.52%
SOUSSE	35.66	35.82	0.46%
MONASTIR	7.69	8.53	10.93%
MAHDIA	5.03	4.82	-4.31%
SFAX	722.41	734.51	1.67%
GABES	554.46	529.73	-4.46%
MEDNINE	1465.10	1441.20	-1.63%
Total	**3673.61**	**3654.34**	**-0.52%**

	wetlands		
Governorate	2015 (km^2)	2020 (km^2)	% of increase
JENDOUBA	2.05	0.66	-67.96%
BEJA	0.90	1.65	82.60%
BIZERTE	15.86	16.11	1.54%
ARIANA	34.14	33.84	-0.88%
TUNIS	3.14	2.95	-6.01%
BEN AROUS	1.91	1.95	2.06%
NABEUL	9.26	9.46	2.18%
ZAGHOUAN	-	-	#DIV/0!
SOUSSE	48.72	43.75	-10.20%
MONASTIR	66.23	62.41	-5.76%
MAHDIA	2.30	1.94	-15.34%
SFAX	60.72	59.04	-2.78%
GABES	8.92	9.21	3.25%
MEDNINE	143.90	139.77	-2.86%
Total	**398.05**	**382.74**	**-3.84%**
	waterbodies		
Governorate	2015 (km^2)	2020 (km^2)	% of increase
JENDOUBA	1.31	2.99	127.66%
BEJA	16.65	15.72	-5.58%
BIZERTE	107.29	110.95	3.42%
ARIANA	2.06	2.88	39.39%
TUNIS	25.37	25.67	1.19%
BEN AROUS	7.80	7.88	1.00%
NABEUL	9.01	10.19	13.08%
ZAGHOUAN	-	-	-
SOUSSE	0.81	1.55	90.81%
MONASTIR	3.79	4.89	29.27%
MAHDIA	0.33	0.56	69.70%
SFAX	16.42	16.43	0.05%
GABES	0.12	0.13	4.58%
MEDNINE	247.58	252.52	1.99%
Total	**438.54**	**452.35**	**3.15%**

3.3.2.3. increase of built-up area, or land take within LEZ

This table shows the evolution of the built-up area in the (LECZ) of the Tunisian governorates between 2015 and 2020, as well as the percentage increase over this period. The aim is to assess urbanization in these areas, which are particularly vulnerable to coastal risks (sea-level rise, erosion, flooding).

Overall, the total built-up area in the LECZ rose from 302.83 km² in 2015 to 305.27 km² in 2020, representing an increase of only +0.80% over the entire Tunisian coastline. However, regional disparities are notable, with some governorates showing an increase in built-up area, while others are recording a reduction.

Tableau 13 increase of built-up area in the coastal zones between 2015 and 2020 winthin LEZ

Governorate	built-up area in LEZ 2015	built-up area in LEZ 2020	% of increase of built-up area in LEZ
JENDOUBA	1.37	1.44	5.01%
BEJA	0.25	0.26	3.47%
BIZERTE	13.09	12.77	-2.45%
ARIANA	30.95	32.63	5.44%
TUNIS	41.42	41.25	-0.43%
BEN AROUS	29.48	29.08	-1.36%
NABEUL	28.39	28.93	1.89%
ZAGHOUAN	0.00	0.00	-
SOUSSE	17.24	17.32	0.47%
MONASTIR	25.38	25.11	-1.06%
MAHDIA	18.51	18.23	-1.55%
SFAX	48.93	49.92	2.04%
GABES	11.34	11.66	2.80%
MEDNINE	36.50	36.69	0.53%
Total	**302.83**	**305.27**	**0.80%**

Governorates with a strong increase in urbanization in the LECZ, Ariana (+5.44%) shows the highest increase. Jendouba (+5.01%) and Béja (+3.47%): These increases remain moderate, but they indicate an increase in urbanization in low-lying areas. Sfax (+2.04%) and Gabès (+2.80%) are historically characterized by industrial and port urbanization. Médenine (+0.53%) and Sousse (+0.47%) also showed slight growth.

Some governorates saw a decrease in built-up area. Bizerte (-2.45%): A notable decline. Tunis (-0.43%) and Ben Arous (-1.36%): Despite their high urban density, these governorates recorded a slight decrease. Monastir (-1.06%) and Mahdia (-1.55%).

Governorate	0 - 300 m	300 - 1 km	1 - 10 km	Total
JENDOUBA	-2.63%	15.15%	9.59%	5.01%
BEJA	3.76%	36.05%	-31.94%	3.47%
BIZERTE	-4.51%	0.51%	-1.55%	-2.45%
ARIANA	1.61%	-0.42%	5.86%	5.44%
TUNIS	-0.70%	-1.09%	-0.33%	-0.43%
BEN AROUS	-0.86%	0.96%	-2.70%	-1.36%
NABEUL	0.06%	4.25%	3.72%	1.89%
	-	-	-	-
SOUSSE	-0.44%	1.20%	1.20%	0.47%
MONASTIR	0.40%	-0.45%	-2.17%	-1.06%
MAHDIA	-0.93%	-0.64%	-3.56%	-1.55%
SFAX	3.91%	1.51%	1.22%	2.04%
GABES	3.92%	1.50%	1.13%	2.80%
MEDNINE	1.86%	0.94%	-1.50%	0.53%
Total	**0.78%**	**1.24%**	**0.60%**	**-**

3.3.2.4. change of other land cover classes within LEZ

This table presents the percentage changes in the different land use classes in the LECZs of the Tunisian governorates over the period 2015-2020. The aim is to assess the transformation dynamics of vulnerable coastal landscapes.

The overall evolution of land use classes in LECZ (2015-2020) shows Urbanization in LECZ: +0.80%. A slight increase in agricultural land in LECZ: +1.20%. Regression of forests and semi-natural environments: -1.00%. Loss of wetlands: -3.45%. Slight increase in water bodies: +1.72%.

Tableau 14 increase of other land cover classes in the coastal zones between 2015 and 2020 within LEZ

Governorate	% of increase of built-up area in LEZ	% of increase of agricultural land in LEZ	% of increase of forest and semi natural area in LEZ	% of increase of wetland in LEZ	% of increase of waterbodies in LEZ
JENDOUBA	5.01%	-4.24%	14.03%	-15.31%	-32.41%
BEJA	3.47%	-15.08%	7.16%	-0.85%	-2.66%
BIZERTE	-2.45%	-0.33%	4.02%	5.42%	-0.40%
ARIANA	5.44%	-2.56%	56.81%	-0.88%	39.25%
TUNIS	-0.43%	-0.74%	19.62%	-6.50%	1.19%
BEN AROUS	-1.36%	-0.48%	43.16%	1.91%	1.02%
NABEUL	1.89%	-2.76%	15.04%	3.56%	13.05%
ZAGHOUAN	-	-	-	-	-
SOUSSE	0.47%	1.67%	9.69%	-9.47%	32.32%
MONASTIR	-1.06%	3.67%	15.39%	-5.73%	29.17%
MAHDIA	-1.55%	0.37%	0.18%	-15.36%	69.60%
SFAX	2.04%	5.99%	-5.89%	-2.90%	-0.12%
GABES	2.80%	4.04%	-4.36%	2.70%	4.58%
MEDNINE	0.53%	4.53%	-0.95%	-2.41%	1.70%
Total	**0.80%**	**1.20%**	**-1.00%**	**-3.45%**	**1.72%**

Some governorates recorded a significant increase in built-up area in LECZ. Ariana (+5.44%) showed the strongest growth. Jendouba (+5.01%) and Béja (+3.47%) show notable increases. Gabès (+2.80%), Sfax (+2.04%) and Nabeul (+1.89%) also posted moderate increases.

By contrast, Bizerte (-2.45%), Monastir (-1.06%), Mahdia (-1.55%) and Ben Arous (-1.36%) recorded decreases.

The overall increase in farmland was small (+1.20%), but some governorates saw strong growth. Sfax (+5.99%), Gabès (+4.04%), Médenine (+4.53%) and Monastir (+3.67%) show an increase, which may indicate agricultural intensification in low-lying areas. Sousse (+1.67%) and Mahdia (+0.37%) show more moderate growth. Conversely, the majority of governorates show a reduction in agricultural land in LECZ, notably Béja (-15.08%), Jendouba (-4.24%) and Ariana (-2.56%).

Forests and semi-natural environments in the LECZ (-1.00%) show an overall decrease, although some governorates show marked increases. Ariana (+56.81%) and Ben Arous (+43.16%). Tunis (+19.62%), Nabeul (+15.04%) and Monastir (+15.39%) also showed increases. Some governorates are recording a loss of these natural environments, notably Sfax (-5.89%), Gabès (-4.36%) and Médenine (-0.95%).

There has been a worrying loss of wetlands (-3.45%). Jendouba (-15.31%) and Mahdia (-15.36%) show the greatest losses. Sousse (-9.47%) and Tunis (-6.50%) also recorded significant decreases. Only Bizerte (+5.42%), Nabeul (+3.56%) and Gabès (+2.70%) showed an increase.

Increase in water bodies in LECZ (+1.72%). Mahdia (+69.60%), Sousse (+32.32%), Ariana (+39.25%) and Monastir (+29.17%) show notable increases. Béja (-2.66%), Jendouba (-32.41%) and Bizerte (-0.40%) recorded decreases.

	built-up area in LEZ		
Governorate	**2015 (km²)**	**2020 (km²)**	**% of increase**
JENDOUBA	1.37	1.44	5.01%
BEJA	0.25	0.26	3.47%
BIZERTE	13.09	12.77	-2.45%
ARIANA	30.95	32.63	5.44%
TUNIS	41.42	41.25	-0.43%
BEN AROUS	29.48	29.08	-1.36%
NABEUL	28.39	28.93	1.89%
ZAGHOUAN	0.00	0.00	-
SOUSSE	17.24	17.32	0.47%
MONASTIR	25.38	25.11	-1.06%
MAHDIA	18.51	18.23	-1.55%
SFAX	48.93	49.92	2.04%
GABES	11.34	11.66	2.80%
MEDNINE	36.50	36.69	0.53%
Total	**302.83**	**305.27**	**0.80%**
	agricultural land in LEZ		
Governorate	**2015 (km²)**	**2020 (km²)**	**% of increase**
JENDOUBA	5.80	5.55	-4.24%
BEJA	0.62	0.53	-15.08%
BIZERTE	61.13	60.92	-0.33%
ARIANA	159.04	154.97	-2.56%
TUNIS	16.07	15.95	-0.74%
BEN AROUS	6.13	6.10	-0.48%
NABEUL	68.22	66.34	-2.76%
ZAGHOUAN	-	-	-
SOUSSE	115.87	117.81	1.67%
MONASTIR	55.49	57.53	3.67%
MAHDIA	108.68	109.08	0.37%
SFAX	136.55	144.73	5.99%
GABES	28.82	29.99	4.04%
MEDNINE	61.04	63.80	4.53%
Total	**823.46**	**833.31**	**1.20%**
	forest-seminatural in LEZ		
Governorate	**2015 (km²)**	**2020 (km²)**	**% of increase**
JENDOUBA	1.44	1.65	14.03%
BEJA	1.28	1.37	7.16%
BIZERTE	5.33	5.54	4.02%

ARIANA	3.30	5.18	56.81%
TUNIS	1.00	1.19	19.62%
BEN AROUS	0.73	1.04	43.16%
NABEUL	4.62	5.32	15.04%
ZAGHOUAN	-	-	-
SOUSSE	23.71	26.01	9.69%
MONASTIR	5.98	6.90	15.39%
MAHDIA	3.29	3.30	0.18%
SFAX	125.84	118.42	-5.89%
GABES	39.51	37.79	-4.36%
MEDNINE	398.79	394.99	-0.95%
Total	**614.83**	**608.70**	**-1.00%**

	Wetlands in LEZ		
Governorate	**2015 (km^2)**	**2020 (km^2)**	**% of increase**
JENDOUBA	0.13	0.11	-15.31%
BEJA	0.25	0.24	-0.85%
BIZERTE	13.21	13.93	5.42%
ARIANA	34.14	33.84	-0.88%
TUNIS	3.11	2.91	-6.50%
BEN AROUS	1.91	1.95	1.91%
NABEUL	4.85	5.02	3.56%
ZAGHOUAN	-	-	-
SOUSSE	48.32	43.74	-9.47%
MONASTIR	66.18	62.39	-5.73%
MAHDIA	2.29	1.94	-15.36%
SFAX	60.12	58.38	-2.90%
GABES	8.67	8.91	2.70%
MEDNINE	139.60	136.24	-2.41%
Total	**382.79**	**369.60**	**-3.45%**

	waterbodies in LEZ		
Governorate	**2015 (km^2)**	**2020 (km^2)**	**% of increase**
JENDOUBA	0.01	0.01	-32.41%
BEJA	0.16	0.15	-2.66%
BIZERTE	100.67	100.26	-0.40%
ARIANA	2.06	2.87	39.25%
TUNIS	25.36	25.66	1.19%
BEN AROUS	7.77	7.85	1.02%
NABEUL	3.63	4.11	13.05%
ZAGHOUAN	-	-	-
SOUSSE	0.80	1.06	32.32%
MONASTIR	3.78	4.89	29.17%
MAHDIA	0.33	0.56	69.60%
SFAX	16.40	16.38	-0.12%
GABES	0.12	0.13	4.58%
MEDNINE	247.47	251.68	1.70%
Total	**408.58**	**415.61**	**1.72%**

4. Discussion

Improving CCI25 methodology: From proportional analysis to a density-based approach

Several parameters of the CCI25 indicator are expressed as rates, representing the proportion of surface area of a specific theme (land use class, LECZ, protected area) in different coastal strips of a governorate, compared to the total surface area of the same theme in the governorate as a whole.

However, this methodology has an intrinsic limitation: as the surface area of the analysis units is directly correlated to the width of the coastal strip under consideration, these rates increase naturally as the strip widens. This characteristic constitutes a significant methodological bias that compromises the ability of the CCI25 indicator to highlight the anthropic pressure exerted on each reporting unit.

Proposed alternative methodology based on density analysis

To overcome this limitation, it would be methodologically more relevant to calculate and analyze densities - defined as the ratio between the area of the theme considered in a given spatial unit and the total area of the same unit. This approach would offer several substantial advantages:

- establish statistically valid comparisons between different spatial units within the same governorate
- Precise identification of anthropogenic pressure gradients on particularly vulnerable coastal zones
- Objective quantification of the spatial concentration of the phenomena studied

Application to parameter 4 :

Parameter 4, currently defined as (% of built-up area within coastal strips of different width compared to wider coastal units), illustrates this problem perfectly.

The current formulation generates, by mathematical construction, increasing values according to the gradient of coastal strip widening (from 0-300m to 1-10 km), which makes it impossible to objectively assess the real concentration of urbanization in the coastal zones most vulnerable to artificialization phenomena.

An appropriate analytical reformulation would be to establish a comparative ratio between :

1. **Artificial density of the spatial unit (D_1) = built-up area in the spatial unit / total area of the spatial unit.**
2. **Artificial density of reference administrative unit (D_2) = built-up area in administrative unit / total area of administrative unit.**

This methodology would make it possible to highlight areas where the artificialisation coefficient is significantly higher than the territorial average, thus providing a robust spatial analysis tool to effectively guide sustainable coastal management.

	Coastal strips			Coastal zone	*Coastal strips*			*Coastal zone*
2021_FCS30D	**0 - 300 m**	**300 - 1000 m**	**1 - 10 km**	**0-10 km**	***0 - 300 m***	***300 - 1000 m***	***1 - 10 km***	**0-10 km Control column**
Governorate	**Areas in km²**				***% of c. strips within c. zone (0m - 10 km)***			
JENDOUBA	0.83	1.72	7.04	9.60	8.68%	17.94%	73.37%	100.00%
BEJA	0.04	0.01	0.60	0.66	6.47%	1.28%	92.25%	100.00%
BIZERTE	4.10	8.06	40.43	52.59	7.79%	15.33%	76.88%	100.00%
ARIANA	0.50	0.85	45.00	46.35	1.08%	1.84%	97.08%	100.00%
TUNIS	4.64	7.53	58.92	71.08	6.52%	10.59%	82.88%	100.00%
BEN AROUS	3.81	8.61	52.06	64.48	5.91%	13.35%	80.74%	100.00%
NABEUL	10.50	25.50	99.13	135.13	7.77%	18.87%	73.36%	100.00%
ZAGHOUAN			0.03	0.03	0.00%	0.00%	100.00%	100.00%
SOUSSE	6.35	13.02	92.71	112.08	5.66%	11.62%	82.72%	100.00%
MONASTIR	7.36	16.47	62.01	85.84	8.57%	19.19%	72.24%	100.00%
MAHDIA	6.28	10.75	35.60	52.64	11.94%	20.43%	67.64%	100.00%
SFAX	9.41	18.09	169.59	197.09	4.77%	9.18%	86.05%	100.00%
GABES	2.47	6.60	47.89	56.95	4.33%	11.59%	84.08%	100.00%
MEDNINE	10.96	23.27	108.45	142.68	7.68%	16.31%	76.00%	100.00%
Total	**67.24**	**140.50**	**819.45**	**1027.20**	6.55%	13.68%	79.78%	100.00%

Governorate	0 - 300 m	300 - 1000 m	1 - 10 km	0-10km
JENDOUBA	*9.85%*	*9.44%*	*2.72%*	*3.36%*
BEJA	*0.53%*	*0.05%*	*0.31%*	*0.30%*
BIZERTE	*8.02%*	*8.11%*	*3.86%*	*4.39%*
ARIANA	*6.87%*	*5.28%*	*17.13%*	*16.20%*
TUNIS	*56.92%*	*47.78%*	*50.21%*	*50.32%*
BEN AROUS	*54.38%*	*59.56%*	*28.18%*	*31.27%*
NABEUL	*16.30%*	*18.83%*	*6.51%*	*7.85%*
ZAGHOUAN			*0.70%*	*0.70%*
SOUSSE	*28.85%*	*25.58%*	*13.31%*	*14.56%*
MONASTIR	*35.49%*	*41.80%*	*16.12%*	*19.29%*
MAHDIA	*28.65%*	*23.57%*	*7.23%*	*9.40%*
SFAX	*9.37%*	*10.27%*	*11.97%*	*11.64%*
GABES	*9.01%*	*11.14%*	*6.36%*	*6.79%*
MEDNINE	*9.42%*	*10.29%*	*5.53%*	*6.20%*
Grand total	*14.52%*	*15.36%*	*8.82%*	*9.62%*

The first table illustrates the percentage of built-up area within coastal strips of different width compared to wider coastal units. Interpretation of these data reveals a predominant absolute concentration of urbanized areas in the retro-littoral strip (1-10 km), which totals 819.45 km² of artificialized space, or 79.78% of the total built-up area observed.

At the same time, the second table, showing urban density, highlights the particularly high urban pressure on the first few kilometers of coastline, reflecting the high relative urbanization of the seaside. Conversely, the 1-10 km band shows more diffuse urbanization, suggesting a more spread-out expansion dynamic behind the immediate coastline.

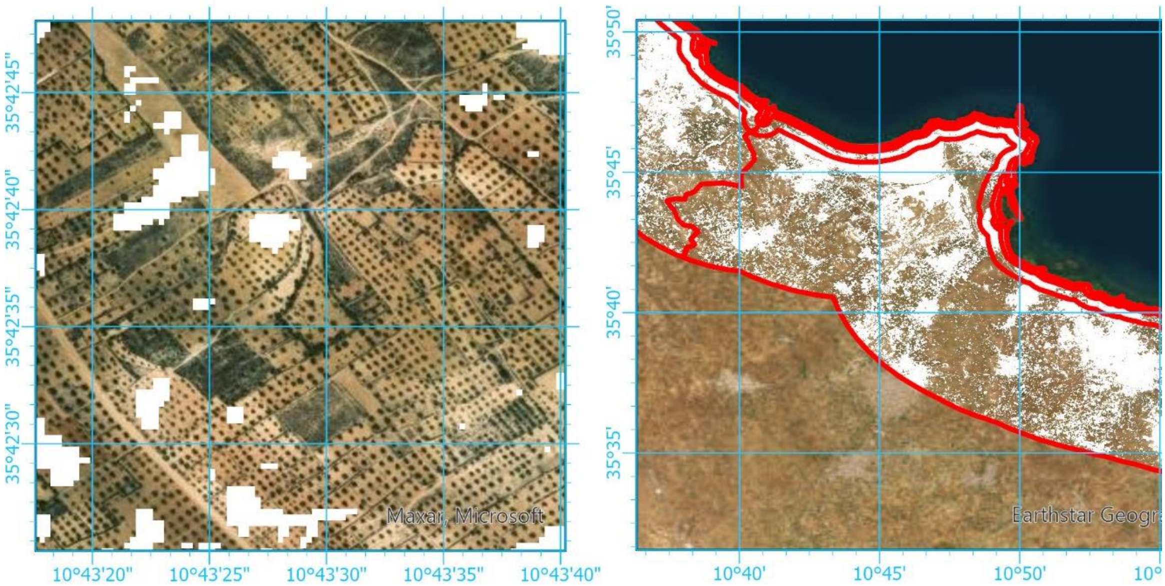
Discrepancies in land use data

Critical analysis of land classification in WorldCover 2021 and GLC_FCS30D data: the specific case of the Tunisian coastal zone

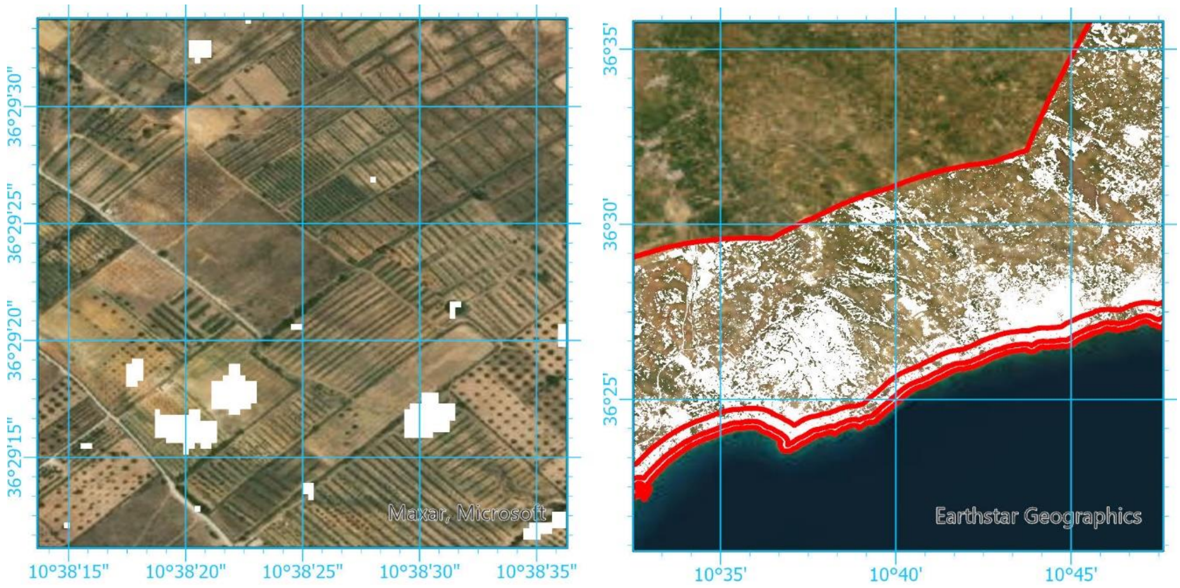
Analysis of the 2021 Land Use/Land Cover (LULC) data reveals a significant anomaly in the categorization of land classified as "Forest and Semi-Natural Land". This classification inappropriately includes considerable areas dedicated to agricultural activities, particularly arboriculture. This discrepancy intensifies along a north-south gradient, correlated with increasing aridity and the predominance of olive growing in these regions.

Origin of anomaly in WorldCover 2021 data

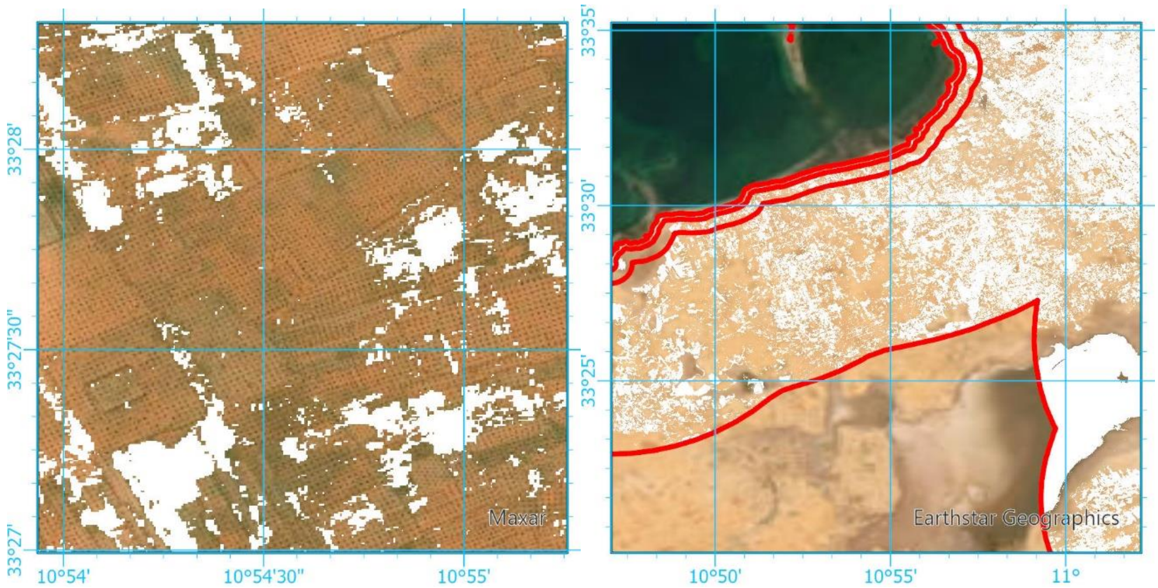
The origin of this anomaly can be traced back to the WorldCover 2021 data classification methodology. The "Forest & Semi-Natural Land" class results from the reclassification and grouping of the following categories: Tree Cover (10), Shrubland (20), Grassland (30), Bare/Sparse Vegetation (60), Snow and Ice (70) and Moss and Lichen (100). Our analysis shows that this reclassification erroneously includes areas dedicated to arboriculture in the "Grassland" and "Bare/Sparse Vegetation" categories, thus compromising the validity of the classification.



Monastir arboriculture 30 grass land



Nabeul arboriculture 30 grassland



Medenine arboriculture dans 60 Bare / sparse vegetation

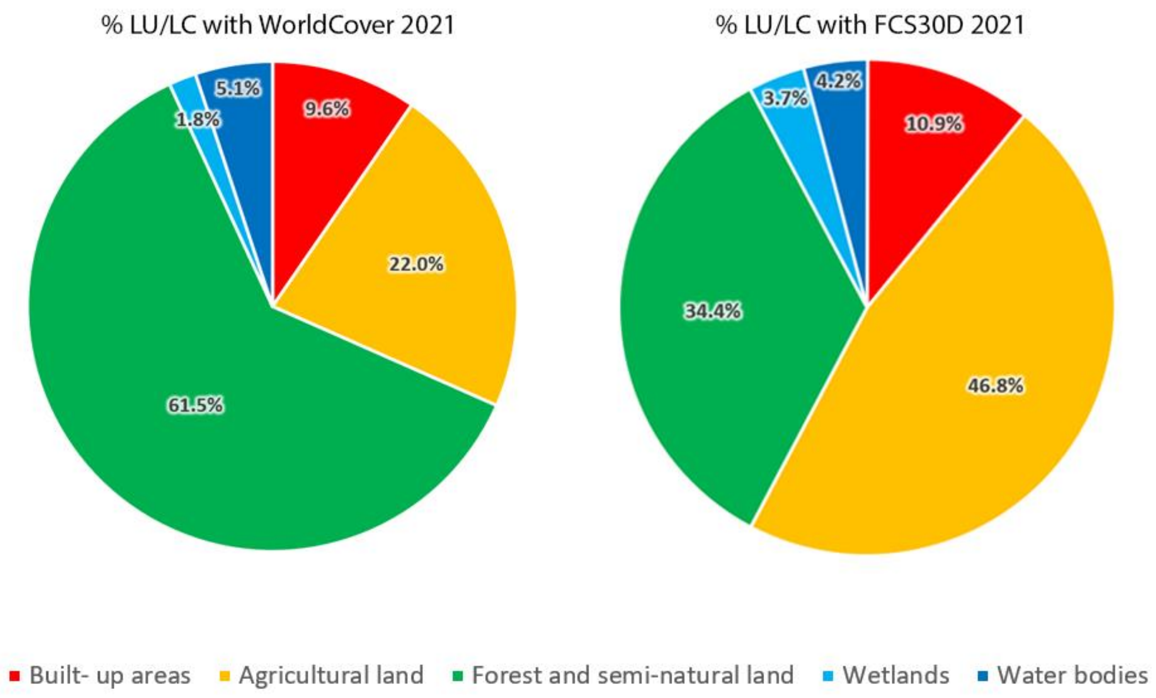
Quantitative error assessment

To quantify this error, stratified random sampling was carried out within the areas categorized as "forests and semi-natural land". The results are revealing: of 99 points assessed, only 44 points (44%) actually correspond to the class assigned, while 47 points (47%) are occupied by agricultural land. This observation demonstrates a substantial error in the initial classification of WorldCover 2021 data for the Tunisian coastal zone, despite a claimed overall accuracy of 76.7%.

Comparison with GLC_FCS30D data

A comparative analysis was carried out with Chinese data GLC_FCS30D, which has an overall accuracy of 80.88%. Similar random sampling was carried out on 166 points covering areas classified as "forests and semi-natural land". The results show that only 78 points (47%) correspond to the assigned class, while 85 points (51%) are located on agricultural land. This accuracy, although comparable to that of the WorldCover 2021 data, reveals considerable discrepancies in the distribution of total areas between classes.

Comparative analysis of surface distributions



	WorldCover 2021	GLC_FCS30D
Built-up area	9.6%	10.9%
Agricultural land	22%	46.8%
Forest and seminatural land	61.5%	34.4%
Wetlands	1.8%	3.7%
Water bodies	5.1%	4.2%

The comparative table shows significant differences between the two data sources with regard to the distribution of land use classes in the Tunisian coastal zone. While the "Built-up area", "Wetlands" and "Water bodies" classes show relatively convergent values, major discrepancies appear for the "Forest and Semi-Natural Land" and "Agricultural Land" classes.

WorldCover 2021 significantly underestimates the "Agricultural Land" class (22% vs. 46.8% according to GLC_FCS30D), a negative difference of 24.8 percentage points. This underestimation explains the excessive allocation to the "Forest and Semi-Natural Land" class (61.5%). Nevertheless, the GLC_FCS30D estimate of 46.8% is probably still lower than the actual figure, suggesting a general tendency for both sources to underestimate the importance of agricultural land in this region.

Critical environmental implications of underestimating olive growing

This underestimation of olive growing in the classification data cannot be overlooked, as it directly affects the calculation of the CCI25 indicator on the state of coastal ecosystems. The misclassification of olive-growing areas as "Forest and Semi-Natural Land" leads to a significant overestimation of natural areas and, consequently, to an underestimation of the index of anthropogenic pressure on coastal ecosystems, albeit to a less pronounced degree than urbanization or industrialization.

Tunisian olive growing is currently undergoing a rapid transition from a traditional rain-fed model to intensive irrigated systems, driven by the economic value of olive oil and accentuated by climate change.

The resulting intensification of underground water withdrawals is taking place against a backdrop of already critical water stress in Tunisia, exacerbating the vulnerability of coastal ecosystems to cumulative anthropogenic disturbances. This additional water pressure, combined with the effects of climate change, potentially compromises the ecological balance of coastal areas and their resilience to future environmental alterations.

This intensification, insufficiently documented in current classifications, is likely to amplify the pressure on already limited water resources and accelerate the degradation of fragile coastal ecosystems. Failure to take this reality into account when calculating the CCI25 indicator risks masking the urgency of the situation and distorting the assessment of medium- and long-term environmental trends.

In the case of the Tunisian coastal zone, rectifying this classification error is therefore essential to guarantee a realistic assessment of the CCI25 indicator, and to enable reliable monitoring of the evolution of anthropogenic pressures on Tunisian coastal ecosystems.