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PROTECTION AND ENHANCEMENT OF THE COASTAL AREA OF THE WILAYA OF EL TARF (ALGERIA): AUTOMATIC ANALYSIS USING COMPUTER TOOLS

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Abstract

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The coastline of El Tarf province, stretching for 90 km, presents a great variety of forms and complex ecosystems that need to be protected. The Coastal Law 02-02 was established to achieve this goal by using geographic information system (GIS) and remote sensing to assess the degree of implementation of this law on the ground. This evaluation highlighted a significant evolution of land use in the coastal zone of El Tarf province over a period of 32 years, from 1990 to 2022. In 1990, the area was predominantly forested (55.08%) with a proportion of agricultural land of 27.26% and a significant portion of wetland areas (17.26%). Over time, the forested area decreased to reach 48.58% in 2022, while agricultural land and urban areas increased. This evolution suggests increasing pressure on natural resources, with potential implications for the environment and biodiversity of the region. Despite the 2002 Coastal Law 02-02**,** which sets specific provisions for the protection and enhancement of the coastline, it is important to emphasize the importance of sustainable management of natural resources and land use in the region. It is essential to implement measures to protect the fragile ecosystems of the region and ensure the sustainability of natural resource use to preserve the environment and biodiversity of the region for future generations. This analysis could also eventually enable decision-makers to have supporting elements to evolve the law 02.02 with the aim of better preserving the coastal area.

Key words: land use, evolution, coastal strip, machine learning, dune cord, forests.

Introduction

When considered from the perspective of territorial sustainability, the development of coastal areas is a complex issue, encompassing various territorial stakes (Liziard, 2013). The coast is subject to significant pressure due to its attractiveness. The phenomenon of coastalization is characterized by a powerful migration toward coastal territories (Dachary-Bernard et al., 2011). From this versatility, numerous conflicts and challenges emerge, requiring strong coordination between the public and private actors at multiple levels. Given that the attractiveness of coasts operates on various levels (economic, commercial, touristic, etc.), they have become particularly developed territories (Daeden, 2015). Therefore, it is crucial to reconcile the different functions of the coast by ensuring an integrated and sustainable management of the coastal zone, involving the active participation of various stakeholders.

The management and preservation of the coast are, therefore, major challenges to ensure the sustainability of this ecosystem (Cadoret, 2011). This includes the implementation of integrated coastal management policies, protection of sensitive areas, regulation of human activities, etc.

That is why, Algeria has endeavored to enact Law No. 02-02 on the protection and enhancement of the coast on February 5, 2002, to protect and sustainably manage natural spaces, landscapes, and economic activities of the coast (Ghodbani, Bougherira, 2019). It aims to limit excessive urbanization, preserve natural environments, and promote a balanced development of this coastal zone. This law allows for the preservation of natural resources, protection of biodiversity, maintenance of water quality, and prevention of natural risks, while ensuring the sustainability of economic activities related to the coast (Kacemi, 2013; Khelil et al., 2019; Rabehi et al., 2019).

Geographic information system (GIS) and remote sensing are essential tools for understanding the coast (Amyay, Ouammou, 2020; Diédhiou et al., 2020; Elkafrawy et al., 2021; Yousefi et al., 2022). GIS allows for the storage, analysis, and display of geographic data, such as maps, satellite images, digital terrain models, and environmental data (Deshayes, Chery, 2000).

GIS can be used to study land use and land use changes, while remote sensing allows for the collection of data from airborne or satellite sensors, obtaining high-resolution images of the coast at

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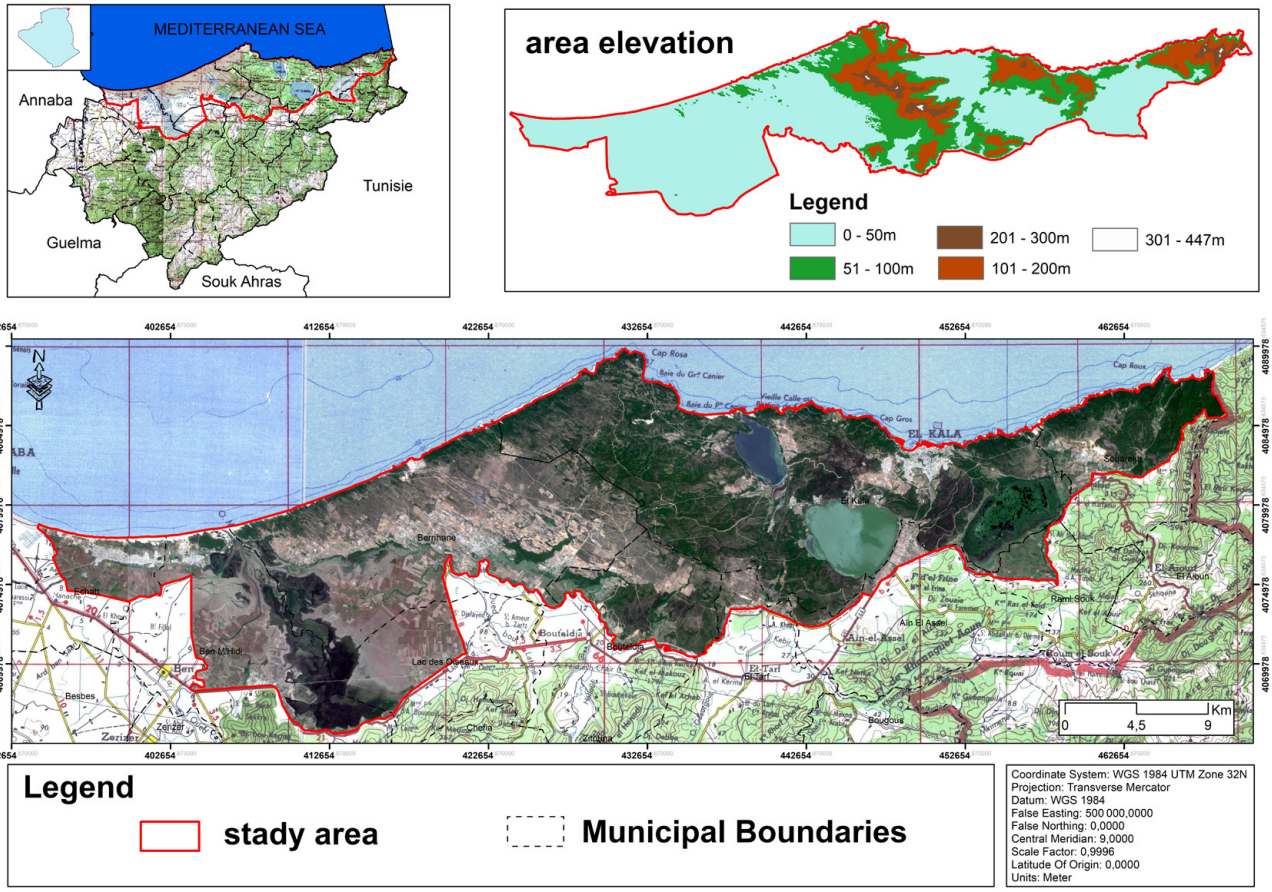


Fig. 1. Geographic location map of the study area.

different scales. Remote sensing enables the monitoring of coastal changes, measuring the movements of dunes and beaches (Ennouali et al., 2023; Grottoli et al., 2020). By combining GIS and remote sensing data, we can better understand coastal processes and environmental dynamics, thereby contributing to more effective and sustainable management of coastal zones.

Land use and land cover (LULC) information plays a key role in the analysis of terrestrial information for human development. It plays an important role in planning, management, and monitoring programs at local, regional, and national levels (Rana, Suryanarayana, 2020).

Empirical studies conducted by researchers from various disciplines have proven that LULC information is essential for various applications such as hydrology, agriculture, forestry, environment, geology, and ecology (Masayi et al., 2021; Yonaba, 2020).

Several methods can be used to detect changes in land use. These include unsupervised classification, hierarchical classifications, object-oriented classifications, and so on. In addition, machine learning–based methods, such as convolutional neural networks (CNNs) and image segmentation methods, offer the possibility of automatically detecting changes in land cover (Ozguven, Adem, 2019).

The primary objective of this study is to carry out an in-depth analysis of the evolution of the coastal zone of the wilaya of El Tarf, in accordance with the provisions of Law No. 02-02 relating to the protection and enhancement of the coastline. This analysis will involve quantifying and recording changes in land use over the period from 1990 to 2022. The working method chosen for this study is supervised classification, recognized for its efficiency and accuracy.

Material and methods

Study area

The coastal area of the wilaya of El Tarf is limited to the east by the border between Algeria and Tunisia, or more precisely by the mouth of the Oued Souani Es Sebâa. To the west, the estuaries of Oued Boukhmira and Oued Khelidj delimit both the coastline of the wilaya of Annaba and that of El Tarf (Fig. 1).

This zone includes a variety of coastal features, including low and high beaches, coastal dunes, and barrier beaches. Low-lying beaches are relatively close to sea level and are flat, wide, and low lying. They are formed by the accumulation of coastal sediments, such as sand, carried by waves and ocean currents. These beaches are often accessible and ideal for recreational activities and swimming.

Upland beaches, on the other hand, are found at a higher elevation above sea level. They may be higher than adjacent low-lying beaches due to coastal erosion, cliff formation, or the presence of dunes.

Table 1. Distribution of population among agglomerations.

	Agglomerations chief place	Secondary agglomerations	Sparse zone	Total
Coastal municipalities	68914	32463	10830	112207
Inland municipalities	158724	87690	44882	291296
Total	227638	120153	55712	403503

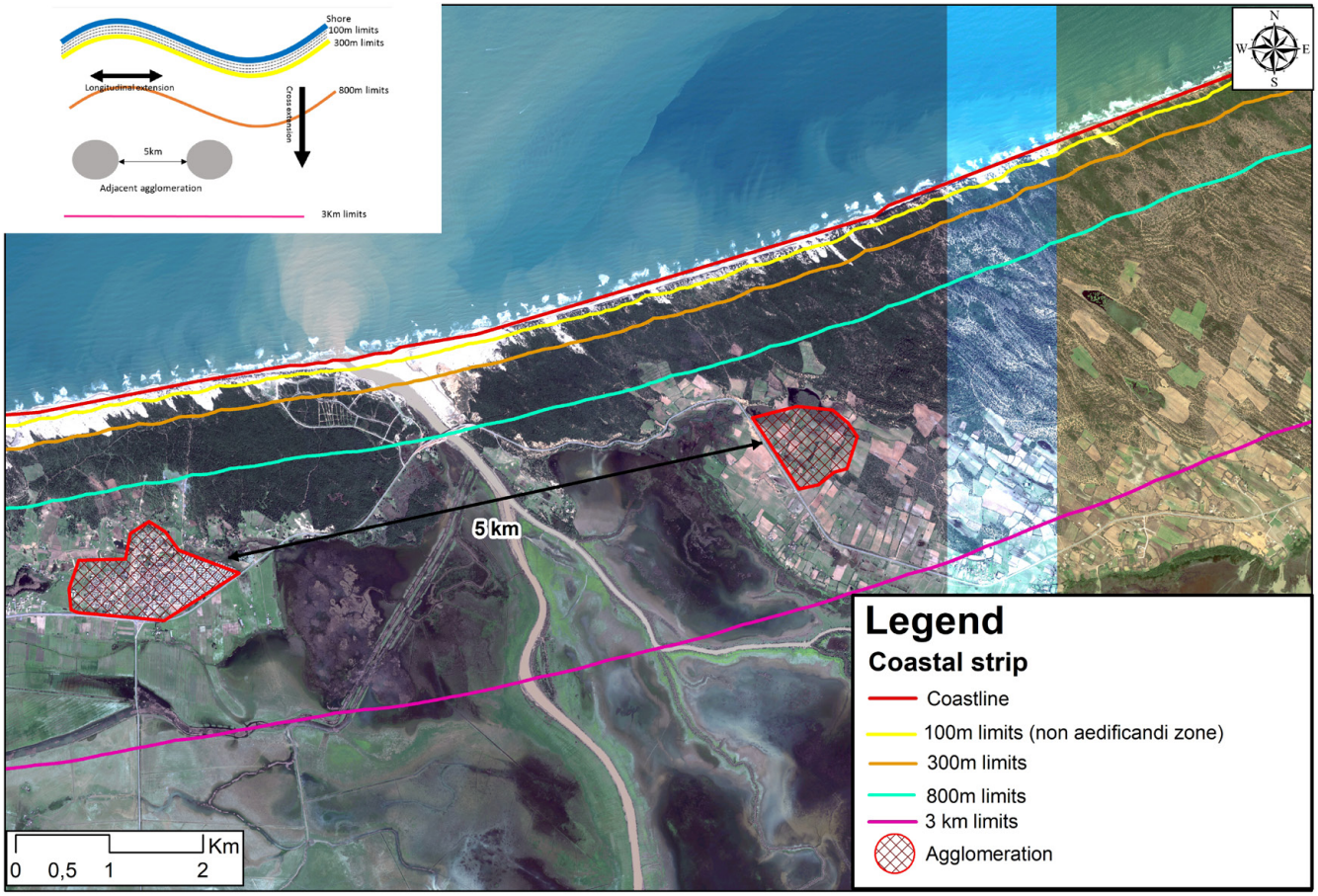


Fig. 2. Area delimited by Law 02-02 of February 5, 2002.

Dunes cover 56.52 km or 62.8% of the wilaya's coastline. The rest of the coastal zone consists of rocky coasts, cliffs, bays, and beaches.

According to the General Census of Population and Housing in 2008, the population was 403,503 inhabitants. The population density was 230 inhabitants/km². Of the 24 regions, five are on the coastal front, which are divided into two Daïras, namely, the Daïra of El Kala with coastal municipalities named El Kala and Souarekh and the Daïra of Ben M'hidi with its three coastal municipalities named Ben M'Hidi, Echatt, and Berrihane. In terms of area, these five municipalities cumulate an area of 806 km², which is 28% of the total area of the wilaya (Table 1). The El Tarf wilaya is characterized by two main vocations, tourism and agriculture.

Methodology

The methodology used in this study is based on two main pillars. The first pillar is based on Law No. 02-02 of February 5, 2002, on the protection and valorization of the coastline, where we have highlighted, from the articles of this law, the most important measures taken to preserve the Algerian coastline.

Law 02-02 of February 5, 2002 on the protection and enhancement of the coastline aims to improve the management of coastal areas in Algeria. It defines the coastline as an entity comprising different zones and imposes restrictions on urban development in three bands, defined according to their distance from the highest maritime waters. Band 1 (100 m) is nonbuildable, band 2 (800 m) prohibits new roads parallel to the coastline, and

Table 2. Characteristics of the Landsat images used.

Date of acquisition	Sensor	Spectral band (μm)	Spatial resolution
01.06.1990 24.06.1990 28.06.2000 21.07.2000	Landsat 5 TM	Blue (B1): 0.45-0.52 Green(B2): 0.52-0.6 Red(B3) :0.63-0.69 Infrared(B4) :0.76-0.9	Multispectral=30m Panchromatic =15m
17.06.2022 24.05.2022	Landsat 8 OLI	Bleu (B2) :0,45-0, 515 Vert(B3):0,525- 0,6 Rouge(B4) :0,63-0,68 Infrared (B5) :0.845-0.885	Multispectral=30m Panchromatic =15m

band 3 (3 km) prohibits any longitudinal extension of the urban perimeter, the extension of two adjacent towns on the coastline, and new transit roads parallel to the coastline (Fig. 2).

The second pillar of our methodology is based on the use of GIS and remote sensing system, with which we have studied the land use and distribution in the coastal zone for the years 1990, 2000, 2010, and 2022. To carry out this task, we chose to apply a maximum likelihood supervised classification method using Landsat 5 Thematic Mapper (TM) and Landsat 08 (OLI) sensor images (Table 2).

Maximum likelihood classification takes into account variance and covariance. It is based on Bayes' rule (Richards, 1961) as follows:

$$\Pr\{A_i|B\} = \frac{\Pr\{A_i\}.\Pr\{B|A_i\}}{\sum \Pr\{A_i\}.\Pr\{B|A_i\}},$$

where A_i represents class i and B represents the pixel's response values.

Pr{A|B} is the conditional probability that class A_i is the class in which to place pixel B.

Remote sensing data processing

Before the classification of satellite images, preprocessing operations were carried out to facilitate their exploitation. These included combining individual bands of Landsat imagery into a single multispectral image and extracting the study area from the multispectral images using the coastal zone boundaries defined in the coastal development plan (PAC) for the wilaya of El Tarf, drawn up by the Algerian Ministry of the Environment.

The geometric enhancements proved unnecessary following the 2016 reorganization of the Landsat archive on the official USGS website of the US government. This reorganization introduced a multilevel collection management structure called the Landsat collection. In addition, Collection 2 introduces several data processing enhancements, particularly in the geometric and radiometric areas.

However, to ensure data compatibility and consistency, all other complementary cartographic data such as administrative boundaries, global positioning system (GPS) data, hydrographic data, and communication routes were reprojected into the Universal Transverse Mercator (UTM) coordinate system using the WGS84 geodetic system and zone 32 (Snyder, 1987).

Projecting data in UTM system offers several advantages for spatial analysis. Firstly, it allows data to be presented in a conformal projection, which preserves local angles and enables accurate measurements of distances and angles in the field. What is more, the UTM system divides the Earth's surface into narrow rectangular zones, making small-scale calculations and analysis easier.

Supervised classification

The maximum likelihood classification tool classifies image pixels according to the spectral characteristics of the training classes. Using the ArcGIS Spatial Analyst extension, it is possible to group raster cells into classes. A class represents a known category, such as forests, urban areas, or water bodies.

Training samples, which are real locations that identify known class zones, are defined on a polygon layer. The training samples, which are actual locations that identify areas of known classes, are defined on a polygon layer.

This supervised classification approach has been used in LULC studies and has demonstrated its effectiveness by revealing significant correlations between land use and field data interpretation ((Benz et al., 2004; Blaschke, Strobl, 2001; Congedo, 2016; Jensen, 1996). The implementation of this method requires the availability of several external data sources, such as topographic maps, the National Forest Inventory (IFN), and archival imagery from Google Earth Pro. The integration of these external data sources provides additional distinguishing elements (Batini, Scannapieco, 2016) to enhance the identification and interpretation of the thematic classes sampled in the images.

Land cover classes

The CORINE land cover nomenclature is a three-level hierarchical typology covering the whole territory (Cover, 2000). This European standard allows the mapping of the entire territory and provides information on the state of the environment. It focuses specifically on biophysical land use, emphasizing the characterization of different elements such as forests, crops, water bodies, bare rock, etc.

Based on the CLC nomenclature, the selected land use classes are as follows:

- Forest class: consisting of forested areas, degraded forests with lower tree density, and scrubland.
- Beach class: including sandy beaches and dunes.
- Agricultural land class: refers to regions or zones of land used primarily for cultivation, farming, or agricultural activities. These areas may include cultivated fields, orchards,

Table 3. Confusion matrix of Landsat image classifications for the years 1990, 2000, 2010 and 2022.

Land cover	1990						
	Forest	**Beach**	**Agricultural land**	**Urban areas**	**Wetland area**	**Bare rock**	**Total**
Forest	67	1	1	2	1	1	73
Beach	0	19	0	0	0	0	19
Agricultural land	1	0	72	10	4	0	87
Urban areas	0	0	0	17	0	0	17
Wetland area	0	0	0	1	34	0	35
Bare rock	0	0	0	0	0	9	9
Total	68	20	73	30	39	10	240
					Kappa coefficient		0,87
					Confusion Matrix		90.83%

Land cover	2000						
	Forest	**Beach**	**Agricultural land**	**Urban areas**	**Wetland area**	**Bare rock**	**Total**
Forest	58	5	1	0	0	0	64
Beach	1	17	0	0	1	0	19
Agricultural land	0	0	52	3	5	1	61
Urban areas	2	0	2	30	0	0	34
Wetland area	0	1	1	0	43	0	45
Bare rock	0	0	0	1	0	16	17
Total	61	23	56	34	49	17	240
					Kappa coefficient		0,87
					Confusion Matrix		90%

Land cover	2010						
	Forest	**Beach**	**Agricultural land**	**Urban areas**	**Wetland area**	**Bare rock**	**Total**
Forest	101	0	2	2	4	1	110
Beach	0	3	0	0	0	0	3
Agricultural land	9	0	60	3	4	3	79
Urban areas	1	0	0	14	0	0	15
Wetland area	0	0	2	0	29	0	31
Bare rock	0	0	0	0	0	2	2
Total	111	3	64	19	37	6	240
					Kappa coefficient		0,80
					Confusion Matrix		90%

Land cover	2022						
	Forest	**Beach**	**Agricultural land**	**Urban areas**	**Wetland area**	**Bare rock**	**Total**
Forest	52	1	2	1	0	0	55
Beach	0	19	0	0	0	1	18
Agricultural land	3	0	73	5	4	0	89
Urban areas	0	1	1	31	0	1	36
Wetland area	0	0	0	0	36	0	36
Bare rock	1	0	0	0	0	8	6
Total	58	19	77	37	39	10	240
					Kappa coefficient		0,88
					Confusion Matrix		91%

vineyards, pastures, and other areas used for agricultural production.
- Urban areas class: Areas occupied principally by dwellings and buildings used for administrative/public services, including associated areas (associated land, access network, car parks).
- Wetland class: encompassing lakes, ponds, and flooded plains.
- Bare rock class: refers to areas where the land surface consists predominantly of exposed, unconsolidated, or consolidated rock with no significant vegetation cover or soil layer.

Post-classification processing and validation of results

Once the classification was completed, further processing was performed to refine, evaluate the accuracy, and validate the results. The first processing step involved passing the classified image through a majority filter that replaces raster cells with the majority value of adjacent contiguous cells. The classification was simplified, and isolated pixels were removed.

The accuracy of the classifications was assessed using a confusion matrix (Foody, 2002). A grid of 1×1 km points (240 sampling points) was used. Ground truth information or land cover types at these points were collected using the GPS data collected in the field, or using Google Earth Pro for inaccessible or difficult-to-reach locations, such as remote areas, protected zones, or rugged terrain, where conducting GPS surveys on the ground may be limited or impossible. In such cases, Google Earth Pro proved extremely useful in obtaining reliable reference data for assessing the accuracy of the classifications. Two classification validation indices were calculated: the overall accuracy (proportion of correctly classified pixels, calculated as a percentage) and the kappa index (ratio of correctly classified pixels to the total number of sampled pixels) (Schlaepfer, Bütler, 2002).

Change detection

To measure changes in land use classes, annual evolution rate and global change rate between 1990 and 2022 were determined, respectively, through the equation proposed by FAO (Project, 1996) (1) and that of Bernier (1992) (2) commonly used to measure the growth of macroeconomic aggregates between two given periods (Kpedenou et al., 2016; Rabehi et al., 2019; Xiuwan, 2002). In our case, the aggregate would be the combination of all these land use classes to form an overall measure of the total area occupied by these different categories. Positive values represent an increase in the area of the class during the analyzed period, while negative values indicate a loss of surface area of a class between the two dates. Values close to zero indicate that the class remains relatively stable between the two dates.

$$\boldsymbol{T_g} = \frac{s_2 - s_1}{s_1} \times 100\,, \tag{1}$$

$$\boldsymbol{T_c} = \left(\frac{Ln\,S_2 - LnS_1}{(t_2 - t_1) * Ln(e)}\right) * 100, \tag{2}$$

Here, $\boldsymbol{S_1}$ is the surface of a class of surface unit at date t_1, $\boldsymbol{S_2}$ is the surface of the same class of surface unit at date t_2, $\boldsymbol{L_n}$ is the natural logarithm, and $\boldsymbol{e}$ is the base of natural logarithms (e = 2.71828).

Results

Accuracy assessment of classifications

Assessing the accuracy of satellite image classifications is a crucial step to ensure the quality and reliability of obtained information, as well as to ensure their relevance for intended applications ((Kpedenou et al., 2016; Rabehi et al., 2019; Xiuwan, 2002). To do so, the confusion matrix is one of the most commonly used tools. It allows for the calculation of the kappa coefficient (Cohen, 1968) that varies between 0 and 1. This index reflects a higher level of agreement (concordance), the closer its value is to 1. The Kappa coefficient is calculated using the following formula:

$$K = \frac{Pr(a) - Pr(e)}{1 - Pr(e)}\,,$$

where Pr(a) is the proportion of agreement between coders and Pr(e) the probability of random agreement.

This process allows for a more objective and reliable assessment of accuracy. The results show that our classification has a strong agreement (Table 3).

Land use dynamics

On the coastal domain

A supervised classification was used to produce a land use map of the study area (Fig. 3). In 1990, the study showed that the forested area was dominant, accounting for 55.08% of the total area of the study area, while the agricultural land area was estimated at 27.26%; the area of the wetland zone was approximately 16.38%, while urban areas accounted for only 0.71% and the bare rock class accounted for 0.13% (Table 4).

For the year 2000, the study showed that forest land was predominant with an estimated percentage of 53.36% of the total area of the study area located in the center and east of the area, while agricultural land covered an estimated 29.02%, located in the west of the area. The area of wetland zones was about 15.45%, while urban areas accounted for only 1.38% and bare rock areas accounted for 0.16% (Table 4).

In 2010, the total area of the study area consisted of 49.39% forest, 32.42% agricultural land, and 2.42% urban land. Wetlands and bare soil represented 14.96 and 0.17% of the total study area, respectively (Table 4).

In 2022, the forest class was estimated at 48.58%, while agricultural land and urban areas accounted for 33.02 and 2.85%, respectively, of the total area of the study area. Concerning wetland zones and bare rock areas, they occupied 14.51 and 0.39%, respectively, of the total area of the study area. Based on the analysis shown in Table 4, it appears that two of the six identified land use classes in the study area have undergone regres-

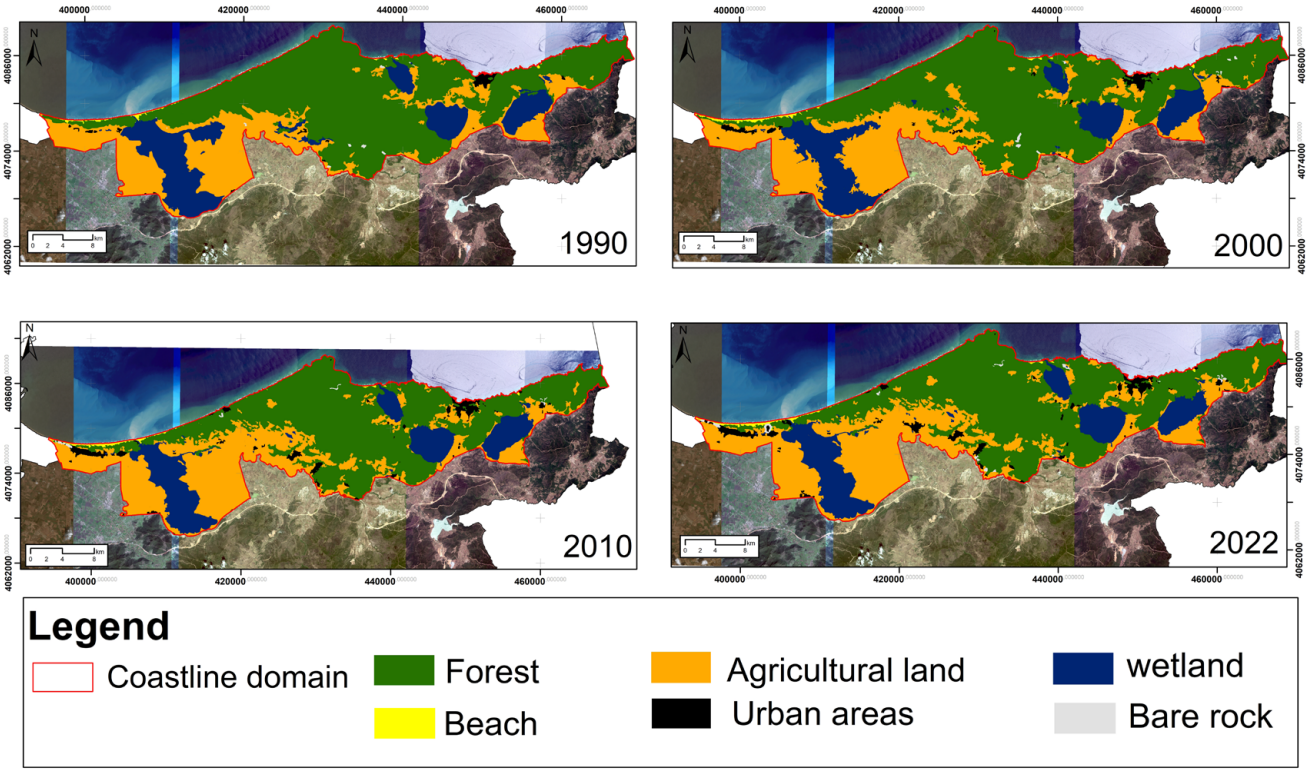


Fig. 3. Land use map for the years 1990, 2000, and 2022.

Table 4. Area in hectares and percentage of land use classes.

Year	1990		2000		2010		2022	
Land use	surface (ha)	percentage %	surface (ha)	percentage %	surface (ha)	percentage %	surface (ha)	percentage %
Forest	40957,42	55,08	39678,38	53,36	36726,86	49,39	36128,20	48,58
Beach	343,37	0,46	461,29	0,62	472,71	0,64	481,67	0,65
Agricultural land	20268,91	27,26	21582,64	29,02	24107,10	32,42	24552,07	33,02
Urban areas	525,64	0,71	1024,45	1,38	1803,07	2,42	2118,94	2,85
Wetland	12177,34	16,38	11492,44	15,45	11127,56	14,96	10792,09	14,51
Bare Rock	93,20	0,13	122,04	0,16	125,97	0,17	290,42	0,39

sion, namely, forests and wetland zones. The regression of these two classes varied for each period (Table 5). For forests, a rate of change of -3.2% was recorded between 1990 and 2000, -7.4% between 2000 and 2010, and -1.6% between 2010 and 2022. For wetland zones, the regression was established at -6.5% between 1990 and 2000, -3.2% between 2000 and 2010, and -3% between 2010 and 2022. Considering the entire 32-year period, forests experienced a total regression of -11.8%, while for wetland zones, this regression reached -12.2%.

Furthermore, the other land use classes have experienced progression, that is, agricultural land at a rate of 22%, the coastal class at a rate of 40.3%, bare rock with an overall rate of change of 150.8%, and the urban areas experienced the most spectacular progression at a rate of 303.1% (Table 5).

In detail, the dynamics of land use are very complex (Table 6). Analyzing a few examples helps to better understand it. Between 1990 and 2022, the proportion of forest land class significantly decreased from 55.08 to 48.59%, representing a reduction of 6.49% points. In terms of surface area, this decrease amounts to a loss of 5058,04 ha of forest, which is equivalent to an average annual deforestation rate of -0.41%.

Of the original 55.08% forest, 6.54% has been converted to farmland as a result of illegal logging, particularly, the clearing of vegetation cover to grow seasonal crops such as watermelons, 0.24% has been converted to beach, as the study area is characterized by the presence of a dune ecosystem maintained by vegetation cover and because of human activities on this

Table 5. Annual growth rate and overall change rate.

	Between 1990-2000		Between 2000-2010		Between 2010-2022		Between 1990-2022	
	Tg (%)	Tc (%)	Tg (%)	Tc (%)	Tg(%)	Tc (%)	Tg (%)	Tc (%)
Forest	-3,2	-0,3	-7,4	0,8	-1,6	-0,1	-11,8	-0,4
Beach	34,3	3,0	2,5	-0,2	1,9	0,2	40,3	1,1
Agricultural land	7,4	0,6	11,6	-1,2	1,8	0,2	22,0	0,6
Urban fabric	94,9	8,0	76,0	-4,3	17,5	1,3	303,1	4,4
Wetland area	-6,5	-0,7	-3,2	0,3	-3,0	-0,3	-12,2	-0,4
Bare rock	9,6	4,6	-0,8	3,8	130,5	7,0	150,8	2,9

Table 6. Land use transition matrix between 1990 and 2022 (area in percent).

Years		**2022**						**Total general**
	Land use (%)	**Forest**	**Beach**	**Agricultural land**	**Urban areas**	**Wetland area**	**Bare rock**	
1990	Forest	47,04	0,24	6,54	0,59	0,36	0,31	**55,08**
	Beach	0,04	0,39	0,00	0,02	0,00	0,00	**0,46**
	Agricultural land	0,74	0,01	23,97	1,60	0,87	0,06	**27,25**
	Urban areas	0,03	0,00	0,03	0,64	0,00	0,00	**0,71**
	Wetland area	0,70	0,00	2,39	0,00	13,28	0,00	**16,38**
	Bare rock	0,03	0,00	0,08	0,00	0,00	0,02	**0,13**
Total general		**48,59**	**0,64**	**33,02**	**2,85**	**14,52**	**0,29**	**100%**

Table 7. The area in hectares of land use on the different coastal strips in the years 1990, 2000, 2010 and 2022.

	Land use band 100m				Land use band 300m				land use band 800m				Land use band 3km			
Years Land use	**1990**	**2000**	**2010**	**2022**	**1990**	**2000**	**2010**	**2022**	**1990**	**2000**	**2010**	**2022**	**1990**	**2000**	**2010**	**2022**
forest	677,98	653,57	608,84	600,03	1542,79	1399,43	1368,62	1333,54	3802,20	3680,16	3628,28	3501,95	12407,82	12290,35	10959,01	10959,01
Beach	192,94	192,57	219,31	221,82	115,44	216,50	200,91	201,65	28,28	47,15	41,20	41,23	0,87		5,68	5,68
Agricultural land	13,63	16,35	10,10	15,49	32,44	30,87	22,01	36,62	183,88	176,72	185,32	215,83	3084,84	3090,32	4172,65	4172,65
urban areas	33,84	52,96	70,89	71,61	61,38	82,35	127,64	146,57	117,15	151,87	227,24	276,63	213,47	637,09	752,20	752,20
wetland	0,01		4,17	4,17	5,15	0,95	10,70	10,70	39,13	33,77	49,47	49,47	1582,05	1255,80	1370,44	1370,44
bare rock		2,49	1,20	1,39		27,05	27,31	28,11	3,37	84,35	42,45	88,83	44,60	60,01	73,74	73,74

ecosystem, particularly the construction of tourist projects and government facilities such as the military zone on this ecosystem (Fig. 4), causing erosion and the advancement of sand toward inland areas, which explains this change (Belloulou et al. 2023), of which 0.59% is urban fabric, 0.36% submerged and 0.31% bare soil, 0.59% to urban areas, 0.36% to wetland areas, and 0.31% became bare rock.

Over the past 32 years, the urban areas have experienced a significant increase in surface area, from 525.64 ha (0.71%) in 1990 to 2118.94 ha (2.85%) in 2022, with an average annual growth rate of 4.4%. This increase mainly occurred at the expense of agricultural land (1.6%) and forests (0.59%).

The landscape dynamics reveal that 85.33% of the area remained stable and did not change to other classes, while 4.34% of the surface area evolved to higher classes. However, 11.02% of the landscape suffered degradation.

On the coastal strips

Using the polygon intersection tool in ArcGIS software, we were able to extract the distribution of land use on the different coastal bands (Table 7).

- **100 m band:**
  What is remarkable about the 100-m coastal band is the regression of the forest class. As it is an attractive area for the population, the vegetation cover has been removed to establish residential and/or economic projects such as the power plant project at Kedyet El-Draouche in the municipality of Berihanne (Fig. 4). Indeed, it has gone from 677.98 ha in 1990 to 600 ha in 2022, which represents a loss of 77.8 ha of the forest area. The "beach" class remained relatively stable between 1990 and 2000 with an area of 192 ha. However, between 2000 and 2022, there was a slight increase in this area,



Fig. 4. Kodyet El-Draouche power station, municipality of Berihanne (source Google Earth Pro).

which now reached 221.82 ha. We also noticed that during the study period, the classes of bare rock, wetland zones, and agricultural lands remained relatively stable, with little change. What is also remarkable is the increase in the surface area of the "urban area" class over time, from 33.84 ha in 1990 to 52.96 ha in 2000, then to 71.61 ha in 2022.

- **300 m band:**
  The statistical results of land use in the 300-m coastal band show that the "agricultural lands," "wetland zones," and "bare rock" classes did not experience significant changes in area during the study period. However, for the "forests" class, there was a contained regression in area, which went from 1542.79 ha in 1990 to 1333.55 ha in 2022, representing a loss of 209.25 ha. There was also a slight but steady increase in the area of the "urban fabric" category along the 300-m coastal strip. Indeed, the area increased from 61.38 ha in 1990 to 82.35 ha in 2000, then to 127.64 ha in 2010 and finally to 146.57 ha in 2022.
- **800 m band:**
  The analysis of land use in the 800-m coastal band shows a regression in the area of the "forests" class, while other classes such as "agricultural lands," "urban areas," "beach," "wetland zones," and "bare rock" experienced an increase in area over time.
- **3 km band:**
  Regarding the evolution of the area of the different land use classes in the 3-km coastal band, it is observed that two classes are in regression: the "forests" class, which went from 12,407.82 ha in 1990 to 10,959 ha in 2022, and the "wetland zones" class, which went from 1582.5 ha in 1990 to 1370.44 ha in 2022. Conversely, the areas of the "agricultural lands" and "urban areas" classes have increased, while there is an absence of the "bare rock" and "beach" classes.

Discussion

The results of this study show a significant change in land use in the study area over the past 32 years (from 1990 to 2022). In 1990, forested areas were dominant, representing over half of the total area of the study area (55.08%), while agricultural land represented about a quarter of the total area (27.26%). Wetland areas accounted for a significant proportion of the total area (nearly 16%). Urban areas and bare rock were undeveloped, representing only a small fraction of the total area.

The results show a decrease in forested areas in 2000, which dropped to 53.36% of the total area of the study. This decrease was offset by an increase in agricultural land, which represented about 29% of the total area in 2000. Wetland areas also decreased

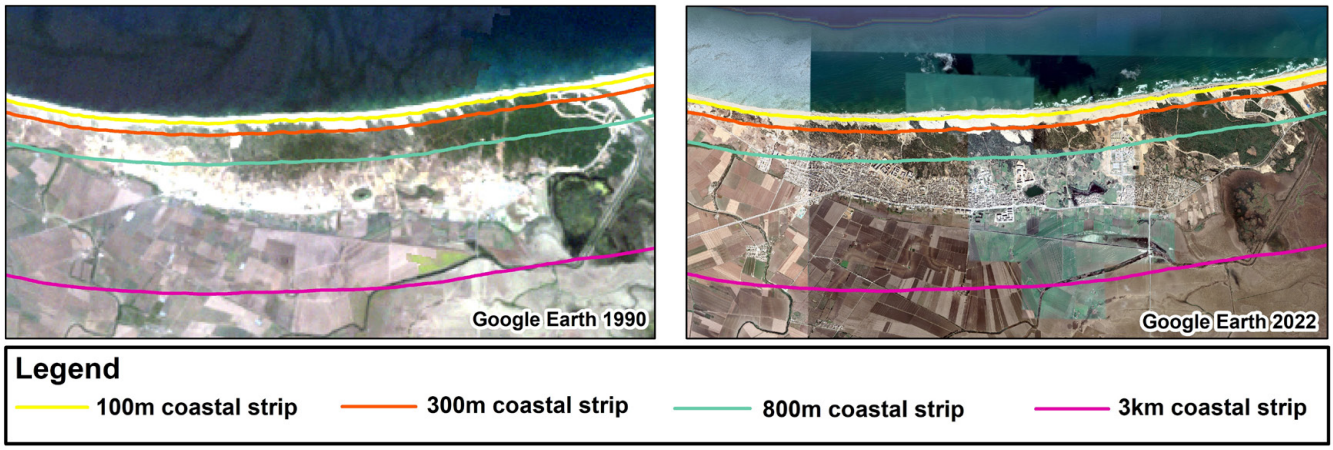


Fig. 5. Echatt municipality between 1990 and 2022 (Google Earth Pro).



Fig. 6. Housing construction projects on the dune ridge of the municipality of El Chatt.

to represent approximately 15.45% of the total area. Urban areas increased slightly, but remain a small fraction of the total area, while bare rock areas slightly increased.

In 2010, there was a reduction in forest area, which fell to 49.39% of the total area of the study zone. This was offset by an increase in agricultural land, which accounted for around 32.42% of the total area that year. Wetland areas also decreased, representing 14.96% of the total surface area. Although urban areas increased slightly, they remain a small fraction of the total surface area, while uncultivated areas increased slightly.

In 2022, there was a more significant decrease in forested areas, which dropped to 48.58% of the total area of the study. Agricultural land increased to represent about one-third of the total area, while urban areas also increased to represent nearly 3% of the total area. Wetland areas decreased slightly to represent approximately 14.5% of the total area, while bare rock areas also slightly decreased.

These results suggest a trend toward a decrease in forested area in the study area over time, which can have significant implications for the environment and biodiversity of the region (Mostari et al., 2021). On the other hand, the simultaneous increase observed in the area of agricultural land and urban zones indicates a proportional response to growing demand. However, this trend also means increasing pressure on the region's natural resources, habitats, and species (Amar, 2010). These results highlight the importance of sustainable management of natural resources and land use in the region. The observed regression in forests and wetland areas is concerning, as these areas are important for biodiversity and ecosystem regulation (Doumenge, 1990). Similarly, the reduction of wetland areas can have effects on water quality and flood regulation (Breil, 2018). On the other hand, the observed progression in agricultural lands, bare rocks, the coastal class, and urban areas may be related to human expansion and increased demand for these areas. However, this expansion can have negative consequences on the environment (Wang et al., 2020), such as loss of arable land, increased pressure on natural ecosystems, and habitat fragmentation.

Law 02-02 of February 5, 2002, relating to the protection and valorization of the Algerian coastline, sets out specific provisions



Fig. 7. Projects of tourist complexes on the dune cordon (municipality of El Chatt).

for the protection and valorization of the coastline. This law defines the coastline as an entity encompassing all islands and islets, the continental shelf, and a strip of land with a minimum width of 800 m, running along the sea and including various areas such as hill and mountain slopes, coastal plains, forest areas, agricultural lands, wetlands and their shores, as well as sites with a cultural, historical, or landscape character.

The study results show an uneven evolution of land use in the different coastal bands studied. In the 100-m band, the forest class has undergone a significant loss of area, while the coastline class has remained relatively stable. Wetland areas, agricultural land, and deforested land have not experienced significant changes. In the 300-m band, the forest class has also regressed, while the urban areas class has increased. The other classes have experienced minimal changes. In the 800-m band, there has been a regression in the area of the forest class, while all other classes have increased. In the 3-km band, both the forest and wetland area classes have undergone regression, while the agricultural land and urban areas classes have increased.

These results highlight the negative impact of human activity (urbanization and agriculture) on biodiversity and coastal ecosystems, particularly on coastal forests. The loss of area of these forests can have significant consequences on biodiversity and coastal ecosystems (Burak et al., 2004), affecting the habitats of animal and plant species and ecological processes.

The growth of urban areas in coastal areas can also lead to environmental problems (Cui, Shi, 2012) such as water and air pollution, fragmentation of natural habitats, and destruction of coastal wetlands. These results emphasize the importance of conservation measures and urban planning to preserve coastal ecosystems and protect biodiversity in coastal areas.

Legally speaking, regarding the degree of enforcement of the coastal law in the El Tarf province, we found the following elements: despite a formal prohibition of any new construction in the 100-m coastal strip, urbanization has continued to develop. This is largely explained by the presence of long-established urban areas in the coastal 100-m strip, as well as the construction of the "Draouche" power plant in the Berihanne municipality, which needs to be located near the sea. Regarding the prohibition of two adjacent agglomerations on the coast, unless the distance separating them is at least 5 km, the reality shows that this article of the law is not applied, as we observed in the municipalities of Echatt and El-Kala, as well as for new transit routes parallel to the coast and the longitudinal extension of the urbanized area (Fig. 5).

It is also worth noting that the law attaches great importance to the protection and valorization of coastal dunes as a fragile ecosystem and prohibits any construction on them, except for light installations or constructions necessary for the management, functioning, and development of this ecosystem (Article 10 of Law 02-02). However, our study shows that the coastal dune in the El Tarf wilaya is heavily occupied by urban development, despite the prohibition of building on coastal dunes under the coastal law, aimed at limiting urban expansion and protecting this fragile ecosystem (Fig. 6).

The implementation of the littoral law is very complex (Ghodbani, Bougherira, 2019) and requires coordination among different actors (local authorities, landowners, real estate investors, developers, etc.). There may be bureaucratic, legal, or financial obstacles that prevent the effective implementation of the law. In addition, there is strong land pressure on the coast of the wilaya of El Tarf, especially in the commune of Echatt, mainly due to the economic and tourist potential of these areas. This has pushed landowners or real estate investors to seek ways to circumvent the law for maximizing their profits (Fig.7).

Fig. 7. Projects of tourist complexes on the dune cordon (municipality of El Chatt).

The "Littoral" law was promulgated in response to the degradation caused by coastal urbanization. However, once the law was passed, the implementing decrees were delayed. For this law to be effectively enforced, it requires no less than 11 decrees (Kacemi, 2013). Similarly, Law 90-29 of December 1, 1990 on planning and urban development prescribes a nonbuildable zone of 100 m along the shoreline but allows constructions requiring proximity to the sea. The decree specifying these activities has not yet been promulgated, creating a "gap" in Law 90-29 and allowing for numerous abuses. The provisions of this law have not prevented urbanization from spreading in areas close

to the shoreline, and these spaces are also affected by significant degradation due to unauthorized sand extraction and excessive beach attendance.

It is common for the law to be circumvented in the absence of clear and precise texts. Thus, to avoid this problem, it is essential that legal texts be defined with precision and do not contain vague notions that could lead to confusion. Moreover, it is important to clarify the responsibilities of each party and allow for the adaptation of regulations to local territorial realities, taking into account geography. Implementing decrees must be published promptly after the law's promulgation to ensure effective enforcement. In addition, better collaboration between scientists from different disciplines and policymakers, as well as wide dissemination of information could contribute to a more informed decision-making process.

Conclusion

The study shows a significant change in land use in the coastal region of the El Tarf province over the last 32 years, characterized by a progressive decrease in forested areas (6.49% points) and an increase in agricultural land (overall rate of change = +22%) and urban areas with an average annual growth rate of 4.36%. These results suggest increasing pressure on the region's natural resources, as well as on the habitats and species that live there. This trend is concerning because forested and wetland areas are important for biodiversity and ecosystem regulation (Doumenge, 1990), such as loss of arable land, increased pressure on natural ecosystems, and habitat fragmentation.

The promulgation of the law on the protection and enhancement of the coastline is a major step forward in creating the necessary conditions for ensuring sustainable development of this strategic area of the national territory. This law is an essential tool for protecting and preserving the natural resources of the coastline, as well as for promoting integrated management of this area. Chapter 1 of this law clearly highlights the involvement of all stakeholders concerned in the establishment of measures for the protection and enhancement of the coastline. The fundamental principles of the law emphasize that all actions must be coordinated among the state, local authorities, organizations, and associations involved in this field. This also implies a perspective of sustainable development, where the measures taken must take into account current needs without compromising the abilities of future generations to meet their own needs.

In other words, the law on the protection and enhancement of the coastline establishes a legal framework that allows for reconciling the imperatives of environmental protection and economic development of this area. This law also offers a comprehensive vision of coastal management by promoting an integrated and coordinated approach that takes into account the interactions between the different uses of the coastal zone (tourism, fishing, maritime transport, etc.). Although the promulgation of the law related to the protection and valorization of the coastline is a major advancement for the preservation of this strategic area, it should be noted that some aspects of the law still require clarification and precision. These articles relate, in particular, to issues such as the regulation of economic activities on the coastline, the management of protected coastal areas, coordination among the various actors involved in coastline management, etc.

These provisions requiring clarification should not be seen as an obstacle to the implementation of this law. On the contrary, they demonstrate the complexity of coastline management and the need to carefully consider the measures to be taken to ensure effective protection of this area. Furthermore, the development of complementary legal texts should not be seen as an end in itself, but rather as an opportunity to improve the implementation of this law. The legal texts that will be developed must be designed from a perspective of coherence and complementarity with the law related to the protection and valorization of the coastline, to ensure an integrated and effective management of the coastline.

Finally, it should be noted that the effective application of this law will also depend on the mobilization of local actors and citizen participation. The actors involved must actively participate in the implementation of this law by contributing to the development of necessary legal texts and ensuring their effective application on the ground.

In summary, although some aspects of the law related to the protection and valorization of the coastline still require clarification and precision, this should not call into question the importance of this law for the preservation of this strategic area. On the contrary, it highlights the complexity of coastline management and the need for in-depth reflection to ensure effective protection of this area.

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