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Research Article

Monitoring land-cover changes in Mediterranean coastal dunes, northwest Tunisia, using remote sensing data

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Abstract

Coastal dune landscapes are subject to morphological and ecological changes. In many parts of the world, coastal dunes are under severe pressure. The present study illustrates an integrated remote sensing and Geographical Information System (GIS) approach, i.e., geospatial techniques for assessing land-cover dynamics in Zouaraa coastal dunes, located in northwest Tunisia. As a main result, the analysis of the situation in the past six decades indicates that the dune area showed a decreasing trend with up to 31% (i.e., 6198 ha) in favour of forest area, which has increased by up to 6485 ha. The geo-spatial analysis revealed that restoration works have positively contributed to stabilize coastal dune systems with a substantial increase in vegetation cover. An increase in drought frequency and intensity was detected during the 1952-2017 period using the SPEI index, which enhanced the vegetation activity and growth in the study area. The SPEI significantly correlated with vegetation greenness on the 12- and 24-months' time scales. The croplands, water and buildings in the study area have increased respectively by 6% (i.e., 1256 ha), 13% (i.e., 3073 ha) and 3% (i.e., 719 ha). In contrast, land cover like shrub and bare soil has decreased respectively by 13% (i.e., 3073 ha) and 2% (i.e., 1831 ha) during the same period. Furthermore, this study highlights the importance of the revegetation techniques undertaken for conserving coastal dune systems. The findings of this study allow land-use planning decision makers to manage and improve situations in similar coastal regions.

Keywords: coastal dune systems; land-cover changes; Mediterranean ecosystem; remote sensing; Tunisia

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Introduction

Analysing the changes that occurred on earth's surface use is essential for better understand the interactions between natural resources and anthropozoic pressure. It is also a necessity to improve decision-making strategies for the sustainable management of our worlds' capacities (Lu *et al.*, 2004; Seif and Mokarram, 2012). The detection of land-cover changes involves applying multitemporal remote sensing (RS) information to analyse the historic quantitative evolution that has occurred in space, and to help to understand the effects of these changes on land-cover properties in a spatio-temporal situation (Zoran, 2006; Ahmad, 2012; Seif and Mokarram, 2012; Liu *et al.*, 2018).

Many studies focusing on land cover have emerged and pose an important research question as it can cause environmental modification on a larger scale. Information on land cover can play a vital role in natural resources management (Iqbal and Khan, 2014; Kantakumar and Neelamsetti, 2015; Lin *et al.*, 2019). Climate change and drought events could change land-cover types. However, a general theory of the effects of drought on land vegetation is lacking and is subject for scientific debate (Knapp and Smith, 2001; Samanta *et al.*, 2010; Touhami *et al.*, 2020). For example, farmers in agrarian areas could leave their lands during drought. Climate change can convert many agricultural areas and forests into barren lands, which forces rural communities to abandon their lands (Cheng *et al.*, 2018; Jagarnath *et al.*, 2019). Applying the RS method allowed land-cover development to be studied in a shorter time, at a lower cost and more accurately. Landsat images have been used to classify different landscape components on a larger scale (Ozesmi and Bauer, 2002; Singh and Dubey, 2012; Sathya and Deepa, 2017). Recently, several changes in detection techniques and algorithms have been developed and reviewed for their advantages and disadvantages. Of these techniques, including unsupervised classifications or clustering, supervised classification, principal component analysis, hybrid classification and fuzzy classification, are often the most widely applied land-cover classification techniques (Zhang *et al.*, 2000; Rundquist *et al.*, 2001; Lu *et al.*, 2004; Muke and Haile, 2018; Mohamed and El-Raey, 2018).

In the last 20 years, some authors (Cracknell, 1999; Taramelli *et al.*, 2018) have provided an initial overview of the capabilities of RS for coastal zone studies. Environment changes, ecological studies and land cover are currently some of the most well-covered topics for which RS techniques are used (Liu *et al.*, 2018; Valdez *et al.*, 2019; Tajbakhsh *et al.*, 2020). One of the most interesting ecosystems to study is coastal dune ecosystems, as they present a complex biotic and abiotic interactions mostly vulnerable to environmental conditions. These ecosystems are extremely variable because of the shifting substrate, sand movement, rare fauna and flora, high soil porosity and poor organic matter content (Maun, 2009; Nehren *et al.*, 2016). Several studies worldwide focus on coastal dunes restoration. Many different and contrasting actions have been followed during restoration activities (Pickart and Sawyer, 1998; Provoost *et al.*, 2011; Martínez *et al.*, 2013). However, very little attention has been paid to assess and monitor long-term land-cover changes in coastal dune ecosystems (Kutiel *et al.*, 2000; Muñoz-Reinoso *et al.*, 2013; Pickart, 2013). By considering available data, existing vegetation cover types and the possibility of assessing the results of a restoration project in the long term, the Zouaraa coastal dunes in northwest Tunisia were selected for monitoring the land-cover changes that occurred before and after the restoration project carried out over the 1952-2017 period. This study intends to analyse the effects on the land-cover changes corresponding to a dune restoration project 65 years later. This original study allows to: (1) know the changes that have occurred on a long-time scale in changes to vegetation cover types in a coastal dunes ecosystems in the Mediterranean Region; (2) contribute knowledge regarding the spatio-temporal land-cover dynamics in a study area using RS and GIS tools to improve the decision making to manage and plan coastal dunes ecosystems. In this context, the main objective of the present study was to assess the spatio-temporal dynamics of land-cover changes from 1952 to 2017 in the coastal dunes area using RS and GIS tools.

Materials and Methods

Study area

The study area, which corresponds to the Nefza forest subdivision, is located in the Northwestern part of Tunisia on the North African and Southern bound of the Mediterranean Basin (Figure 1). The Zouaraa coastal dunes, which belong to the study area, cover about 200 ha, and are considered one of the most important and well-preserved coastal systems of the western Mediterranean Basin (DGF 2005). According to the Tabarka (36°57N; 8°45E) meteorological station database (From 1952-2017), the bioclimate in the study area is Mediterranean subhumid, characterized by hot summers and mild winters. Precipitations occur mainly from September to March, and a drought period extends from May to August. The average annual precipitations is 1113 mm year^{-1}. The mean annual temperature is 19.3 °C and fluctuates between a minimum of 10 °C in January and a maximum of 26 °C in August. Seasonal temperature variability is marked by the effect of distance from the coast. The reference evapotranspiration is about 1244 mm year^{-1} according to the Penman method (1948). Land-surface elevation varies between 0 and 606 m. a. s. l., with a slope range between 5-30%. Prevailing winds arrive particularly from the northwest and are expected to blow mainly from December to the end of March. The natural vegetation in this coastal area is essentially composed of a low cover of degraded shrub formations with *Pistacia lentiscus* L., *Phillyrea media* L., *Erica multiflora* L., *Quercus coccifera*; *Retama raetam*, etc. Soil texture is typically sandy. The first 40 cm of soil is composed of 82% coarse sand, 8.5% silt, 4% fine sand and 3.5% clay, with small amounts of organic matter (between 0-2.5%).

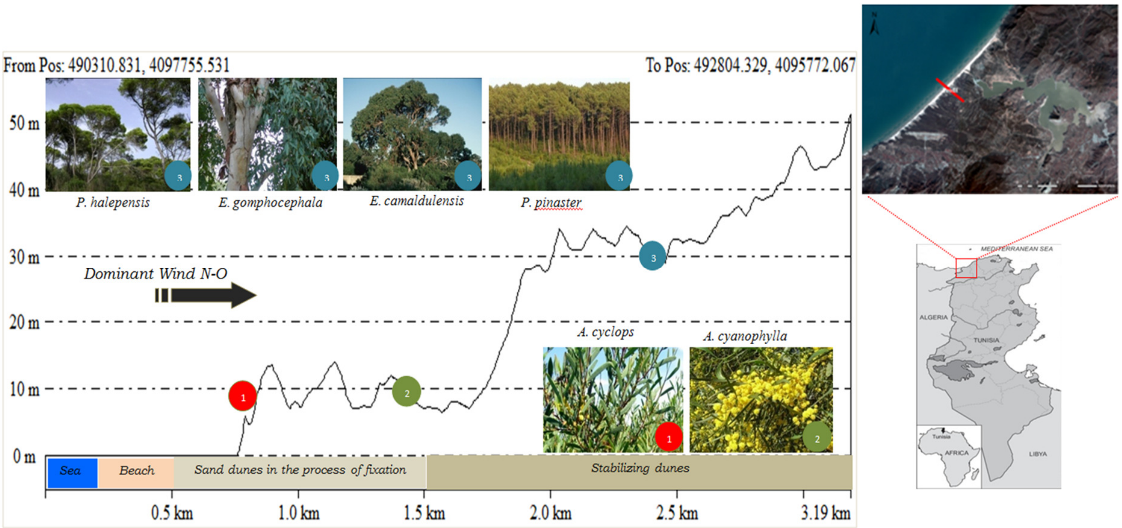

Figure 1. Location map of the study area, and the altitudinal profile and location of the different species used in the fixation and reforestation of the natural Zouaraa coastal dune systems. The number (1, 2, and 3) describes the spatio-temporal process of dune fixation

Restoration project: historic data

The first restoration projects in the region started at the beginning of the 1960s and were carried out by Tunisian forest services (Motte, 1963; DGF, 1996). The objective of this restoration project was to stabilize the movements of 50000 ha of sandy masses, which threaten the spontaneous forest, pastoral vegetation formations, and human habitats and activities in the town of Ouechtata (DGF, 1996; Farnole, 2000). Figure 1 illustrates a synthetic profile to describe the practical process followed during the fixation and revegetation of the Zouaraa natural dunes in this project. The coastal dunes fixation process was divided into physical (primary fixation) and biological (final fixation) steps (Motte, 1963). The physical step consisted of installing a branching hedge of varieties of natural species, for example, *Quercus coccifera*, *Juniperus oxycedrus*, *Retama monosperma*, and *Saccharum aegyptiacum* at the top of the beach along a parallel line to the coastline. As sand was covered, a new hedge was installed on the first. The equilibrium profile was reached at a height of 14 m. Several trenches were then made, but the dune remained alive. It was, therefore, necessary to fix it by always using branches and a weaving system, whose dimensions depended on exposure to wind and slope (varying from 10mx10m up to 40m x 20m). The biological step consisted of planting the dune with two principal acacia species: *Acacia cyclopis* (resistant to sea spray) less than 1 km from the sea; *Acacia cyanophylla* more than 1 km because is sensitive to sea spray. *Acacia cyanophylla* was exploited for between 8 and 10 years. Plantation density lay between 400 and 600 plants per hectare. These two species, called pioneer or temporary, were the first to be established by either direct sowing in pockets or planting to first improve soil, and then to serve as a sublevel for the final afforestation. After stabilizing dunes, most restoration actions were taken using *Eucaluptus* (*E. gomphocephala* and *E. camaldulensis*) and Pine species (*Pinus pinea*, *Pinus pinaster*, and *Pinus halepensis*) (Figure 1). These plantings were carried out during the 1960-1975 period at an average density of 2500 plants per hectare. Several spontaneous species were established after stabilizing coastal dunes, such as *Juniperus phoenicea*; *Juniperus oxycedrus* subsp. *macrocarpa*; *Quercus coccifera*; *Retama raetam*; *Ammophila arenaria* subsp. *australis*, etc. (Gounot and Schoenemberger, 1967). Today several parts of the dune system have been stabilized by major forest recovery (Figure 2).

Figure 2. Photographs of the costal dunes' fixation process in the Zouaraa region. (Photography 2019)

The datasets used in the analysis

GIS and RS software, such as QGIS, were used to analyse the spatio-temporal dynamics of land-cover changes. The ENVI 4.1 software (ENVI User's Guide 2000) was employed to change the detection analysis. The data herein utilized were based on multitemporal satellite imagery and topographic maps. Aerial photographs (1952 and 1963) and Landsat satellite images from different dates (1984, 2000, 2010, and 2017) were used (Table 1). Because aerial photography dates back before satellite imagery, it represents a valuable source of historic landscape data. The processes of ortho-rectified of the aerial photographs consist in spatial manipulation of digital photographs by adding a reference coordinate (x, y, and z), which is commonly derived from existing topographic maps, GIS (geographic information system) data sets (Lillesand *et al.*, 2004).

Table 1. The aerial photographs (AP) and Landsat imageries used in the analysis and their characteristics

Datasets	A.P. 1952	A. P. 1963	Image 84 (Landsat 5)	Image 2000 (Landsat 7)	Image 2010 (Landsat 5)	Image 2017 (Landsat 8)
ID	Tun10-11	Tun X/250	LT51920341984248XXX01	LE71920342000348EDC00	LT51920342010223MPS00	LC81920342017002LGN01
Date	1952	1963	04-09-1984	13-12-2000	11-08-2010	02-01-2017
Type of sensor	-	-	TM (Thematic Mapper)	ETM	TM	OLI
Number of bands	-	-	7	8	7	11
Resolution (m)	12.5	12.5	30	30	30	30
Source	-	-	U.S. Geological Survey	U.S. Geological Survey	U.S. Geological Survey	U.S. Geological Survey
Ortho-rectification	Yes	Yes	Yes	Yes	Yes	Yes
Number of aerial photographs and images used	12	17	1	1	1	1

Landsat Thematic Mapper (TM), Landsat Enhanced Thematic Mapper (ETM) and Operational Land Imager-Thermal Infrared Sensor (OLI_TIRS) were applied to investigate land-cover changes. However, the TM, ETM and OTI_TIRS data were obtained from USGS Earth Explorer (https://glovis.usgs.gov/) and the Global Land-Cover Facility (http://www.landcover.org/). Two Landsat_5 TM images were taken on September 4, 1984 and on August 11, 2010. There were seven spectral bands with a 30-meter spatial resolution for bands 1 to 5 (wavelength range of 0.45-1.75 μm) and seven (wavelength range of 2.08-2.35 μm). The spatial resolution for Band 6 (thermal infrared) was 120 m, but it was resampled to 30-meter pixels (wavelength range of 10.40-12.50 μm). A Landsat-7 ETM image was taken on December 13, 2000 (Table 1) with eight spectral bands and a 30-meter spatial resolution for Bands 1 to 7 (wavelength range of 0.45-2.35 μm). The resolution for Band 8 (panchromatic) was 15 m (wavelength range of 0.52-0.90 μm). A Landsat-8 OLI_TIRS image covering the study area was taken on January 2, 2017 (Table 1), which had nine multispectral bands with a 30-meter spatial resolution for Bands 1 to 7 (wavelength range of 0.43-2.29 μm) and 9 (wavelength range of 1.36-1.38 μm). New band 1 (ultra-blue) is useful for coastal and aerosol studies, while new band 9 is useful for cirrus cloud detection. The resolution for Band 8 (panchromatic) was 15 m (wavelength range of 0.50-0.68 μm). Two thermal infrared bands (10 and 11) are helpful for providing more accurate surface temperatures, collected at 100 m (wavelength range of 10.6-12.51 μm).

This work provides a methodological framework by integrating RS, GIS and spatial analyses tools to facilitate the assessment of the spatio-temporal dynamics of land-cover changes in the Zouaraa coastal dunes from 1952 to 2017. There are many methods for detecting land-cover changes. Choosing one method over another depends, among other things, on landscape, and the types of changes, and the spatio-temporal resolutions, of the data to be used. Of existing methods, post classification processing is often the most appropriate (Lu *et al.*, 2004; Yang and Lo, 2002; El-Hattab, 2016). The land-cover maps developed for the study years 1952, 1963, 1984, 2000, 2010 and 2017 were subjected to a post classification change detection technique. The methodology adopted for this study is illustrated in Figure 3.

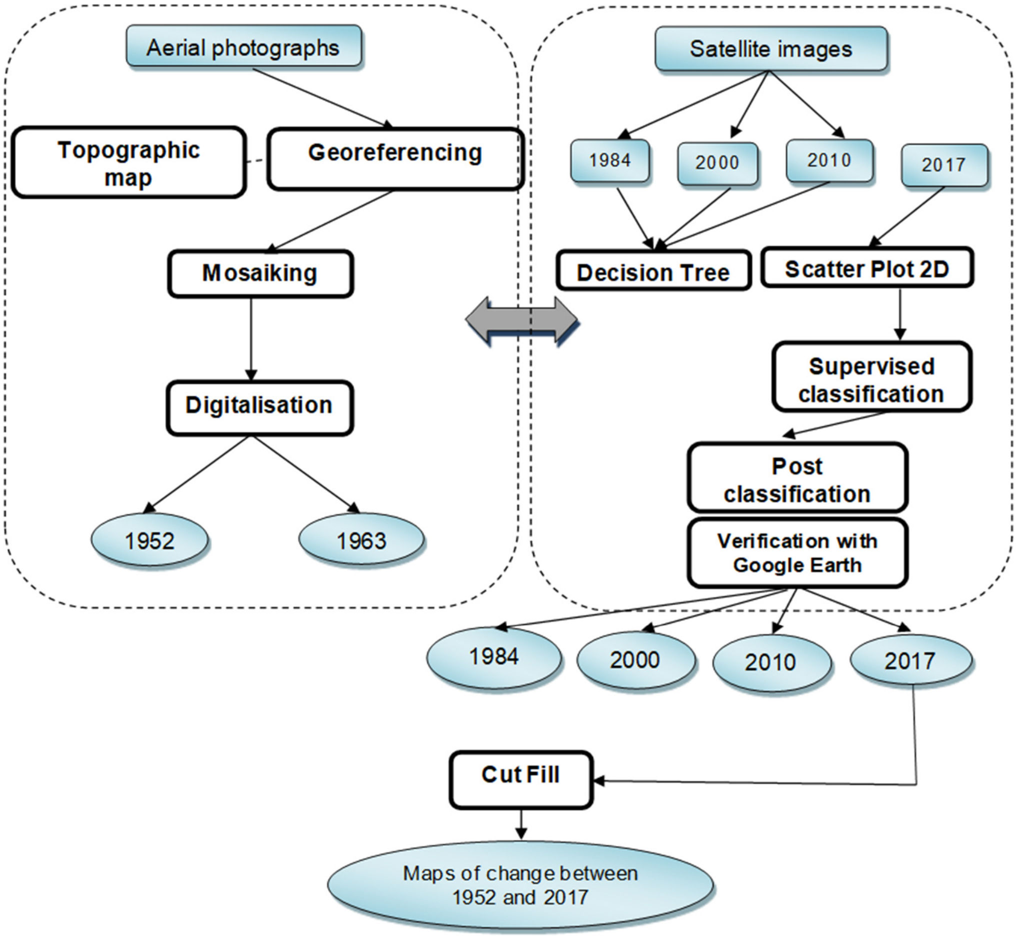

Figure 3. The methodology used for the study area

Supervised Classification: maximum likelihood classification

Image classification is one of the ancient basic tasks of applied RS. Several classification techniques attempt to satisfy certain RS product conditions and use requirements. The most frequent supervised classification techniques are the Maximum Likelihood Classifier (MLC) for parametric input data. The MLC method was herein chosen for data processing (Landsat imagery). It represents one of the most widespread methods to classify satellite imagery. Maximum likelihood classification assumes that the statistics per class in each band are normally distributed, and calculates the probability of a given pixel belonging to a specific class. Unless a probability threshold is selected, all pixels are classified. Each pixel is assigned to the class with the highest probability (i.e., the maximum likelihood). If the highest probability is below a specified threshold, the pixel remains unclassified (Hagner and Reese, 2007; Vorovencii and Muntean, 2013). MLC is performed according to the method proposed by Richards and Jia (1993).

The method consists of choosing the training samples for each desired class from the colour composite image. In the training phase, 35 training sites were selected by the on-screen digitization of specific polygons (5 training samples per thematic class). The obtained files were saved and used for the image classification. Each training field was assigned a number from 1 to 7 to represent land-cover classes, including water body, urban, agriculture, sand, bare soil, forest and shrubs (El Garouani *et al.*, 2017).

ENVI applies an MLC to calculate the following functions per pixel in the image by the following equation proposed by Richards (1999).

$$g_i(x) = ln\, p(\omega_i) - {}^1/_2 \ln |\sum_i| - {}^1/_2 (x - m_i)^T \sum\nolimits_i^{-1} (x - m_i) \qquad (1)$$

where i is class, x is the n-dimensional data (where n is the number of bands), p(ωi) is a probability that class ωi occurs in the image and is assumed to be the same for all classes, |Σi| is a determinant of the covariance matrix of the data in class ωi, Σ i-1 is its inverse matrix and mi is the mean vector.

Classifying and mapping coastal dune systems by RS frequently relies on the data from regions of interest (ROIs) tools (Poldrack, 2007; Rujoiu-Mare and Mihai, 2016). After image classification, which was based on the land-cover categories of forest, shrub area, sand, bare soil, crops, built-up area and water body, relevant map layouts were generated.

Land-cover transition matrix

In order to achieve the overall objective of performing land-cover change detection, a post-classification detection technique was employed. This method has been successfully applied by many researchers for its efficiency in detecting the location, nature and rate of changes (Hardin *et al*., 2007). Change detection employed the simple overlay procedure for the 1952-2017 period. A two-way cross-matrix was obtained by applying this procedure, used to describe the main types of change in the study area. To determine the number of conversions from one particular land-cover category to another, and their corresponding area over the study period, a cross-tabulation analysis was conducted on a pixel-by-pixel basis.

After transforming the link between the two different land-cover periods, the obtained results could be used in the quantitative analysis of a land-cover transition matrix, with access to land transition cases for each period (Chun *et al*., 2018). Thus:

$$A_{ij} = \begin{bmatrix} A_{11} & A_{12} & \cdots & A_{1n} \\ A_{21} & A_{22} & \dots & A_{21} \\ \dots & \dots & \dots & \dots \\ A_{n1} & A_{n2} & \cdots & A_{nn} \end{bmatrix} \qquad (2)$$

where n is a land-cover type number, and Aij refers to the area with i land types during period K by shifting to the j land types during period K+1.

In order to validate the classification results, a comparison with Google Earth was made to collect certain reference points to be compared to the results produced by the classification. Field visits were also organized in April 2017 to collect reference points, spread over the entire study region, which were recorded by GPS. These points served as a basis to validate the classification results.

The Standardized Precipitation-Evapotranspiration Index (SPEI)

In order to assess the sensitivity of drought evolution in the Zouaraa coastal-dune ecosystems from 1952 to 2017, we calculated the Standardized Precipitation-Evapotranspiration Index (SPEI) value on different time scales. The SPEI is a multiscale drought index based on climate data that combines the advantages of the SPI and Palmer drought index (PDSI; Vicente-Serrano *et al*., 2010). It is based on a monthly climate water balance that describes the degree of deviation of regional dry and wet conditions from the climatological mean ones by standardizing the difference between precipitation and potential evapotranspiration (PET). The SPEI was calculated for different time scales (3, 6, 12 and 24 months). The different time scales of the SPEI demonstrated differences in the magnitude and duration of droughts. The temporal evolution of the SPEI with a 3-month lag reflects short- and mid-term moisture conditions, and provides seasonal drought estimation. The 6-month lag contains moisture conditions from the current month and the past 5 months. SPEI 12 and 24 reflect long-term water balance patterns. Longer time scales (> 3-month SPEI) showed greater severity and longer duration for droughts than the short-time scales (Begueria *et al*., 2014; Potop *et al*., 2014).

Results and Discussion

Land-cover category identification and change assessment from 1952 to 2017

A range of land-cover changes (forest, shrub area, sand, bare soil, crops, built-up area, water body), which occurred from 1952-2017, was identified in the study landscape (Figure 4). The results indicated that the sandy area (yellow; Fig. 4) decreased significantly between 1952 (i.e., 32% of the total area; Figure 4-1952-a') and 2017 (i.e., 1% of the total area; Figure 4-2017-a'). In contrast, the forest land cover (green; Figure 4) increased significantly by about 31% (+6487.5 ha; Figure 4-2017-a') during the defined period.

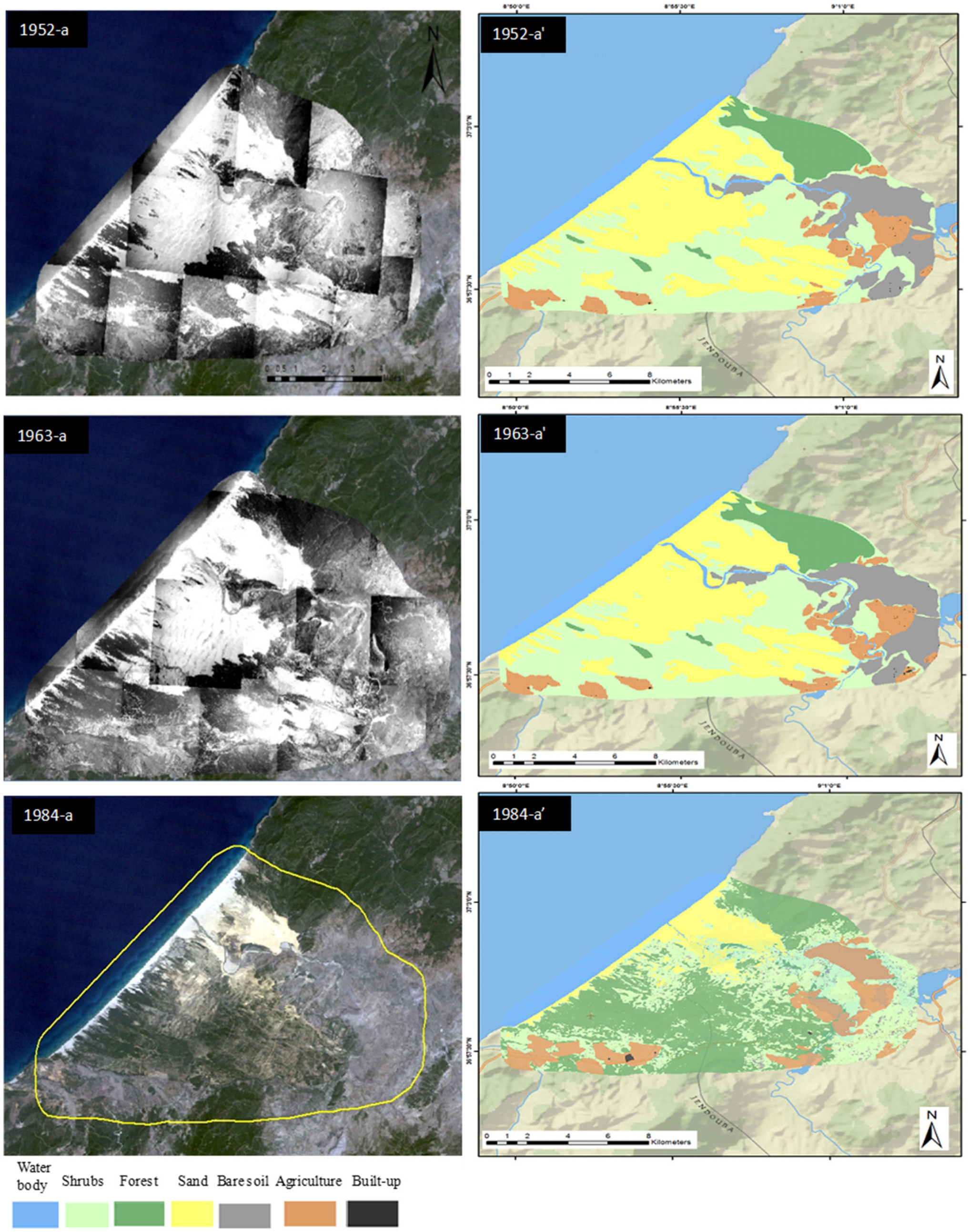

Figure 4. Overview of the different images before (a) and after classification (a') for the 1952-2017 period (Part 1)

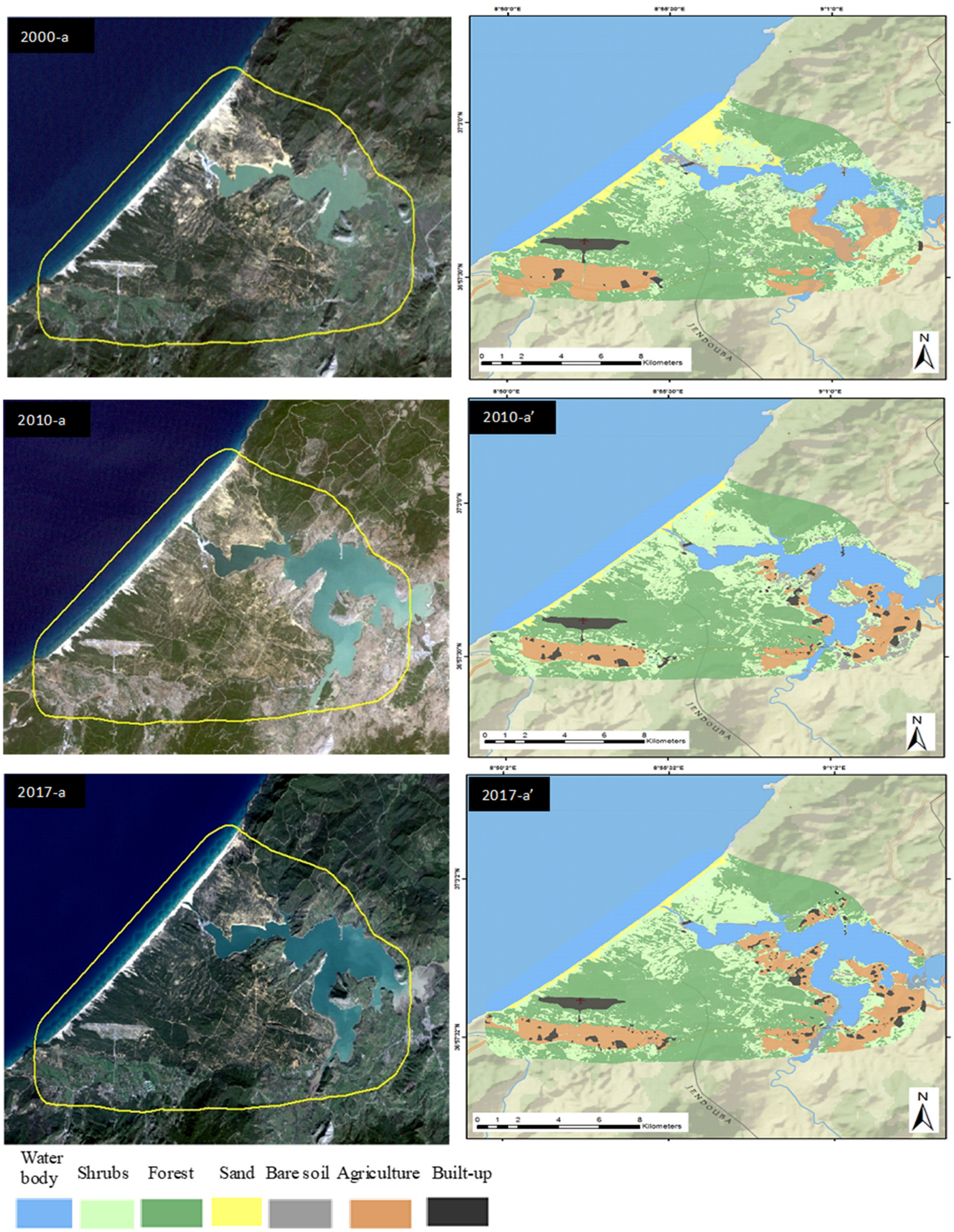

Figure 4. Overview of the different images before (a) and after classification (a') for the 1952-2017 period (Part 2)

The findings of land-cover changes in this study indicate that vegetation cover significantly expanded between 1952 and 2017. Regional forest service reports a perfectly natural evolutionary trend after revegetation actions for the Zouaraa coastal dunes given lack of human impact or anthropic interference (DGF 1996). Nevertheless, in other regions, several authors have reported the negative impact of human activities on dune vegetation communities (e.g. Heslenfeld *et al*., 2004; Carboni *et al*., 2009). It is necessary to emphasize that in many dune systems worldwide, such as Spain (Muñoz-Vallés *et al*., 2011), the USA (Pickart, 2013), Wales (Rhind *et al*., 2013), the Netherlands (Arens *et al*., 2013); New Zealand (Hesp and Hilton, 2013), and many other countries, the stabilization of natural dunes results in loss of space or habitat for native species (reduced natural diversity). Therefore, many Mediterranean coastal dunes ecosystems have been converted into protected areas or nature reserves which limits the most destructive activities that threaten these habitats (Guilcher and Hallégouët, 1991).

As argued by many studies, land-cover changes are considered an inevitable process to better comprehend land dynamics (Hyandye and Martz, 2017). Land-cover changes do not only have the capability to analyse and predict the spatio-temporal changes occurring in the landscape, but can also be used as a decision support tool to enable planners and managers to make more sustainable decisions, particularly for the conservation of coastal dune ecosystems (Flores-Casas and Ortega-Huerta, 2019; Paegelow *et al*., 2013).

Land-cover change detection

The results of the land-cover classification allowed the spatio-temporal land-cover changes in in the study area to be monitored. According to the results shown in Tables 2 and 3, and in Figure 5, positive and negative changes are distinguished based on the land-cover change pattern in the Zouaraa coastal dunes during the study period. Following the imagery classification from individual years, a multidate post-classification comparison change detection was used to determine land-cover changes within the 1952-2017 interval.

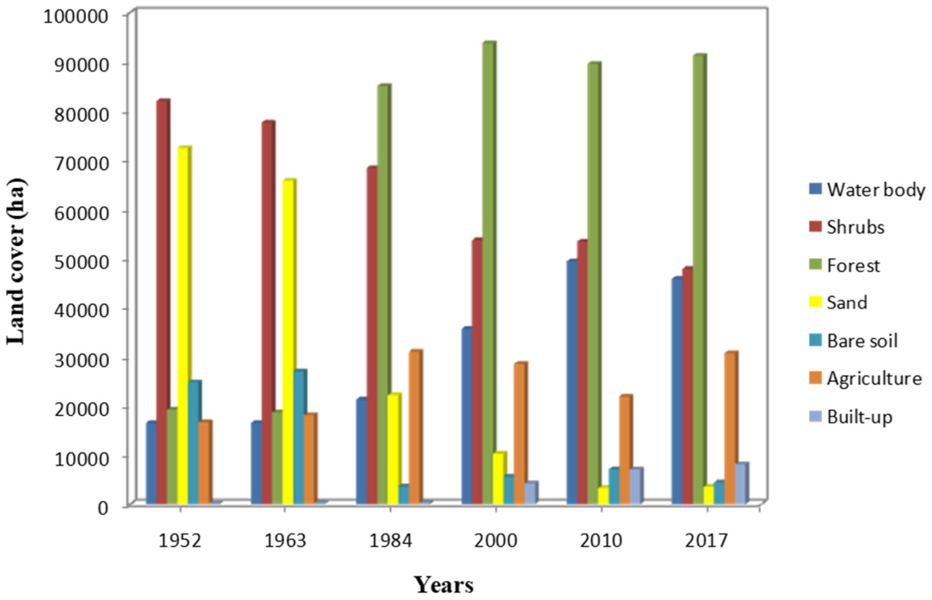

Figure 5. Histogram of land-cover classes for years 1952, 1963, 1984, 2000, 2010 and 2017 in relation to the Zouaraa coastal dunes. Values are expressed as ha

According to the results in Table 2 and Figure 5, the changes detected between 1952 and 1963 in sand use are only a few. From 1963/1984, we recorded a marked decrease in sand class (-4756.1 ha) in favour of the forest and agriculture class, which increased about +5972.9 ha and +1158.7 ha, respectively. We also noted an increase in the water bodies and built-up area class, especially for the 1984/2000 period, of about +1289.5 ha and +362.3 ha, respectively. The increase in water bodies was justified by the construction of the “Sidi El Barrak” dam in 1999 (Zairi *et al*., 1999).

Table 2. State of the land-cover changes between 1952 and 2017 in hectares (ha)

Land cover/Years	1952/1963	1963/1984	1984/2000	2000/2010	2010/2017
Water body	-7.49	+426.78	+1289.45	+1239.98	-324.44
Shrubs	-399.4	-837.94	-1306.62	-32.23	-498.23
Forest	-47.69	+5972.86	+772.56	-370.38	+160.21
Sand	+34.38	-4756.08	-1074.94	-625.87	+14.47
Bare soil	+199.63	-2101.95	+181.5	+130.53	-240.24
Agriculture	+124.47	+1158.72	-222.25	-576.77	+794.57
Built-up	+5.34	+5.75	+362.34	+262.87	+98.57

Positive and negative values indicate increases or decreases in this land cover, respectively, for the corresponding date

The results in Figure 5 reveal a major decline in sand cover and increased forest area over the study period. These land-cover changes were due to the fixation and ecological restoration actions applied to coastal dunes by the regional forest services since 1960 (DGF 1996). However, several studies conducted in world regions have reported contrasting results. In KwaZulu-Natal (South Africa), Van Aarde *et al.* (1996) obtained similar results. They concluded that the rehabilitation of a coastal dune forest ecosystem was successful based on species richness and species diversity. In the Lanphere and Ma-le'l dunes in Northern California (USA), Pickart (2013) pointed out that the restoration goals for these projects focused on monitoring biotic variables, such as vegetation cover, species diversity and endangered plant recovery. Both projects were carried out over a 5- to 6-year period. This author reported that the vegetation in the Ma-le'l dunes is currently lower in cover than the Lanphere restoration, and offers lower species diversity than both the earlier restoration project and non-invaded dunes. At Guardamar del Segura (Spain), Pagán *et al.* (2019) indicated that restoration works have not had the desired effect. Their study detected increased erosion in the study area between 2001-2017.

Relative land-cover changes were assessed based on the data presented in Table 3. The present study was conducted to obtain an overview of the spatio-temporal dune area extension trend (sand) on the one hand, and its impact on other land-covers types on the other hand. We are more interested in sand dynamics over the period, and before and after the restoration project, including other land occupations like forest and shrub areas. The land-cover change from 1952 to 2017 involved negative changes in sand, shrub and bare soil areas (Table 3).

Table 3. Detection of changes between 1952 and 2017

Land cover	Area in 1952 (ha)	Area in 2017 (ha)	Variation in 65 years	
			(ha)	(%)
Water body	1485	4127.49	2642.49	177.94
Shrubs	7381.44	4308.48	-3072.96	-41.63
Forest	1725	8210.34	6485.34	375.96
Sand	6516.36	318.24	-6198.12	-95.11
Bare soil	2228.04	397.08	-1830.96	-82.17
Agriculture	1500.93	2756.52	1255.59	83.65
Built-up	12.6	731.61	719.01	5706.42
Total area	20849.37	20849.37	-	-

Values in hectares (ha). Positive and negative values indicate increases or decreases in this land cover, respectively, for the corresponding date

These results of the changes occurring between 1952 and 2017 (Table 3) indicated that the increases in forest (+6485 ha; +375.96%), agriculture (+1256 ha; +83.65%), water bodies (+2642 ha; +177.94%), and built-up (+719 ha; +5706.42%) areas came mainly from the conversion of the sand (-6198 ha; -95.11%), shrubs (-3073 ha; -41.63%), and bare soil (-1831 ha; -82.17%) areas during the 1952-2017 period. To further evaluate the results of land cover conversions, a matrix of land cover changes from 1952 to 2017 was created (Table 4).

The cross-tabulation matrix shows the nature of change of different land cover classes. These results indicate that increases in forest (+6485 ha), agriculture (+1256 ha), water bodies (+2642 ha), and building (+719 ha) areas mainly came from conversion of the sand (-6198 ha), shrubs (-3073 ha), and bare sol (-1831 ha) areas during the 1952-2017 period. Consistently with these findings, Van Aarde *et al.* (1996) found a natural increase in species richness for most taxa, together with soil enrichment 30 years after the restoration planning in the coastal dune systems of northern KwaZulu-Natal. The revegetation of the Zouaraa dunes provides important protection functions against storm surges and wave action, and prevents accelerated coastal erosion by stabilizing the shoreline. Dunes also protect the freshwater dam of "Sidi el Barak" that provides many towns in north Tunisia with domestic water (Zairi *et al.*, 1999). Nowadays, the restoration of the Zouaraa dunes is an important habitat for rare plants and animal species, and is also a stopover site for migratory birds (FAO, 2012). These coastal dunes are considered multiuse areas that must be managed according to their natural characteristics and potential.

Table 4. Classification matrix between 1952 and 2017. Values in hectares (ha)

Years	1952								
	Class	Water body	Shrubs	Forest	Sand	Bare soil	Agriculture	Built-up	Total Class
2017	Water body	1382	557.82	82.53	683.64	1148.94	271.26	1.26	4127.49
	Shrubs	14.4	3525.75	1306	3109.95	94.05	157.86	2.79	8210.34
	Forest	59.8	1328.31	161.6	1983.06	293.76	477.63	4.32	4308.48
	Sand	6.39	65.16	26.37	220.32	0	0	0	318.24
	Bare soil	11.8	106.74	22.23	61.38	99.81	93.96	1.17	397.08
	Agriculture	10.4	1399.32	85.86	353.34	513.45	391.59	2.52	2756.52
	Built-up	0.18	398.34	41.22	104.67	78.03	108.63	0.54	731.61
	Total class	1485	7381.44	1725	6516.36	2228.04	1500.93	12.6	0
	Class changed	103	6053.13	419.9	6296.04	2128.23	1109.34	12.06	0
	Difference	2642	-3073	6485	-6198.1	-1831	1255.59	719.01	0

Changes in the SPEI values in the Zouaraa coastal area

The sensitivity of the SPEI values on different time scales was variable during the study period in the Zouaraa coastal region (Figure 6). Our results showed that the SPEI of multi-time scales can quantify water balance anomalies for long-term dry and wet conditions (Vicente-Serrano *et al.*, 2010).

Therefore, it can obtain the water resource availability status from rainfall indirectly, and can effectively reflect the degree and duration of drought. The SPEI values on smaller time scales, such as SPEI-3 and SPEI-6, indicated high-frequency fluctuations, which indicated a more obvious change between wet and dry states (Vicente-Serrano *et al.*, 2010). On the contrary, the larger time scale SPEI values exhibited narrower variabilities and revealed long-term drought or wetness (Begueria *et al.*, 2014; Potop *et al.*, 2014). According to Figure 6, the SPEI indicated a slight decreasing trend on different time scales from 1952 to 2017. The fluctuation period of SPEI-3 and SPEI-6 was relatively long, which reflects the changing regularity of the wet-dry season. SPEI-12 and SPEI-24 were relatively stable and could reflect the interannual variation characteristics of drought in the Zouaraa coastal area. In our study area, precipitations occurred mainly in winter (43%), followed by autumn (32%) and spring (21%).

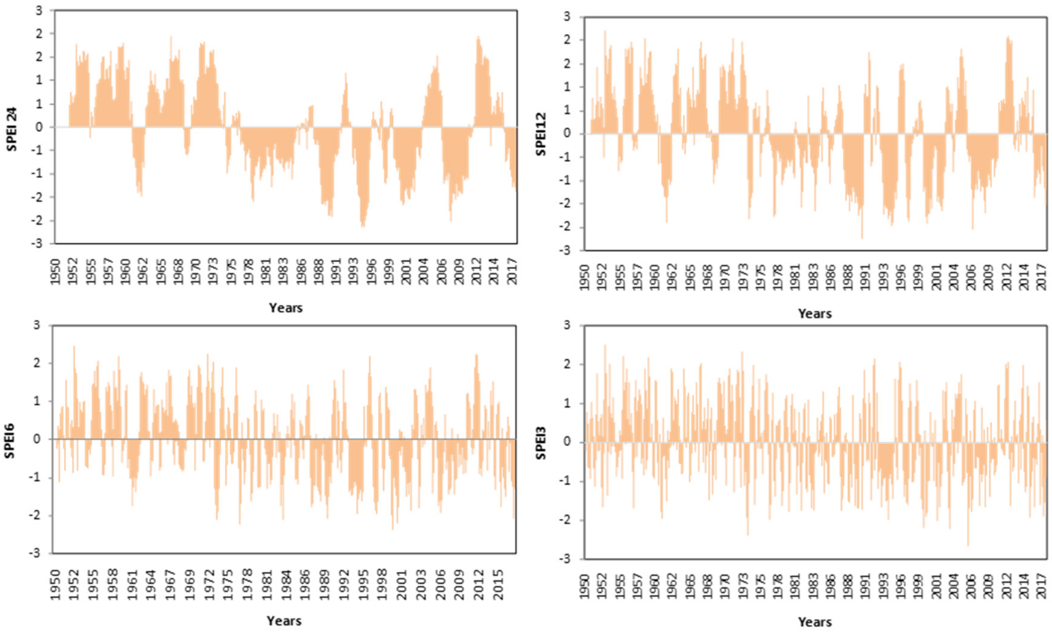

Figure 6. Dynamic SPEI characteristics on multiple time scales in the Zouaraa coastal dunes from 1950 to 2017

Summer remains the driest season, when rainfall rarely occurred with a low percentage of 4%. Precipitation was extremely important during the period preceding the growing season (spring and autumn). The SPEI percentage in the near-normal class (-1<SPEI<1) was about 87%. However, we observed years that were moderate (1.0 <SPEI<1.5) to extremely (SPEI> 2.0) wet. A positive SPEI indicated that water was available for plants, which led to above-normal condition yields. This result agrees with Taotao (2016), who reported a good correlation between vegetation growth and the SPEI. Other study revealed the effect of autumn and spring precipitations on the seasonality phenological changes in Mediterranean forest ecosystem (Touhami *et al.*, 2022). However, the occurrence probability of severe (-1.5<SPEI<-2.0) and extreme droughts (SPEI<-2.0) was considerably slight (about 13%) during the study period. The drought frequency for the 1950-2017 period was low. No drought occurred in most of the studied years. The study area is located in subhumid regions with a positive water balance, where the vegetation control of activity by drought was low. This favors the vegetation growth and, therefore, the establishment of vegetation covers in the Zouaraa coastal dunes (Jazzar *et al.*, 2019; Touhami *et al.*, 2019). Previous observational studies have reported that prolonged drought periods and wide variation in soil water availability could be considered as limitations for seedling establishment (Vicente-Serrano, 2013; Khaine and Woo, 2015).

Our results are consistent with other studies conducted in humid and subhumid regions (Knapp and Smith, 2001; Schuur, 2003; Touhami *et al.*, 2021), which are characterized by a positive water balance, and also by vegetation not exposed to long-term water stress (Schuur, 2003; Huxman *et al.*, 2004; Vicente-Serrano, 2013). Nevertheless, although vegetation activity in humid areas is less determined by drought than in arid ones, drought events also lead to a marked reduction in vegetation activity (Huxman *et al.*, 2004). El Khorchani *et al.* (2007) found that since the 1970s, warming in the studied area had become 3-fold faster than throughout the 20th century, and a significant increase in the frequency of dry years was observed during the 1978-2001 period compared to 1954-1977. Verner *et al.* (2013) reported that the total annual rainfall in northern Tunisia had declined by 5% per decade, especially in the study area, since the 1950s. Nevertheless, these trends must be seen in the very wide variability context from year to year and from decade to decade (Alexander *et al.*, 2006; Verner *et al.*, 2013).

Correlation analysis between the NDVI and SPEI on different time scales

Pearson's correlation analysis between the NDVI and SPEI was characterized by a significant correlation on longer time scales (SPEI-12-24). The NDVI correlated positively with SPEI-24 (Figure 7; r =0.486; p = 0.0406) and SPEI-12 (Figure 7; r =0.516; p = 0.0283), respectively. In contrast, SPEI-6 (r =0.442; p = 0.0659) and SPEI-3 (r =0.372; p = 0.1275) showed a non- significant correlation (p>0.05; Figure 7).

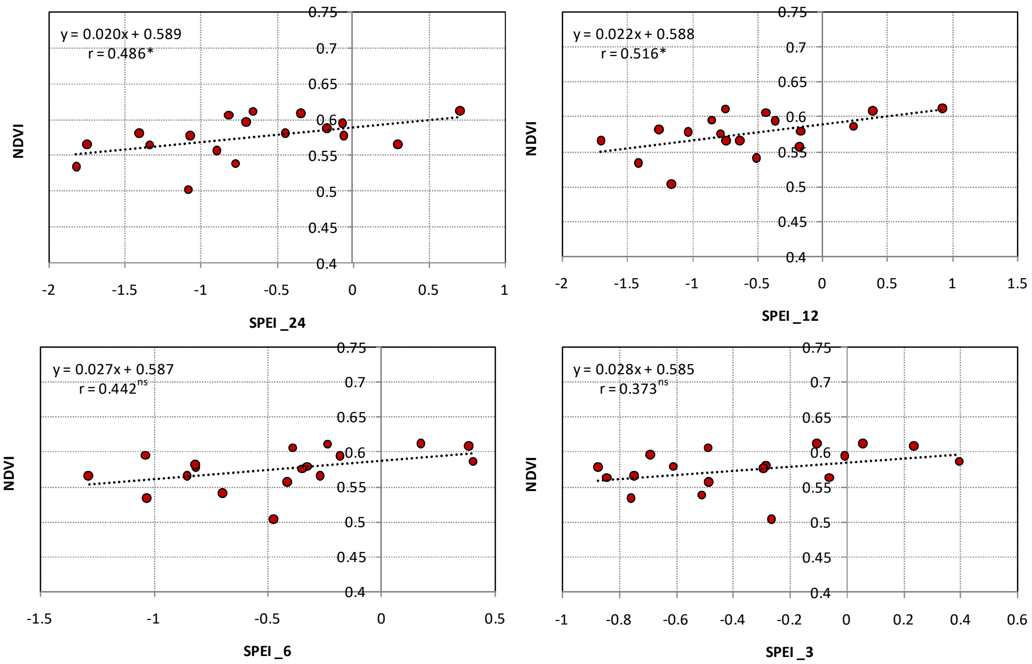

Figure 7. Correlation between the NDVI and (a) SPEI-3, (b) SPEI-6, (c) SPEI-12 and (d) SPEI-24 for the forest land-cover class for study years 1984, 2000, 2010 and 2017.

Linear regression lines and Pearson's correlation are reported, along with their statistical significance. (**) p<0.01; (*) p<0.05; (ns): non-significant

These findings agree with Vicente-Serrano *et al.* (2010), who reported that vegetation in the humid and subhumid regions tends to respond to drought on longer time scales. The vegetation of these regions is adapted to regularly tolerate water deficit periods and has physiological mechanisms to cope with these conditions (Chaves *et al.*, 2003). Therefore, it is reasonable to assume that these plant communities must be exposed to sustained water deficits (i.e., recorded by long-term SPEI scales) and are negatively affected by drought. Other studies have identified a lagged response among drought, declining plant growth (Bréda *et al.*, 2006) and forest mortality (Phillips *et al.*, 2010) in similar humid forests. In contrast, the highest correlations between the SPEI and NDVI have been found on shorter drought time scales in arid areas (Lundholm, 1976; Schwinning and Sala, 2004; Vicente-Serrano *et al.*, 2010). This could be linked with different mechanisms, which would allow plants to reduce any damage caused by water deficits in arid areas (Chaves *et al.*, 2003). In general, arid ecosystems respond in a highly plastic way to soil water availability (Lundholm, 1976) because plant species are adapted to low soil water shortage (Schwinning and Sala, 2004) due to physiological, anatomical and functional strategies to reduce plant water loss, respiration costs, photosynthetic activity and growth rates (Chaves *et al.*, 2003). Our findings suggest that climate conditions, particularly lack of a long drought period, favour vegetation growth in the Zouaraa coastal dunes.

Conclusions

Based on the results obtained by employing GIS and RS applications to meet the specific research objectives, we conclude that the classification of images allowed the spatio-temporal dynamics of the land-cover change occurring from 1952 to 2017 in the Zouaraa coastal dunes to be assessed. The quality of the results was strongly influenced by the characteristics of the original images, mainly spatial resolution and the number of available spectral bands. Particularly, these limit the capacity of extracting vegetation classes. The use of the panchromatic band can certainly improve treatment quality. Despite these constraints, the results obtained in this study highlight some global trends for land-use change detection purposes. The -95.11 % decrease in the sand area from 1952 to 2017 is remarkable evidence. The restoration project performed on these dunes enabled a better control of sand's progress. Indeed, the restoration work carried out at the beginning of the 1960s contributed to the fixation, revegetation and conservation of the Zouaraa coastal-dune ecosystem. In future works toward the integrated management of the Zouaraa dune system, it is essential to know the vegetation community and its evolution using tools like botanical inventories, cartography habitats and the monitoring of plant groups.

Authors' Contributions

Conceptualization: IT, TR, MAK, and KB; Data curation: MAK; Formal analysis: MAK and HA; Investigation: MAK and HA; Methodology; Project administration: AK, MLK and BMT; Resources: JB; Software: MAK and HA; Supervision: AK, IT, TR and BMT; Validation; Visualization: MAK and HA; Writing - original draft: IT, KB, EC and HA; Writing - review and editing: all authors. All authors read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

Not applicable.

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

References

Ahmad F (2012). Detection of change in vegetation cover using multi-spectral and multi-temporal information for District Sargodha, Pakistan. Sociedade Natureza 24:557-572. *https://doi.org/10.1590/S1982-45132012000300014*

Alexander LV, Zhang X, Peterson TC, Caesar J, Gleason B, Klein Tank AM, … Tagipour A (2006). Global observed changes in daily climate extremes of temperature and precipitation. Journal of Geophysical Research: Atmospheres 16:111(D5). *https://doi.org/10.1029/2005JD006290*

Arens SM, Slings QL, Geelen LHWT, Van der Hagen HGJM (2013). Restoration of dune mobility in the Netherlands. In: Martínez M, Gallego-Fernández J, Hesp P (Eds). Restoration of Coastal Dunes. Springer Series on Environmental Management. Springer, Berlin, Heidelberg. *https://doi.org/10.1007/978-3-642-33445-0_7*

Beguería S, Vicente-Serrano SM, Reig F, Latorre B (2014). Standardized precipitation evapotranspiration index (SPEI) revisited: parameter fitting, evapotranspiration models, tools, datasets and drought monitoring. International Journal of Climatology 34(10):3001-3023. *https://doi.org/10.1002/joc.3887*

Bhagat VS (2012). Use of remote sensing techniques for robust digital change detection of land: a review. Recent Patents on Space Technology 2(2):123-144. *https://doi.org/10.2174/1877611611202020123*

Bréda N, Huc R, Granier A, Dreyer E (2006). Temperate forest trees and stands under severe drought: A review of ecophysiological responses, adaptation processes and long-term consequences. Annals of Forest Science 63(16):625-644. *https://doi.org/10.1051/forest:2006042*

Carboni M, Carranza ML, Acosta A (2009). Assessing conservation status on coastal dunes: A multiscale approach. Landscape and Urban Planning 91:17-25. *https://doi.org/10.1016/j.landurbplan.2008.11.004*

Chaves MM, Maroco JP, Pereira JS (2003). Understanding plant responses to drought-from genes to the whole plant. Functional Plant Biology 30(3):239-264. *https://doi.org/10.1071/FP02076*

Cheng M, Jin J, Zhang J, Jiang H, Wang R (2018). Effect of climate change on vegetation phenology of different landcover types on the Tibetan Plateau. International Journal of Remote Sensing 39(2):470-487. *https://doi.org/10.1080/01431161.2017.1387308*

Chun X, Yong M, Liu J, Liang W (2018). Monitoring land cover change and its dynamic mechanism on the Qehan Lake Basin, Inner Mongolia, North China, during 1977-2013. Environmental Monitoring and Assessment 190:205. *https://doi.org/10.1007/s10661-018-6582-x*

Cracknell AP (1999). Remote sensing techniques in estuaries and coastal zones an update. International Journal of Remote Sensing 20:485-496. *https://doi.org/10.1080/014311699213280*

DGF-Direction Générale des Forets (1996). Plan d'aménagement de la forêt domaniale de Ouechtata (2ème série) [Management plan of the domanial forest of Ouechtata (2nd series)]. Rapport interne. DGF, Tunis.

DGF-Direction Générale des Forets (2005) Deuxième inventaire forestier et pastoral national, résultats sur l’échelon de Jendouba [Second national forestall and pastoral inventory, results for Jendouba region]. DGF, Tunis.

El Garouania A, Mulla DJ, El Garouani S, Knight J (2017). Analysis of urban growth and sprawl from remote sensing data: Case of Fez, Morocco. International Journal of Sustainable Built Environment 6(1):160-169. *https://doi.org/10.1016/j.ijsbe.2017.02.003*

El Khorchani A, Gadbin-Henry C, Bouzid S, Khaldi A (2007). Impact de la sécheresse sur la croissance de trois espèces forestières en Tunisie (*Pinus halepensis* Mill., Pinus pinaster Sol. et *Pinus pinea* L.) [Impact of drought on the development of three forest species in Tunisia (*Pinus halepensis* Mill., Pinus pinaster Sol. et *Pinus pinea* L.)]. Sécheresse 18:113-121.

El-Hattab MM (2016). Applying post classification change detection technique to monitor an Egyptian coastal zone (Abu Qir Bay). Egyptian Journal of Remote Sensing and Space Science 19(1):23-36. *https://doi.org/10.1016/j.ejrs.2016.02.002*

ENVI User’s Guide (2000). Research Systems, Inc.

FAO (2012). Etat des Ressources Génétiques Forestières en Afrique du Nord. Rapport National. LES Ressources Génétiques Forestières en Tunisie PROJET TCP/RAB/3303- BABY 2[State of forests genetic resources in North Africa. National report. Forests genetic resources in Tunisia PROJECT TCP/RAB/3303- BABY 2]. FAO, Tunis.

Farnole P (2000). Une réserve littorale pour le Tell septentrional tunisien. Journées Nationales Génie Civil/Génie Côtier [A littoral reserve for the Tunisian Septentorial Tell. National Days of Civil Engineering/Littoral Engineering]. Caen, France.

Flores-Casas R, Ortega-Huerta MA (2019). Modelling land cover changes in the tropical dry forest surrounding the Chamela-Cuixmala biosphere reserve, Mexico. International Journal of Remote Sensing 40(2019):6948-6974. *https://doi.org/10.1080/01431161.2019.1597305*

Gounot M, Schoenenberger A (1967). Carte phyto-écologique de la Tunisie septentrionale, échelle 1/200.000, feuille II: Bizerte - Tunis, feuille III:Tabarka - Souk el Arba, notice détaillée [Phyto-ecological map of septentrional Tunisia, Scale 1/200.000, Map II: Bizerte - Tunis, Map III:Tabarka - Souk el Arba, detailed notice]. Annales de l'Institut National de Recherche Agronomique de Tunisie 40(1):340.

Guilcher A, Bernard Hallégouët (1991). Coastal dunes in Brittany and their management. Journal of Coastal Research 7(2):517-533.

Hagner O, Reese H (2007). A method for calibrated maximum likelihood classification of forest types. Remote Sensing of Environment 110(4):438-444. *https://doi.org/10.1016/j.rse.2006.08.017*

Hardin PJ, Jackson MW, Otterstrom SM (2007). Mapping, measuring, and modelling urban growth. In: Jensen RR, Gatrell JD, McLean D (Eds). Geo-spatial Technologies in Urban Environments: Policy, Practice and Pixels. (second ed.), Springer-Verlag, Heidelberg, pp 141-176

Heslenfeld P, Jungerius PD, Klijn JA (2004). European coastal dunes: ecological values, threats, opportunities and policy development. In: Martínez ML, Psuty NP (Eds). Ecological Studies: Coastal Dunes, Ecology and Conservation. Springer-Verlag, Berlin, Heidelberg Vol. 171, pp 335-351.

Hesp PA, Hilton MJ (2013). Restoration of foredunes and transgressive dune fields: Case studies from New Zealand. In: Martínez M, Gallego-Fernández J, Hesp P (Eds). Restoration of Coastal Dunes. Springer Series on Environmental Management. Springer, Berlin, Heidelberg. *https://doi.org/10.1007/978-3-642-33445-0_5*

Huxman TE, Smith MD, Fay PA, Knapp AK, Shaw MR, Loik ME, … Williams DG (2004). Convergence across biomes to a common rain-use efficiency. Nature 429(6992):651-654. *https://doi.org/10.1038/nature02561*

Hyandye C, Martz LW (2017). A Markovian and cellular automata land-use change predictive model of the Usangu catchment. International Journal of Remote Sensing 38:64-81. *https://doi.org/10.1080/01431161.2016.1259675*

Iqbal MF, Khan IA (2014). Spatiotemporal land use land cover change analysis and erosion risk mapping of Azad Jammu and Kashmir, Pakistan. The Egyptian Journal of Remote Sensing and Space Science 17:209-229. *http://dx.doi.org/10.1016/j.ejrs.2014.09.004*

Jagarnath M, Thambiran T, Gebreslasie M (2019). Modelling urban land change processes and patterns for climate change planning in the Durban metropolitan area, South Africa. Journal of Land Use Science 14(1):81-109. *https://doi.org/10.1080/1747423X.2019.1610809*

Jazzar L, Rzigui T, Ben Fradj R, Touhami I, Zouheir N (2019). Variation in leaf gas exchange under summer drought in Tunisian cork oak from geographically central and marginal populations. Euro-Mediterranean Journal Environmental Integration 4:17. *https://doi.org/10.1007/s41207-019-0105-1*

Kantakumar LN, Neelamsetti P (2015). Multi-temporal land use classification using hybrid approach. The Egyptian Journal of Remote Sensing and Space Science 18:289-295. *http://dx.doi.org/10.1016/j.ejrs.2015.09.003*

Khaine I, Woo SY (2015). An overview of interrelationship between climate change and forests. Forest Science and Technology 11:11-18. *https://doi.org/10.1080/21580103.2014.932718*

Knapp AK, Smith MD (2001). Variation among biomes in temporal dynamics of aboveground primary production. Science 291(5503):481-484. *https://doi.org/10.1126/science.291.5503.481*

Kutiel P, Peled Y, Geffen E (2000). The effect of removing shrub cover on annual plants and small mammals in a coastal sand dune ecosystem. Biological Conservation 94:235-242. *https://doi.org/10.1016/S0006-3207(99)00172-X*

Lillesand TM, Kiefer RW, Chipman JW (2004). Remote Sensing and Image Interpretation. John Wiley and Sons.

Lin J, Wu W (2019). Investigating the land use characteristics of urban integration based on remote sensing data: experience from Guangzhou and Foshan. Geocarto International 34(14):1608-1620. *https://doi.org/10.1080/10106049.2018.1506505*

Liu CH, Zheng L (2018). Shoujing Yin Multi-perspective analysis of vegetation cover changes and driving factors of long time series based on climate and terrain data in Hanjiang River Basin. Arabian Journal of Geosciences 11:509 *https://doi.org/10.1007/s12517-018-3756-3*

Lu D, Mausel P, Brondızio E, Moran E (2004). Change detection techniques. International Journal of Remote Sensing 25:2365-2407.

Lundholm B (1976). Adaptations in arid ecosystems. Can Desert Encroachment Be Stopped? Ecological Bulletin 24. In: Rapp A, Le Houerou NH, Lundholm B (Eds). United Nations Environmental Programme. Stockholm, Sweden.

Martínez ML, Hesp PA, Gallego-Fernández JB (2013). Coastal dune restoration: trends and perspectives. In: Martínez M, Gallego-Fernández J, Hesp P (Eds). Restoration of Coastal Dunes. Springer Series on Environmental Management. Springer, Berlin, Heidelberg. *https://doi.org/10.1007/978-3-642-33445-0_20*

Maun MA (2009). The Biology of Coastal Sand Dunes. Oxford University Press, Oxford.

Mohamed SA, El-Raey EM (2018). Monitoring and predicting land use/land cover changes in Alexandria City using land cover modeler and Markov chain. Assiut University Bulletin For Environmental Researches 22(2).

Motte M (1963). Fixation et reboisement des dunes maritimes en Tunisie et plus spécialement dans la région de Bizerte [Fixation and reforestation of littoral dunes specially in the region of Bizerte]. Ecole National du Génie Rural, des eaux et Forêts (ENGREF). Nancy, France

Muke M, Haile B (2018). Land-use/cover change analysis using remote sensing techniques in the landscape of Majang Zone of Gambella Region, Ethiopia. African Journal of Environmental Science and Technology 12(4):141-149.

Muñoz Vallés S, Gallego Fernández JB, Dellafiore CM (2011). Dune vulnerability in relation to tourism pressure in Central Gulf of Cádiz (SW Spain): a case study. Journal of Coastal Research 27(2):243-251. *https://doi.org/10.2112/JCOASTRES-D-09-00125.1*

Muñoz-Reinoso JC, Saavedra Azqueta C, Redondo Morales I (2013). Restoration of Andalusian coastal juniper woodlands. In: Martínez M, Gallego-Fernández J, Hesp P (Eds). Restoration of Coastal Dunes. Springer Series on Environmental Management. Springer, Berlin, Heidelberg. *https://doi.org/10.1007/978-3-642-33445-0_9*

Myneni RB, Hall FB, Sellers PJ, Marshak AL (1995). The interpretation of spectral vegetation indices. IEEE Transactions on Geoscience and Remote Sensing 33:481-486.

Nehren Udo, Thai, HD, Muh Aris Marfai MA, CRaedig C, Alfonso S, Sartohadi J, Castro C (2016). Ecosystem services of coastal dune systems for hazard mitigation: Case studies from Vietnam, Indonesia, and Chile. In: Renaud, Fabrice G, Sudmeier-Rieux K, Estrella M, Nehren U (Eds). Ecosystem-Based Disaster Risk Reduction and Adaptation in Practice. Advances in Natural and Technological Hazards Research (42). *http://doi.org/10.1007/978-3-319-43633-3*

Ozesmi SL, Bauer ME (2002). Satellite remote sensing of wetlands. Wetlands Ecology and Management 10:381-402. *https://doi.org/10.1023/A:1020908432489*

Paegelow M, Camacho Olmedo MT, Mas JF, Houet T, Pontius RG (2013). Land change modelling: moving beyond projections. International Journal of Geographical Information Science 27(9):1691-1695. *http://dx.doi.org/10.1080/13658816.2013.819104*

Pagán JI, Bañón L, López I, Bañón C, Aragonés L (2019). Monitoring the dune-beach system of Guardamar del Segura (Spain) using UAV, SfM and GIS techniques. Science of The Total Environment 687:1034-1045. *http://doi.org/10.1016/j.scitotenv.2019.06.186*

Penman HL (1948). Natural evaporation from open water, bare soil, and grass. Proceedings of the Royal Society, London 193:120-146.

Phillips OL, Van Der Heijden G, Lewis SL, López-González G, Aragão LE, Lloyd J, … Amaral I (2010). Drought-mortality relationships for tropical forests. New Phytologist 187(3):631-646. *https://doi.org/10.1111/j.1469-8137.2010.03359.x*

Pickart AJ (2013). Dune restoration over two decades at the Lanphere and Ma-le'l Dunes in Northern California. In: Martínez M, Gallego-Fernández J, Hesp P (Eds). Restoration of Coastal Dunes. Springer Series on Environmental Management. Springer, Berlin, Heidelberg. *https://doi.org/10.1007/978-3-642-33445-0_10*

Pickart AJ, Sawyer JO (1998). Ecology and restoration of northern California coastal dunes. California Native Plant Society Press, Sacramento.

Poldrack RA (2007). Region of interest analysis for fMRI. Social Cognitive and Affective Neuroscience 2(1):67-70. *https://doi.org/10.1093/scan/nsm006*

Potop V, Boroneanț C, Možný M, Štěpánek P, Skalák P (2014). Observed spatiotemporal characteristics of drought on various time scales over the Czech Republic. Theoretical and Applied Climatology 115:563-581. *https://doi.org/10.1007/s00704-013-0908-y*

Provoost S, Jones MLM, Edmondson SE (2011). Changes in landscape and vegetation of coastal dunes in northwest Europe: a review. Journal of Coastal Conservation15:207-226. *https://doi.org/10.1007/s11852-009-0068-5*

Rhind P, Jones R, Jones L (2013). The impact of dune stabilization on the conservation status of sand dune systems in Wales. In: Martínez M, Gallego-Fernández J, Hesp P (Eds). Restoration of Coastal Dunes. Springer Series on Environmental Management. Springer, Berlin, Heidelberg. *https://doi.org/10.1007/978-3-642-33445-0_8*

Richards J (1999). Remote Sensing Digital Image Analysis. Springer-Verlag, Berlin.

Richards J, Jia X (1993). Remote Sensing Digital Image Analysis: An Introduction. Springer, 2nd Ed.

Rujoiu-Mare MR, Mihai BA (2016). Mapping land cover using remote sensing data and GIS techniques: A case study of Prahova Subcarpathians. Procedia Environmental Sciences 32(2016):244-255. *https://doi.org/10.1016/j.proenv.2016.03.029*

Rundquist DC, Narumalani S, Narayanan RM (2001). A review of wetlands remote sensing and defining new considerations. Remote Sensing Reviews 20:207-226. *https://doi.org/10.1080/02757250109532435*

Samanta A, Ganguly S, Hashimoto H, Devadiga S, Vermote E, Knyazikhin Y, Nemani RR; Myneni RB (2010). Amazon forests did not green-up during the 2005 drought. Geophysical Research Letters 37(5):L05401. *http://doi.org/10.1029/2009GL042154*

Sathya P, Deepa VB (2017). Analysis of supervised image classification method for satellite images. International Journal of Computer Science Research 5(2):16-19.

Schuur EAG (2003). Productivity and global climate revisited: The sensitivity of tropical forest growth to precipitation. Ecology 84(5):1165-1170.

Schwinning S, Sala OE (2004). Hierarchy of responses to resource pulses in arid and semi-arid ecosystems. Oecologia 141(2):211-220. *https://doi.org/10.1007/s00442-004-1520-8*

Seif A, Mokarram M (2012). Change detection of Gil Playa in the Northeast of Fars Province. Iran Am J Sci Res 86:122-130.

Singh V, Dubey A (2012). Land use mapping using remote sensing and GIS techniques in Naina-Gorma Basin, part of Rewa District, M.P., India. International Journal of Emerging Technology and Advanced Engineering 2(11).

Tajbakhsh A, Karimi A, Zhang A (2020). Modeling land cover change dynamic using a hybrid model approach in Qeshm Island, Southern Iran. Environmental Monitoring and Assessment 192:303 *https://doi.org/10.1007/s10661-020-08270-w*

Taotao CG (2016). Assessment of drought impact on main cereal crops using a standardized precipitation evapotranspiration index in Liaoning Province, China. Sustainability 8:1069. *https://doi.org/10.3390/su8101069*

Taramelli A, Valentini E, Cornacchia L, Monbaliu J, Sabbe K (2018). Self-organized processes between salt marsh vegetation patterns and channel network in a tidal landscape. Journal of Geophysical Research: Earth Surface 123:2714-2731. *https://doi.org/10.1029/2017JF004540*

Touhami I, Chirino E, Aouinti H, El Khorchani A, Elaieb MT, Khaldi A, Nasr Z (2020). Decline and dieback of cork oak (*Quercus suber* L.) forests in the Mediterranean basin: a case study of Kroumirie, Northwest Tunisia. Journal of Forestry Research 31:1461-1477 *https://doi.org/10.1007/s11676-019-00974-1*

Touhami I, Chirino E, Fkiri S, Aouinti H, Moutahir H, Bellot J, ... Nasr Z (2021). An analysis of tree-ring width and the standardized precipitation-evapotranspiration index within the cork oak (*Quercus suber* L.) forests mortality framework in the Kroumirie Mountains, north-western Tunisia. Euro-Mediterranean Journal for Environmental Integration 6(42). *https://doi.org/10.1007/s41207-021-00250-x*

Touhami I, Khorchani A, Nasr Z, Elaieb MT, Rzigui T, Khaldi A (2019). Forest Ecological restoration by the use of native species in the North West of Tunisia: a brand-new experience of participatory approach. Ecologia Mediterranea 45(1).

Touhami I, Moutahir H, Assoul D, Bergaoui K, Aouinti H, Bellot J, Andreu JM (2022). Multi-year monitoring land surface phenology in relation to climatic variables using MODIS-NDVI time-series in Mediterranean forest, Northeast Tunisia. Acta Oecologica 114:103804. *https://doi.org/10.1016/j.actao.2021.103804*

Valdez M, Chen CF, Chiang SH, Chang KT, Lin YW, Chen YF, Chou YC (2019). Illegal land use change assessment using GIS and remote sensing to support sustainable land management strategies in Taiwan. Geocarto International 34(2):133-148. *https://doi.org/10.1080/10106049.2017.1374474*

Van Aarde RJ, Ferreira SM, Kritzinger JJ, van Dyk PJ, Vogt M, Wassenaar TD (1996). An Evaluation of Habitat Rehabilitation on Coastal Dune Forests in Northern KwaZulu-Natal, South Africa. Restoration Ecology 4(4):334–345. *http://doi.org/10.1111/j.1526-100x.1996.tb00186.x*

Verner D, Wilby R, Breisinger C, Al-Riffa, P, Robertson R, Wiebelt M, ... Roos P (2013). Tunisia in a changing climate: assessment and actions for increased resilience and development. The World Bank, Washington, DC. *http://doi.org/10.1596/978-0-8213-9857-9*

Vicente-Serrano S, Beguería S, López-Moreno J (2010). A multi-scalar drought index sensitive to global warming: The standardized precipitation evapotranspiration index. Journal of Climate 23:1696-1718. *https://doi.org/10.1175/2009JCLI2909.1*

Vicente-Serrano SM, Gouveia C, Camarero JJ, Beguería S, Trigo R, López-Moreno JI, … Sanchez-Lorenzo A (2013). Response of vegetation to drought time-scales across global land biomes. Proceedings of the National Academy of Sciences of the United States of America 110(1):52-57. *https://doi.org/10.1073/pnas.1207068110*

Vorovencii I, Muntean MD (2013). Evaluation of Supervised Classification Algorithms for Landsat 5 TM Images. Journal of Geodesy and Cadastre 14(2013).

Yang X, Lo CP (2002). Using a time series of satellite imagery to detect land use and land cover changes in the Atlanta, Georgia metropolitan area. International Journal of Remote Sensing 23(9)(2002):1775-1798. *https://doi.org/10.1080/01431160110075802*

Zairi M, Rouis MJ, Helali JE (1999). Evaluation de l'efficacite´ du vibro-compactage de la fondation du barrage de Sidi El Barrak Tunisie [Evaluation of the efficiency of vibro-compacting in the fondation of Sidi El Barrak dam, Tunisie]. Annales du Bâtiment et des Travaux Publics 3:31-37.

Zhang S, Zhang S, Zhang J (2000). A study on wetland classification model of remote sensing in the Sangjiang plain. Chinese Geographical Science 10:68-73. *https://doi.org/10.1007/s11769-000-0038-1*

Zoran ME (2006). The use of multi-temporal and multispectral satellite data for change detection analysis of Romanian Black Sea Coastal zone. Journal of Optoelectronics and Advanced Materials 8:252-256.

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