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COASTAL ECOLOGICAL DYNAMICS: MONITORING VEGETATION CHANGES IN THE SFIHA-SWANI REGION (MOROCCO)

Alae MOUDDOU ✉, Morad TAHER, Issam ETEBAAI

Research and Development in Applied Geosciences Laboratory, FSTH, Abdelmalek Essaadi University, Tetouan, Morocco

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Abstract. This study examines the dynamics of vegetation cover in the coastal region of Al Hoceima, focusing on Sfiha and Swani beaches. It aims to understand changes in land cover categories, particularly the distribution and dynamics of vegetation cover. The research uses a comprehensive spatio-temporal analysis using advanced remote sensing technology and GIS.
The methodology uses four Landsat satellite images and four aerial photos from Google Earth from 2003 to 2021. It involves digital processing, radiometric and geometric corrections, and on-site ground visits to validate remote sensing data outcomes.
The study used land cover maps and Normalized Difference Vegetation Index (NDVI) maps to analyze changes in vegetation cover over the past 18 years. The maps revealed percentages of 21% (2003), 25% (2010), 33% (2015), and 15% (2021) of vegetation cover changes, indicating degradation in the study area.
The study reveals a significant decline in vegetation in the coastal region due to a combination of human and natural factors. This assessment is crucial for developing effective conservation and management strategies. The findings extend beyond Al Hoceima, providing insights for broader environmental conservation efforts, and highlighting the intricate relationship between human activities and environmental changes.

Keywords: remote sensing analysis, NDVI, GIS technology, vegetation dynamics, land cover mapping, spatiotemporal analysis, coastal management.

✉Corresponding author. E-mail: *alae.mouddou@etu.uae.ac.ma*

1. Introduction

Vegetation cover includes diverse ecosystems, from lush forests to smaller plant communities, forming a crucial element for maintaining ecological balance and sustaining life, as vegetation provides a base for all living beings and plays an essential role in global climate change, such as affecting terrestrial CO_2 levels (Xiao et al., 2004). However, vegetation cover is susceptible to degradation, which can occur in various forms, each posing unique threats to ecosystem health. Human activities like deforestation, agricultural expansion, and urbanization contribute to degradation, leading to land clearing and biodiversity loss (Ahmad & Pandey, 2018; Chapman & Underwood, 2009). Climate change, such as temperature changes, precipitation patterns, and extreme weather events can also disrupt vegetation cover, affecting the composition and structure of vegetation communities (Shilky et al., 2023). Soil degradation, a result of unsustainable land management practices, further aggravates the challenges faced by vegetation cover. Deforestation, overgrazing, and improper agricultural techniques can strip the soil of nutrients, weakening ecosystem resilience and making it more susceptible to degradation (Joe-Ikechebelu Ngozi et al., 2023; Patra et al., 2022). Addressing vegetation degradation requires a multi-faceted approach, including sustainable land management practices, reforestation initiatives, and global cooperation to mitigate climate change. Understanding the interplay of factors influencing vegetation cover can help develop strategies for preserving and restoring this vital component of the biosphere (Jackson & Prince, 2016).

Morocco's vegetation is a tapestry that ranges from the fertile north to the arid south, reflecting the diverse ecosystems of the country (Msanda et al., 2021); In the north, dense cork oak and cedar forests provide habitats for various plant species, demonstrating the ability of plants to adapt to different climatic conditions. In contrast, the southern regions are characterized by arid steppes and desert landscapes, where resilient plant species have evolved to tolerate limited water availability and high temperatures (Rayne et al., 2023). Despite this adaptability, Moroccan vegetation has not been spared from deterioration either (Jaouda et al., 2020). Recent years have witnessed a significant decline in green spaces manifested as deforestation, land-use changes, and shifts in vegetation patterns due to many factors, including climate change, droughts, groundwater depletion, damage to infrastructure (Rayne et al., 2023), and population growth. This degradation poses a profound threat to the ecological equilibrium of the region.

Coastal vegetation, as is the case in the Mediterranean region, especially in the Sfiha and Swani areas, constitutes a distinctive and dynamic ecological niche with multifaceted implications for biodiversity conservation and serves as a natural barrier effective in protecting from tsunami damage (Taher et al., 2022), mitigating the adverse impacts of coastal erosion, and thereby preserving the structural integrity of the shoreline and ecosystem stability (Thompson & Schlacher, 2008). This unique biome is characterized by a variety of plant species specially adapted to the challenging conditions of salt water exposure, fluctuating tidal regimes, and the prevailing climatic nuances inherent to coastal environments (Crawford, 2009; Martins et al., 2013).

However, these intricate coastal ecosystems are increasingly imperiled by anthropogenic activities and the ramifications of climate change (Ley et al., 2007; Gouveia et al., 2017). The burgeoning tourism industry, characterized by unregulated development and increasing human demand, stands as a prominent factor contributing to the degradation of coastal vegetation (Er-Ramy et al., 2022). Also, the anticipated rise in sea levels, shifts in precipitation patterns, and seawater intrusion (Bourjila et al., 2023), the heightened frequency of extreme weather events associated with climate change poses additional challenges to the resilience of these coastal habitats.

Preservation and a comprehensive understanding of the coastal vegetation in the Sfiha and Swani regions demand a strategic and interdisciplinary approach. This approach should encompass ecological conservation strategies and sustainable development practices. Recognizing the urgency of addressing this environmental challenge, this study endeavors to delve into the intricate dynamics of vegetation cover within the coastal region of Al Hoceima, with a focused lens on the Sfiha and Swani beaches. At its core, the research aligns with the global imperative of comprehensively assessing and monitoring Earth's surface, particularly in the context of vegetation, as underscored by global change research initiatives (Committee on Global Change Research, 1999). Recognizing vegetation mapping as pivotal for managing natural resources, our study contributes a meticulous examination of alterations in land cover, placing a specific emphasis on the distribution and dynamics of coastal vegetation.

The study employs advanced remote sensing technology, incorporating four Landsat satellite images (ETM+, OLI) and four aerial photos from Google Earth, (for four pivotal years 2003, 2010, 2015, and 2021). The utilization of a Geographic Information System (GIS) enhances spatial perspectives and facilitates the classification and mapping of vegetation cover (Xie et al., 2008). The methodology encompasses the digital processing of satellite images, on-site ground visits for result validation, detailed land cover mapping, and the construction of NDVI maps to quantify changes in vegetation cover over time. This approach aligns with the need for regularly updated data on vegetation cover changes, as emphasized by global change research initiatives.

By adopting a comprehensive and systematic approach, this research contributes to the understanding of the spatio-temporal dynamics of coastal vegetation in Al Hoceima. The integration of technologies, remote sensing techniques, and ground validation not only aligns with the overarching goals of global change research but also provides a solid foundation for informed conservation and management strategies in critical coastal ecosystems. The study's outcomes are expected to offer valuable insights for initiating vegetation protection and restoration programs, reflecting the commitment to addressing environmental challenges at both local and global scales.

2. Study area

2.1. Geographic location

The Province of Al Hoceima is located in the heart of central Rif, on the northern coast of Morocco, bordering the Mediterranean Sea on the north, on the west by the province of Chefchaouen, east by the province of Driouch, and south by the provinces of Taza and Taounate (Benaissa et al., 2023). The district of Al Hoceima covers an area of 3550 km^2 and is characterized by its coastline of cliffs and sandy shores, due to recent geology influenced by the Mediterranean climate (Benaissa et al., 2020). The city of Al Hoceima is situated midway between Tetouan to the west and Saidia to the east (Figure 1).

The Sfiha-Swani coast is situated within the municipality of Ajdir (recently renamed Ait Youssef Ou Ali), approximately 10 km from Al Hoceima. This area encompasses about 90 hectares of pine and eucalyptus forest that were planted to combat soil erosion.

The region includes two beaches. Swani Beach, located roughly 10 km southeast of Al Hoceima, spans an estimated length of 4 km. While relatively narrow, it extends from the outflow of the Ghiss River to that of the Nekor River. It constitutes the sandiest section of the bay (Infos Tourisme Maroc, n.d.). The other beach is SFIHA, in the Al Hoceima Province, and part of the Ait Youssef Ou Ali community. It is positioned 7 km east of Al Hoceima and extends over an approximate length of 2 km.

2.2. Climate

The climate of the Al Hoceima province is typically Mediterranean, featuring mild winters and hot summers. The region receives moderate to high rainfall, especially during the winter months from November to March. The average annual precipitation (Figure 2) along the coast exceeds 300 mm (Salhi et al., 2011). Summers are marked by clear skies and high temperatures, with average readings ranging from 25 °C to 30 °C (Bourjila et al., 2020). The coastal areas of the province benefit from a cooling effect brought by the Mediterranean Sea, which helps moderate temperatures during the summer months (Figure 3). The region

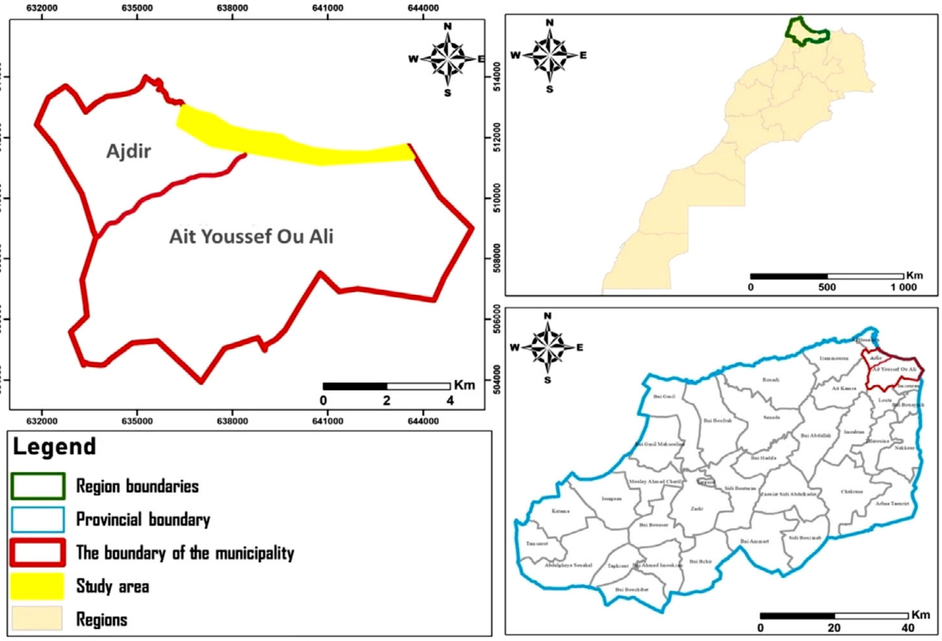


Figure 1. Location map of the study area

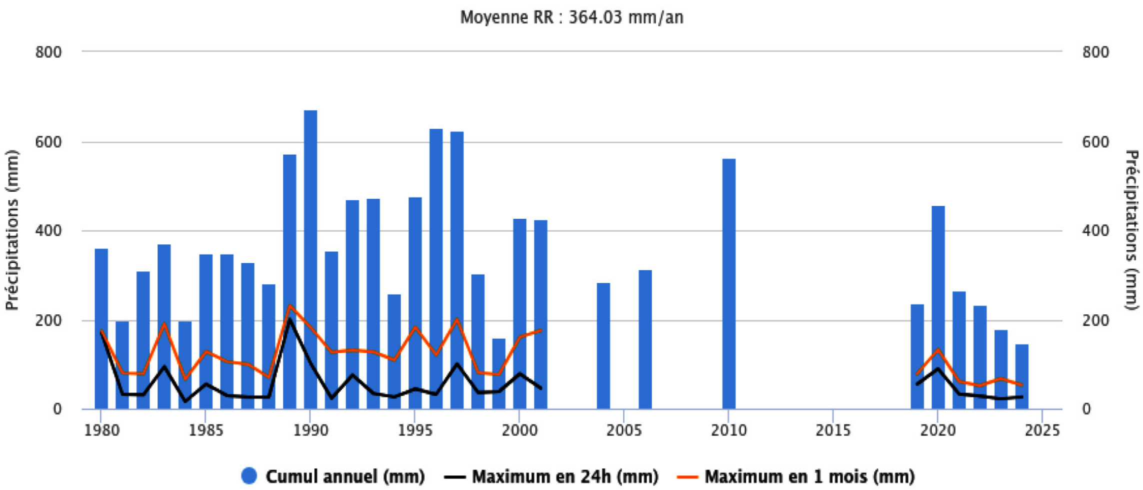


Figure 2. Precipitation in Al Hoceima (1980–2025) (source: Infoclimat, n.d.)

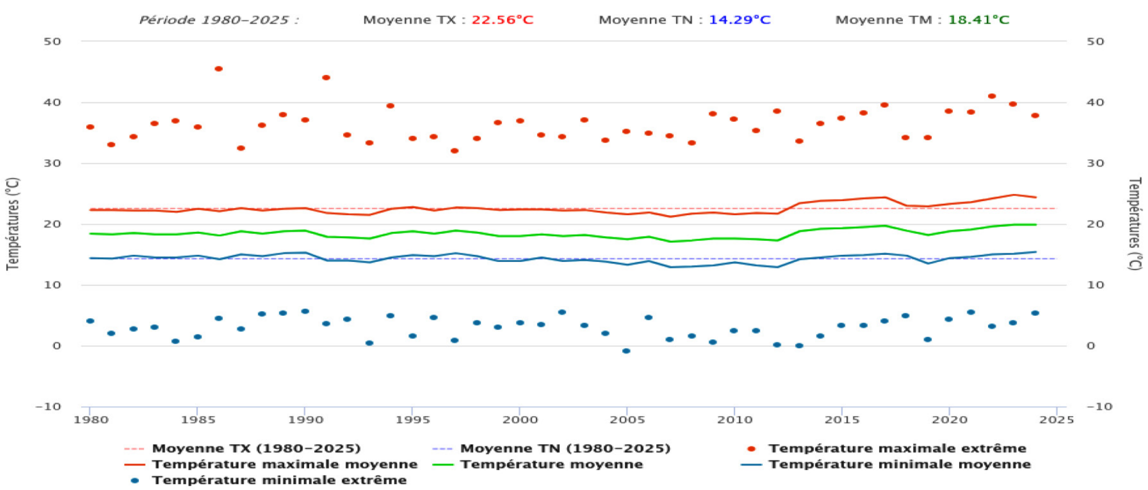


Figure 3. Temperature in Al Hoceima (1980–2025) (source: Infoclimat, n.d.)

is also known for its strong winds, particularly in winter, resulting in rough seas and challenging conditions for fishing and other marine activities.

In a broader context, the province's climate is influenced by the Mediterranean to the north, oceanic influences to the west, and continental influences to the east. This climatic diversity ranges from semi-arid to humid conditions, with distinct seasons characterized by a cold, wet winter and a hot, dry summer.

2.3. The vegetation covers

The Sfiha and Swani beaches are home to a forest cover that extends over dozens of hectares. The forest is characterized by dense to semi-dense vegetation, with an area of approximately 90 and 80 hectares for the Sfiha and Swani beaches, respectively.

The forest in this area is renowned for its variety of tree species, including Eucalyptus trees that cover most of the forest, many Aleppo Pine trees that extend from the cliffs to the beach, as well as Willows and some Juniper trees that occupy smaller areas.

2.4. The hydrographic network

The study area is characterized by two main rivers; Oued Nekor which streams over the center of the valley for a length of 15 kilometers, and Oued Ghiss which flows for a length of 3 kilometers along the downstream (Bouhout et al., 2023). We note that Al-Swani beach extends from the Outfall of Wadi Ghiss to that of Wadi Nekor after the latter begins the beach of Sfiha. Wadi Nekor separates the eastern Rif, which forms the western extremity, and the central Rif (Figure 4).

The Ghiss-Nekor aquifer underlies a triangular area, spanning more than 100 km^2 (Baite et al., 2018), and is one of the most significant groundwater reservoirs in the Rif belt.

Unfortunately, these valleys have witnessed a decline in water levels due to factors such as surging water demand, unpredictable climate shifts, deteriorating water quality, and unregulated pollutant discharges without pre-treatment.

3. Materials and methods

3.1. Materials used

Space remote sensing: Remote sensing sensors are crucial for gathering information about objects or scenes remotely. They can recognize objects based on their distinct spectral properties, such as reflectance or emission zones. Vegetation mapping can be done using spectral vegetation indices (VI), which are directly correlated with photosynthetically active radiation intercepted (Asrar et al., 1984). Remote sensing is a suitable tool for studying the Earth's biosphere and monitoring vegetation cover development, as it provides information at all times and spatial scales. It also provides information about plant structure, density, distribution, health, and productivity (Beeri et al., 2007).

Remote sensing data can be used to create high-resolution maps of vegetation cover, identify problem areas, monitor changes over time, assess climate change effects, predict species distribution, and detect natural and anthropogenic changes on a larger scale than traditional fieldwork data.

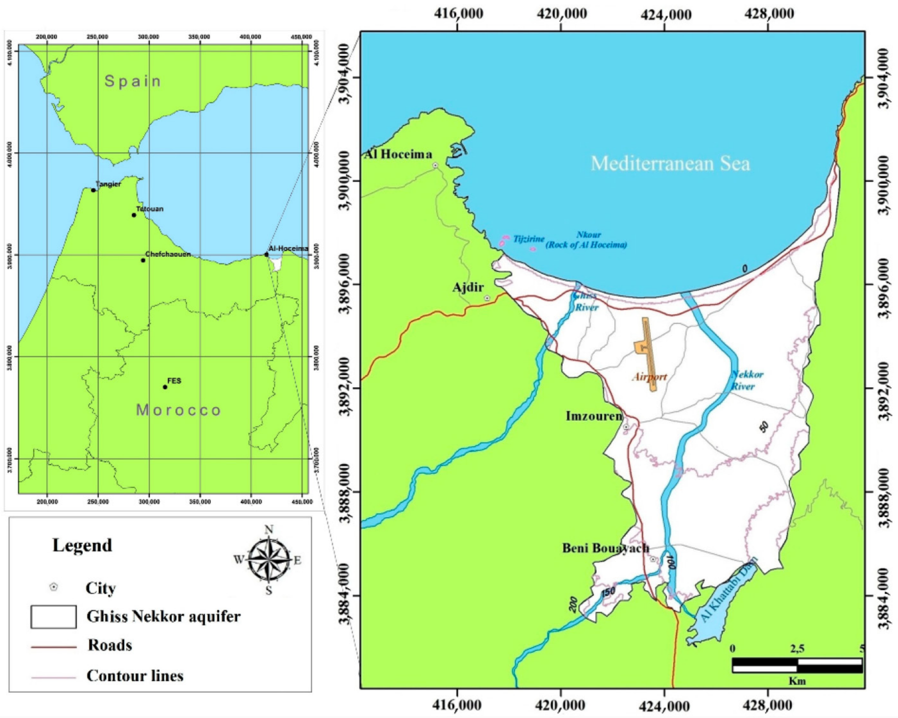


Figure 4. Location map of Oued Ghiss and Oued Nekor (source: El Yousfi et al., 2023)

Landsat images: Landsat images are produced by a series of Earth observation satellites that have been gathering data since 1970 (Xie et al., 2008). These images can be used for a variety of purposes, one of which is the study of vegetation. By comparing images taken at different times, scientists can create vegetation cover maps that are useful for tracking changes in ecosystems over time and for understanding the factors that contribute to those changes, such as land use changes, climate change, and natural disasters (Schroeder et al., 2006).

Utilizing varying spectral ranges to discern between several plant types is one of the most used techniques for analyzing vegetation in Landsat pictures. Researchers may utilize this data to make maps of, for instance, the amount of near-infrared light that a healthy plant reflects compared to diseased or barren soil.

Two types (ETM+ and OLI) of multispectral images from satellite observatory Landsat data were used to study the spatio-temporal evolution of the vegetation cover in the Sfiha-Swani region, Landsat based images with 30×30 m spatial resolution were downloaded from the United States of Geological Survey (USGS) website for the years 2003, 2010, 2015 and 2021, covering the study area, as shown in Table 1.

Table 1. Technical characteristics of the satellite data used

Name of the satellite	Date of acquisition	Spatial resolution
Landsat 7 (ETM+)	02/04/2003	30
	23/05/2010	
	27/05/2015	
Landsat 8 (OLI)	07/12/2021	30

Geographic information systems (GIS): Are crucial tools in various scientific fields, enabling the collection, processing, and presentation of spatial data. By integrating geographic characteristics and tabular data, GIS allows researchers to investigate and decipher links between datasets in a spatial context. This technology aids in decision-making in fields like epidemiology, environmental research, and urban planning (Tomlinson, 2007).

GIS is designed to capture, store, process, analyze, and display spatial or geographic data, it can be used to study vegetation by creating maps showing the spatial distribution and density of different vegetation types, these maps can monitor changes in vegetation cover over time and identify areas at risk (Foody, 2002). GIS technology also enables spatial analysis of vegetation cover data, such as calculating vegetation indices and identifying areas under stress or degradation (Hansen et al., 2013). Overall, GIS is a powerful tool for studying vegetation due to its ability to integrate and analyze various types of geospatial data, providing a comprehensive understanding of spatial patterns and dynamics.

ArcGIS Software version 10.8: ArcGIS, a leading Geographic Information System (GIS) platform developed by ESRI, serves as a powerful tool for integrating and analyzing land use data. This includes NDVI maps and soil occupation maps, providing valuable insights into vegetation health, land cover, and soil characteristics (Tayyebi et al., 2008). The platform supports informed decision-making in agriculture, environmental monitoring, and resource management.

Utilizing ArcGIS, researchers can import and analyze NDVI data to assess changes in vegetation cover over time. Simultaneously, soil occupation maps, either created or imported, undergo spatial analysis to further enhance the understanding of land dynamics. The platform's capabilities extend to land use classification, facilitating the identification and mapping of various land cover types, ranging from agricultural fields and forests to urban areas. Additionally, ArcGIS enables the comparison of historical and current vegetation cover data, playing a crucial role in change detection analysis. This analytical function is indispensable for monitoring deforestation, urban expansion, and shifts in vegetation patterns (Turner et al., 2015).

Google Earth Pro: Stands as a powerful geospatial exploration tool developed by Google, providing an interactive platform that amalgamates satellite imagery, aerial photography, and geographic information systems (GIS) data.

Google Earth leverages high-resolution satellite imagery, enabling researchers to conduct remote sensing analysis for vegetation cover studies (Gorelick et al., 2017). This reservoir of imagery serves as a crucial asset for researchers, enabling meticulous observation and analysis of temporal changes in vegetation patterns it facilitates temporal research and change detection in vegetation cover through its extensive collection of historical imagery (Turner et al., 2015).

Aerial photos: Satellite and aerial images in Google Earth are captured by satellite and airborne cameras, which collect each image at a specific date and time. These images can be used in Google Earth as a single image with a specific collection date.

Aerial photos allow for the updating of collected data (topographic maps, aerial photographs, etc.), and they also make it possible the study the changes in vegetation cover during different periods.

3.2. Methods

3.2.1. Pre-treatement

The preprocessing functions are operations usually required before the primary analysis and extraction of information. They are divided into radiometric and geometric corrections.

Radiometric correction:

To ensure proper thresholding and visualization of images, during processing, we made some radiometric corrections, which may be required due to differences in lighting and visual geometry of a scene, atmospheric conditions, noise, and the reaction of the sensors. Each of these factors depends on the sensor and platform used, as well as the data acquisition conditions. It is often desirable to convert and calibrate the data using a known (absolute) unit of radiation or reflection to enable accurate comparison of the data, the principle of this correction is the conversion of the digital values of the scene into a luminance value and then extracting the atmospheric disturbances giving a physical measure of the reflectance at the target surface. We then developed two types of color compositions of satellite images, the first being the composition of false colors, which makes it possible to highlight the vegetation cover (appearing in red). In contrast, the second composition aims to visualize an image in natural colors (RGB = Red, Green, Blue), to use it in the classification under ArcMap software (Girard & Girard, 1999).

Geographical correction:

The objective of this step is to reduce the geometric deformations involved in the recording of the scene such as the deformations induced by the environment, distortions due to measurement errors, and distortions due to the movements of the platform, and the transformation of the data into real coordinates (for example in latitude and longitude) so that they can be superimposed on the other information layers (Bennour, 2014).

Geometric corrections have been applied to the images so that they are georeferenced in the UTM coordinate system, and make them superimposable to allow classifications to be compared and to detect changes between dates. This operation involves the geometric transformation of an image so that it conforms to the desired map projection,and each pixel is then placed in this projection.

Delimitation of the study area:

After the geometric and radiometric correction of the Landsat images, we delimited the study area and eliminated all the parts of the image outside the area, with the help of a shapefile making it possible to extract the portion of the satellite scene that we wish to study.

3.2.2. Treatment

NDVI cards:

The Normalized Difference Vegetation Index (NDVI) is commonly used in remote sensing analysis. It is calculated from the red and near-infrared bands of satellite or aerial imagery. It is used to assess the density and health of vegetation cover across a given landscape (Huang et al., 2021). After calculating the indicator, using Equation (1), we obtain an image showing the distribution of the vegetation cover depending on density so that each pixel of the image takes on a color indicating a number between –1 (bare floor) and 1 (dense vegetation cover) after we convert the image into a map (Sellers, 1987).

$$\mathrm{NDVI} = \frac{\mathrm{PIR} - \mathrm{R}}{\mathrm{pIR} + \mathrm{R}} \quad \text{(Rouse et al., 1974).} \tag{1}$$

In short, the NDVI index is a valuable tool for studying the health and distribution of vegetation on the Earth's surface and is widely used in various applications, including agriculture, forestry, and environmental monitoring.

Land use map:

It refers to a type of map that displays the different types of land use or land cover in a specific area, such as urban areas, forests, croplands, and water bodies. Land use maps are important tools for land management, urban planning, and environmental monitoring, as they visually represent how land is being used and how it may change over time.

After georeferencing the aerial photos from Google Earth, we used supervised classification (also known as directed classification) to identify the different land cover classes to be displayed on the maps. The method is based on an oriented approach, where we define polygons for each pixel to determine its corresponding class. The pixels are then grouped based on their belonging to homogeneous regions, considering their spectral, spatial, morphological, and textural characteristics. This approach enables the calculation of each pixel's probability of belonging to one class versus another, with the pixel being assigned to the class with the highest probability of belonging.

Statistical study:

To study the evolution of vegetation cover, we use the ArcGIS program to calculate the area of vegetation cover for each NDVI map and land use maps for all selected years. The collected measurements allow us to make comparisons between the different years. Then, we group the measurements in Excel and convert them into diagrams to more easily study and determine the intensity of vegetation loss and evolution.

Fieldwork:

Admittedly, satellite images and aerial photos are handy for studying the evolution of land cover for a given place, but fieldwork must be added, which aims to validate the satellite images and supplement them with photographs that make it possible to apprehend certain phenomena, which makes it possible to understand the factors of the evolution of the occupation of the ground (Figure 5).

The purpose of fieldwork is to know the genus and status of species that characterize the vegetation of this region, as well as their distribution, that is to say, the location of areas characterized by high density and others with a low rate of vegetation.

The field visit also provides information on human activities that directly or indirectly cause damage leading to the loss of vegetation (Figure 6).

4. Results

4.1. NDVI maps

The calculation of the vegetation index (NDVI) has given five classes; very dense vegetation cover, low-density vegetation cover, agricultural systems, bare soil, and water (sea), respectively. In this part, only the first four categories will be analyzed.

– 2003

The calculation of the vegetation index for the year 2003 results in four distinct categories. The first category

(0.65–0.35) represents areas with dense vegetation cover with high chlorophyll content, covering 8% of the total study zone (Figure 7) and spanning an area of 0.77 km^2. Additionally, areas with low vegetation density (0.35–0.2) cover 0.52 km^2, which is smaller than the dense vegetation cover, constituting 6% of the total area.

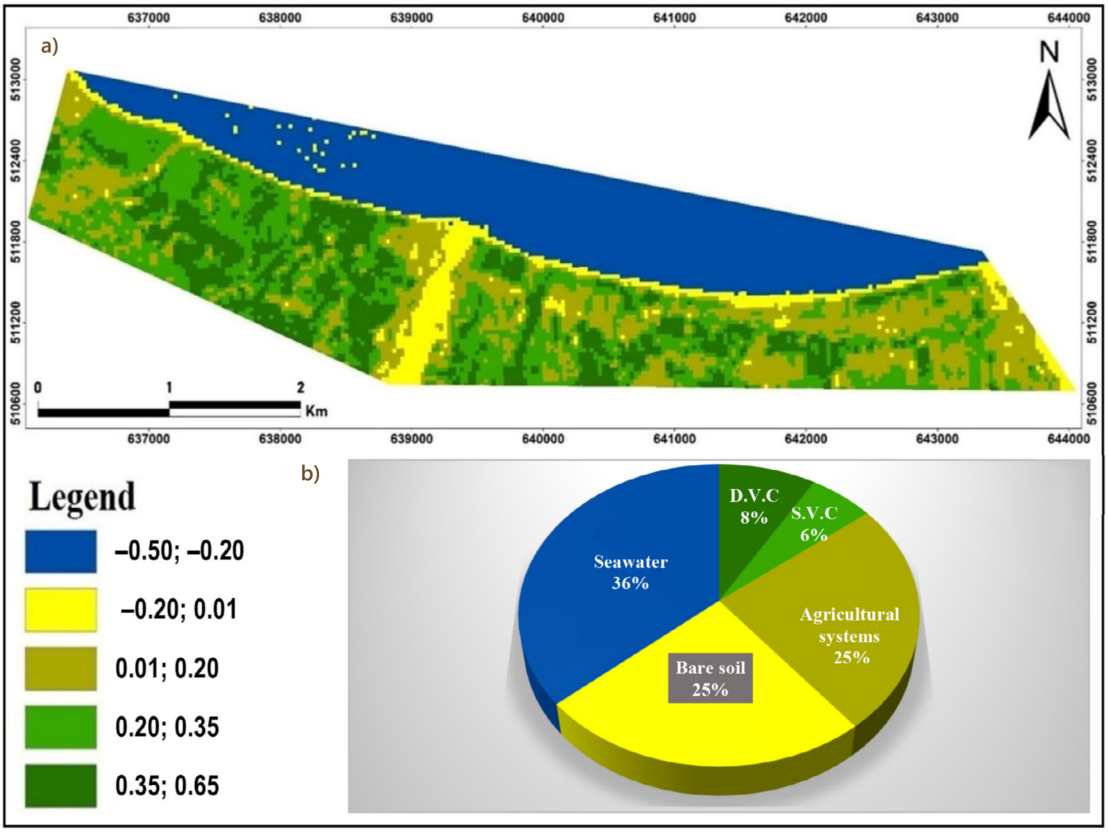
On the other hand, the majority of the study zone is divided between two categories: agricultural systems and semi-bare areas with an NDVI between (0–0.2), covering 25% of the area, and bare soil, characterized by NDVI values ranging from −0.2 to 0, occupying 25% of the total area.

– 2010

According to the NDVI map of 2010 (Figure 8), it is evident that 26% of the area is characterized by agricultural systems and semi-bare soil (0.09–0.044), encompassing an area of 2.29 km^2, followed by two categories with comparable proportions: sparse vegetation (0.23–0.095) covers an area of 1.25 km^2, constituting 17% of the total area, while dense vegetation (0.5–0.23) spans 1.09 km^2, representing 12% of the study area.

Figure 5. Vegetation covers in the Sfiha-Swani area

Figure 6. Tourist complexes in the Sfiha-Swani area



Note: D.V.C – Dense vegetation cover, S.V.C – Sparse vegetation cover.

Figure 7. The proportions of NDVI classes according to the area: a – NDVI map; b – diagram (source: Sfiha-Swani, 2003)

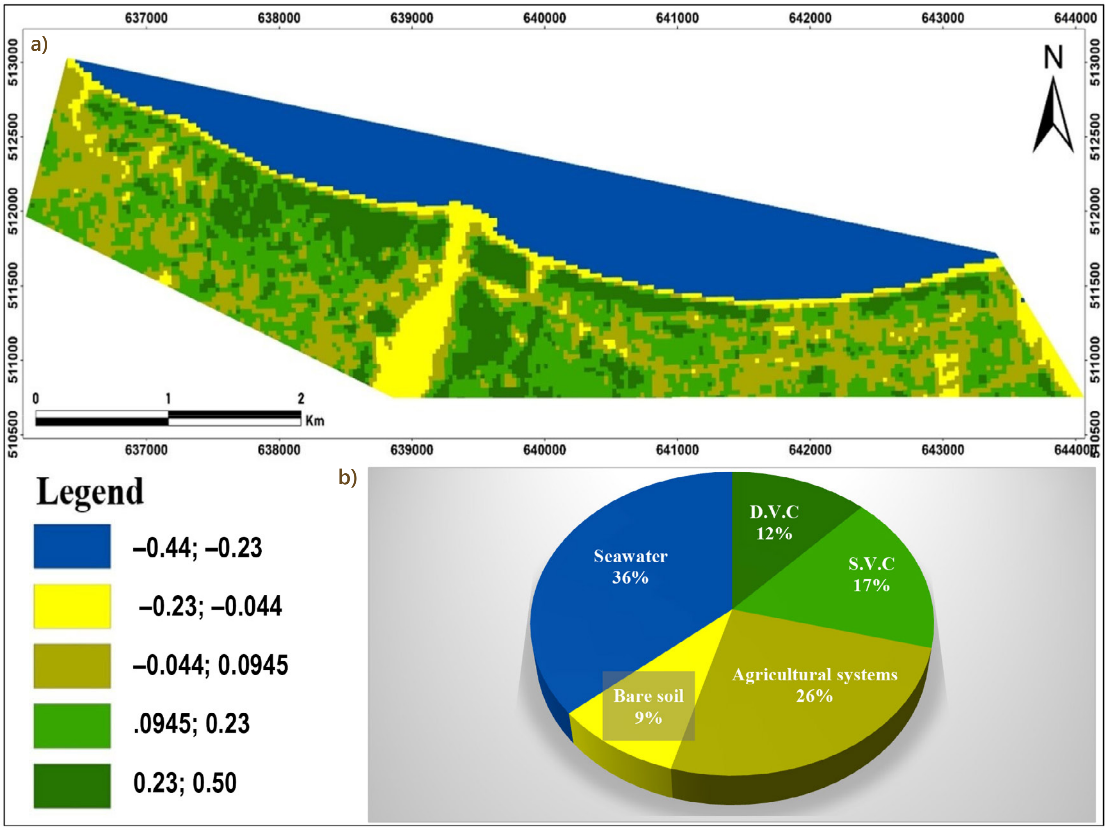


Figure 8. The proportions of NDVI classes according to the area: a – NDVI map; b – diagram (source: Sfiha-Swani, 2010)

– 2015

Similar to the findings in 2010, the NDVI map of 2015 (Figure 9) shows that a large portion of the area is occupied by agricultural systems and semi-bare soil (0.25–0.16), estimated to cover an area of 2.21 km^2. Following this, the sparse vegetation cover (0.35–0.25) occupies 1.56 km^2, constituting 17% of the total area, and the dense vegetation cover class (0.6–0.35) spans an area of 1.28 km^2, representing 14% of the zone. The remaining land (9%) is bare soil (0.16–0), with an area of 0.84 km^2.

– 2021

The diagram and the NDVI map of 2021 (Figure 10) indicate that the largest percentage of occupancy is divided between the agricultural systems and semi-bare soil class (0.15–0.098) and the bare soil class (0.098–0), covering 1.87 km^2, and 1.93 km^2, respectively, followed by the sparse vegetation class (0.22–0.15), which occupies up to 15% of the zone and is estimated to cover an area of 1.37 km^2. The dense vegetation cover class accounts for the lowest percentage of land use, ranging from 0.044–0.22, which accounts for only 8% of the total area and covers a total area of 0.7 km^2.

4.2. Land use maps

In this section, we conduct a diachronic analysis of land use maps spanning 13 years (2003–2021) to evaluate landscape changes and detect their evolution over time and space. The results allow us to identify six distinct land use classes: dense forest cover, light forest cover, agricultural systems, buildings, bare soil, and water.

– 2003

According to the land use map of 2003 (Figure 11), it is possible to determine that a vast area is covered by bare land, with an area of approximately 2 km^2, followed by dense forest cover and agrosystems, each with an equal surface area of 0.37 km^2. Clear forest cover occupies 0.27 km^2, and buildings occupy a negligible area of only 0.026 km^2. It can be said that the percentage of bare land, 66%, exceeds half of the total area. In comparison, the two classes of dense forest cover and agrosystems each represent 12% of the total area, and sparse forest cover occupies 9% of the total surface area.

– 2010

After analyzing the land use map of 2010 (Figure 12), the majority of the study area is covered by bare land 1.82 km^2, which represents 61% of the area, followed by dense forest covering 14% of the total area. sparse forest cover and agrosystems occupy a smaller area in comparison, while buildings have a very low occupancy rate.

– 2015

According to the land use map of 2015 (Figure 13), a large part of the study area (53%) is covered by bare land, followed by dense forest covering 2.22% of the area. Sparse forest cover and agrosystems occupy the same proportion of the area (11%), while buildings have a very low occupancy rate, 3% of the total area.

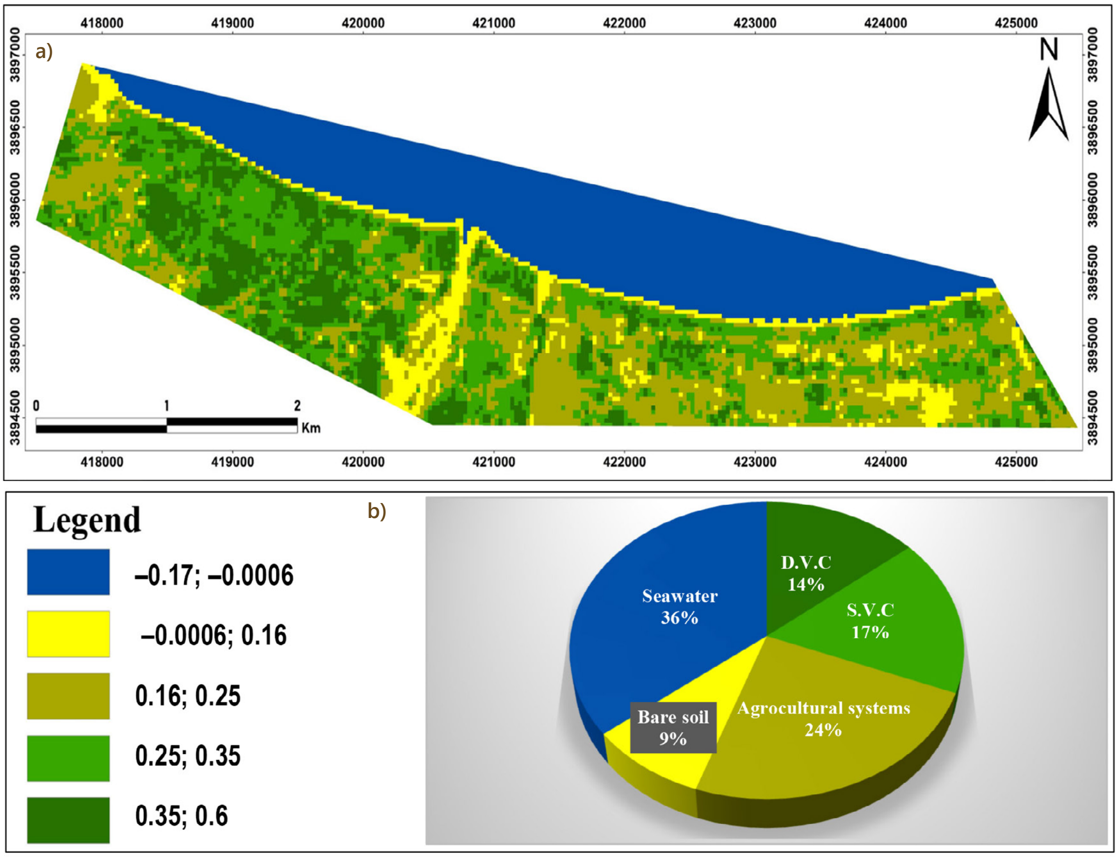


Figure 9. The proportions of NDVI classes according to the area: a – NDVI map; b) – diagram (source: Sfiha-Swani, 2015)

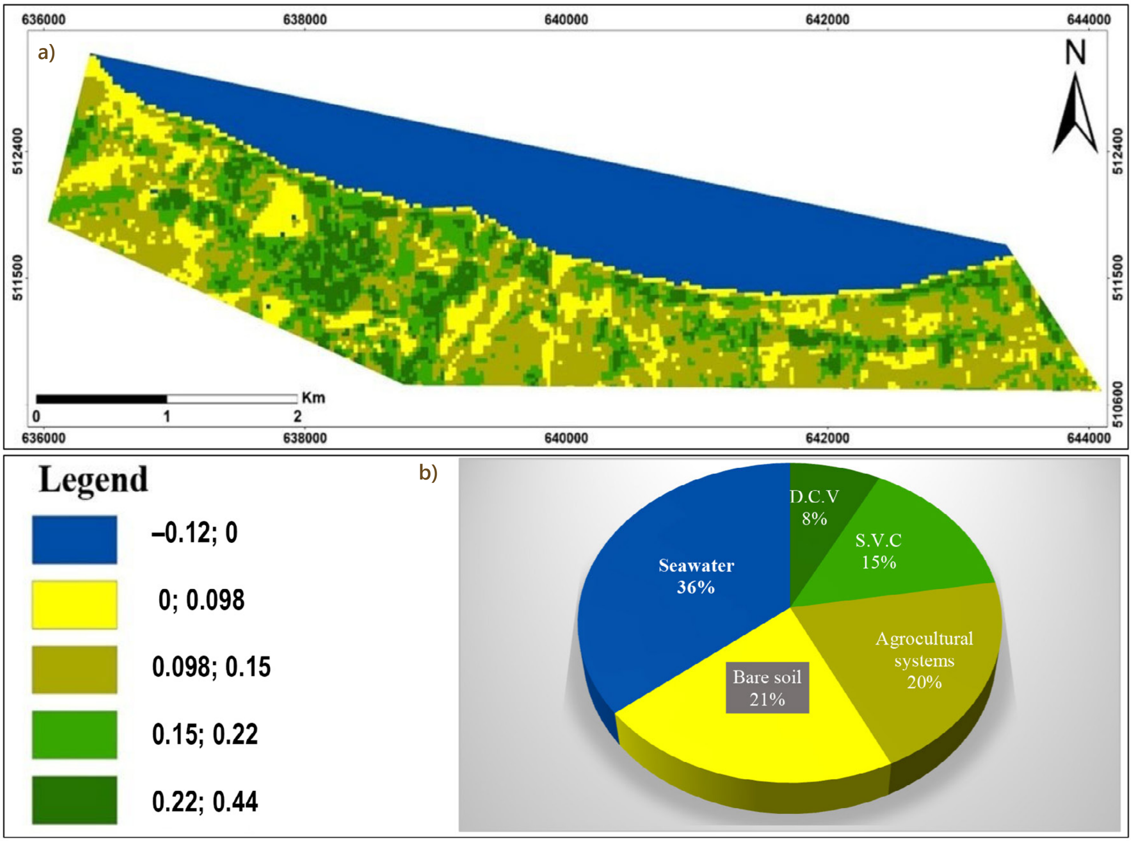


Figure 10. The proportions of NDVI classes according to the area: a – NDVI map; b – diagram (source: Sfiha-Swani, 2021)

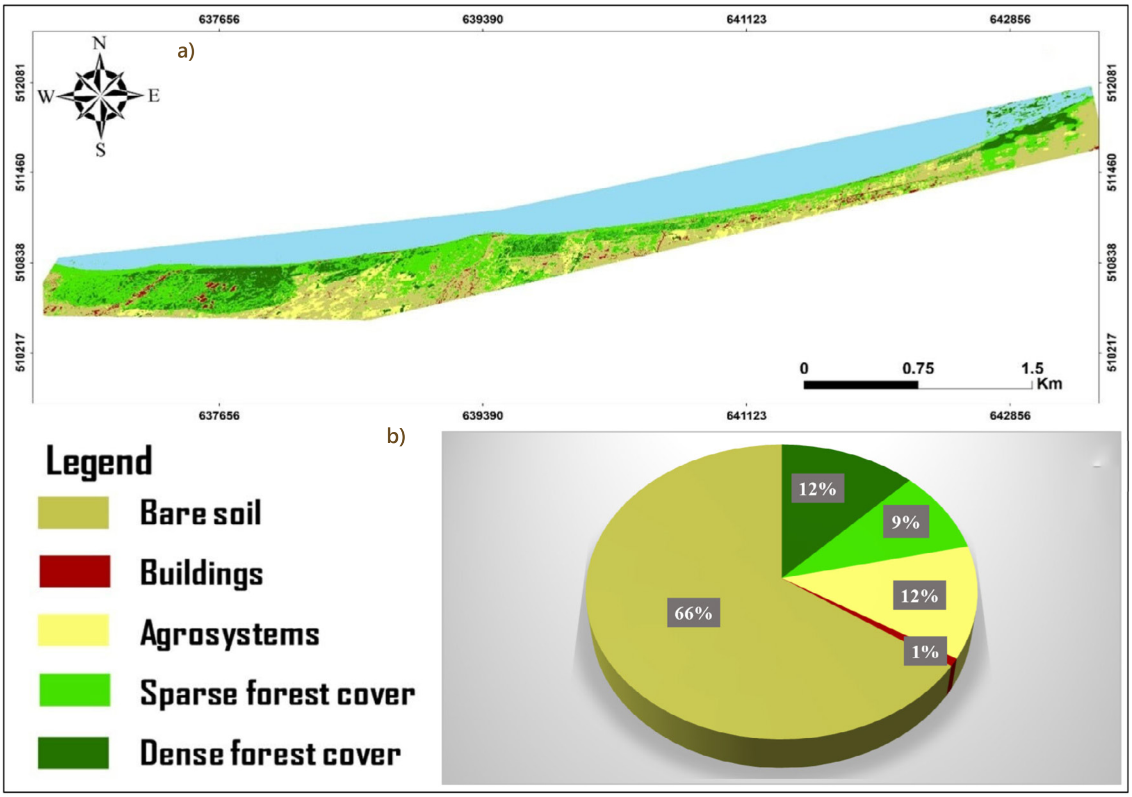


Figure 11. The proportions of the classes that occupy the ground: a – land use map; b – diagram (source: Sfiha-Swani, 2003)

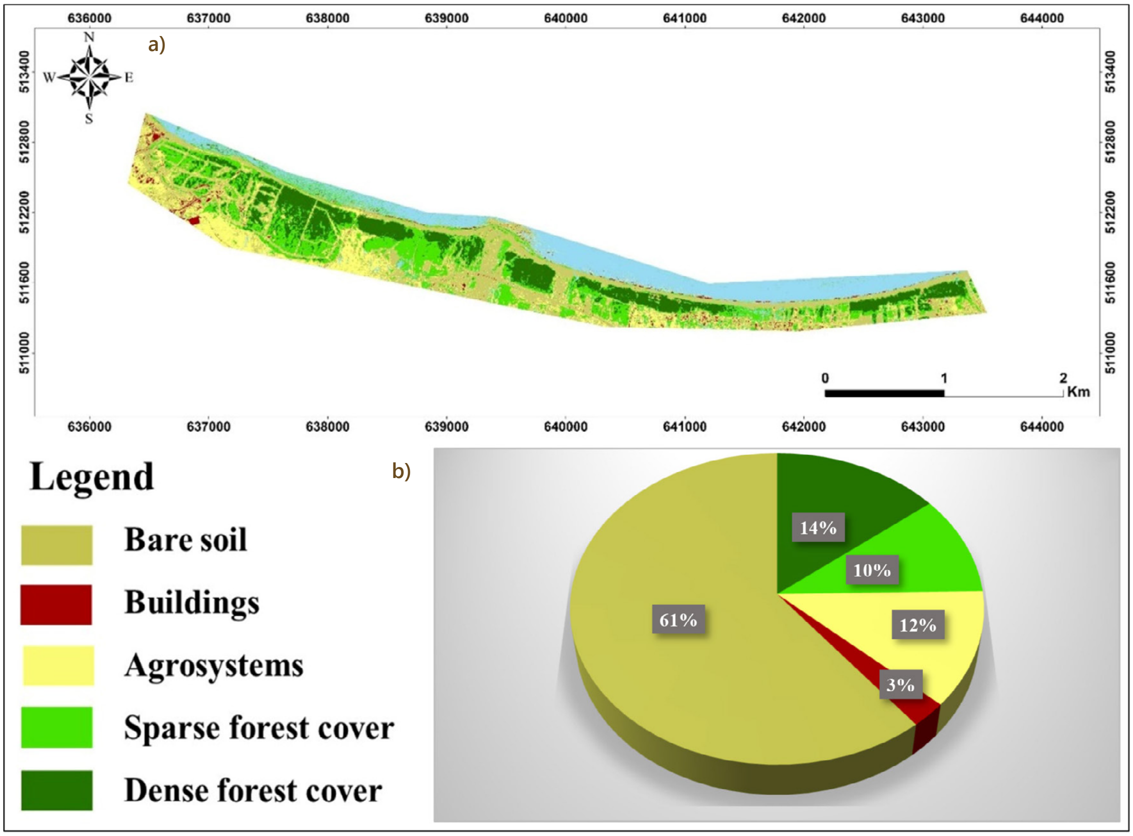


Figure 12. The proportions of the classes that occupy the ground: a – land use map; b – diagram (source: Sfiha-Swani, 2010)

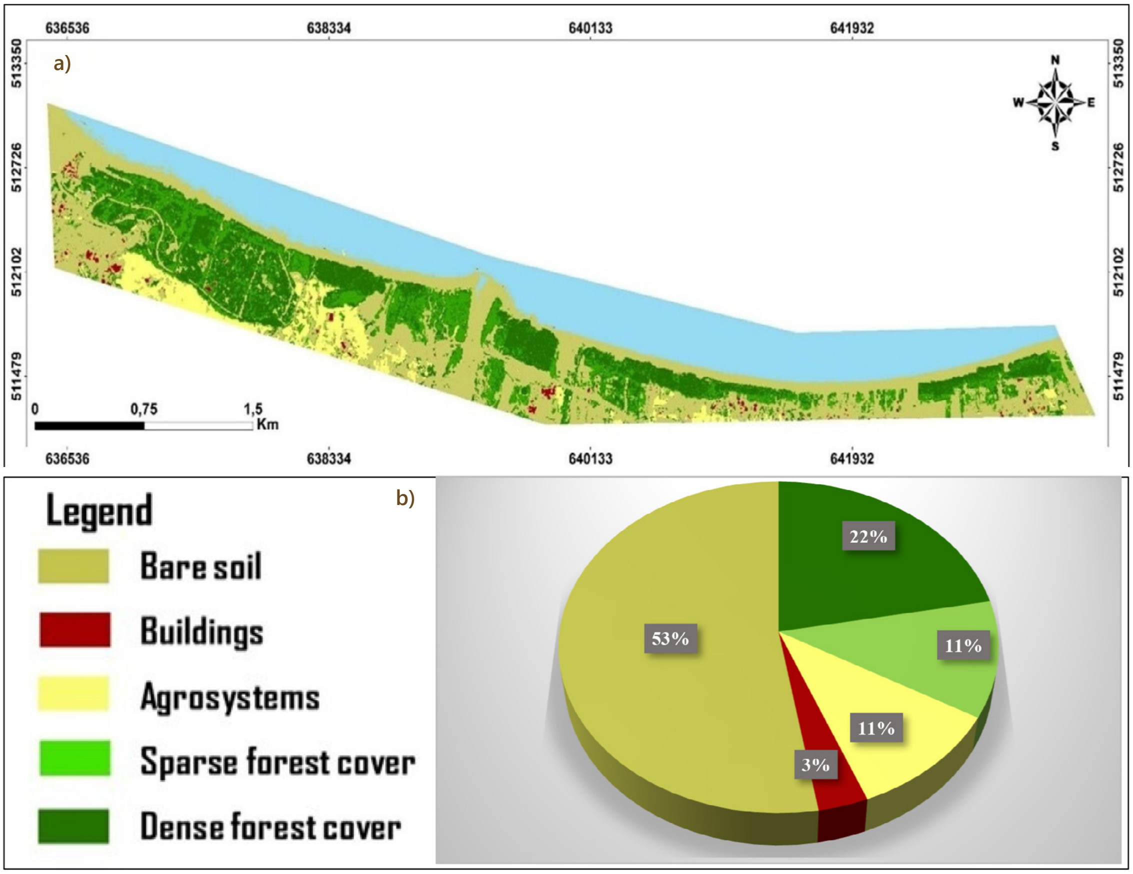


Figure 13. The proportions of the classes that occupy the ground: a – land use map; b – diagram (source: Sfiha-Swani, 2015)

– 2021

After analyzing the 2021 land use map (Figure 14), we notice that bare soil is the dominant land cover, occupying 1.59 km^2, which represents 53% of the total area. This is followed by a significant proportion (25%) of built-up areas, estimated at 0.77 km^2. Dense vegetation covers 9% of the study area, equivalent to 0.27 km^2, surpassing sparse forest cover (0.17 km^2) and agrosystems (0.2 km^2).

The land use maps spanning from 2003 to 2021 illustrate significant changes in the study area's land cover. In 2003, the majority of the area was characterized by bare land (66%), followed by dense forest cover and agrosystems.

By 2010, there was a noticeable shift, with the proportion of bare land decreasing to 61% while dense forest cover increased to 14%. In 2015, bare land continued to dominate (53%), with sparse forest cover, agrosystems, and dense forest cover following in proportion.

In 2021, bare soil retained its dominance, covering 53% of the total area, followed by built-up areas at 25%, and dense vegetation at 9%. Sparse forest cover and agrosystems occupied smaller proportions of the area. Notably, the percentage of buildings and development increased over time, while the proportion of vegetation cover decreased.

4.3. Comparison of results

The comparison and analysis between each NDVI map and land use maps reveal differences between them. One difference is the number of categories studied, with six categories for land use maps and five for NDVI maps. Another difference is observed in the static data, where the proportions of the same categories vary between the two types of maps. For example, the rate of dense vegetation cover development from 2003 to 2015 is estimated to be 28% in NDVI maps and 12% in land use maps. The results of the two maps also show a difference in the bare soil category, with land use maps showing a decrease in the area occupied by bare soil from 2003 to 2021, while NDVI maps showed a decrease from 2003 to 2015 but an increase in 2021 due to the inclusion of urban areas.

Overall, both maps show a positive development in vegetation cover in the Sfiha-Swani area from 2003 to 2015, followed by a deterioration from 2015 to 2021 and an increase in urban areas.

5. Discussion

Our findings highlight the dynamic and variable nature of vegetation cover between 2003 and 2015. This period witnessed noticeable fluctuations in vegetation distribution, notably highlighted by a substantial escalation in forest cover from 21% to 33% (Figure 15). Throughout these

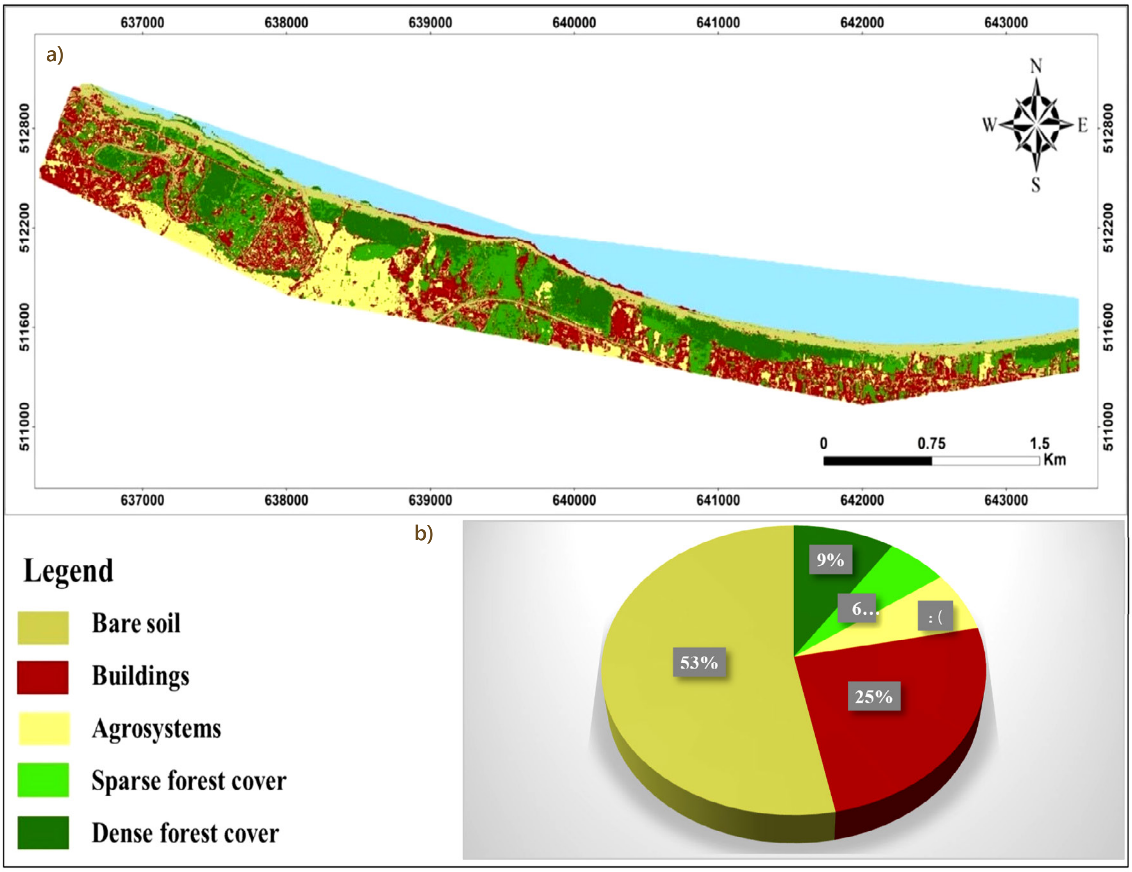


Figure 14. The proportions of the classes that occupy the ground: a – land use map; b – diagram (source: Sfiha-Swani, 2021)

years, the prevalent land cover categories were predominantly characterized by bare soil, followed in prominence by dense forest cover, agrosystems, and sparse forest cover, while buildings occupied comparatively smaller portions (Figure 16). The augmentation of vegetation coverage can be attributed to the proliferation of new plant growth across distinct geographical points, most notably observed in the vicinity of Swani beach. This trend may be attributed to augmented levels of precipitation between 2003 and 2010, potentially facilitated by a decline in the water level of Oued Ghis. Furthermore, the influence of climate change cannot be dismissed, as it may have played a role in enhanced vegetation coverage. Factors such as rising temperatures and increased atmospheric carbon dioxide concentration could have stimulated plant metabolic processes and photosynthesis, thus contributing to the observed expansion of vegetation.

Between the years 2015 and 2021, our diachronic investigation has unveiled substantial disruptions to the vegetation cover within the studied region, culminating in its degradation (Figure 15). This deterioration is pronounced over this period, with evident signs from 2015 to 2021. The extent of this degradation is quantified at approximately 18%, manifesting as a reduction in forest cover from 33% in 2015 to 15% in 2021. In contrast, a noteworthy and substantial upsurge in urban areas has occurred, with a remarkable 22% increase recorded in 2021. It is pertinent to highlight that the predominant zones within the study area are now characterized by arid lands and constructed structures, surpassing the expanse occupied by forest cover (Figure 16).

In general, the extent of plant growth in the Sfiha-Swani region has undergone a notable reduction between the years 2003 and 2021, as depicted in (Figure 15). An analysis of fixed-timepoint observations indicates that over 18 years, the proportion of forest cover has shrunk by 20%, corresponding to a loss of 0.2 km^2 (Figure 17). This decline has mainly been observed in the densely forested

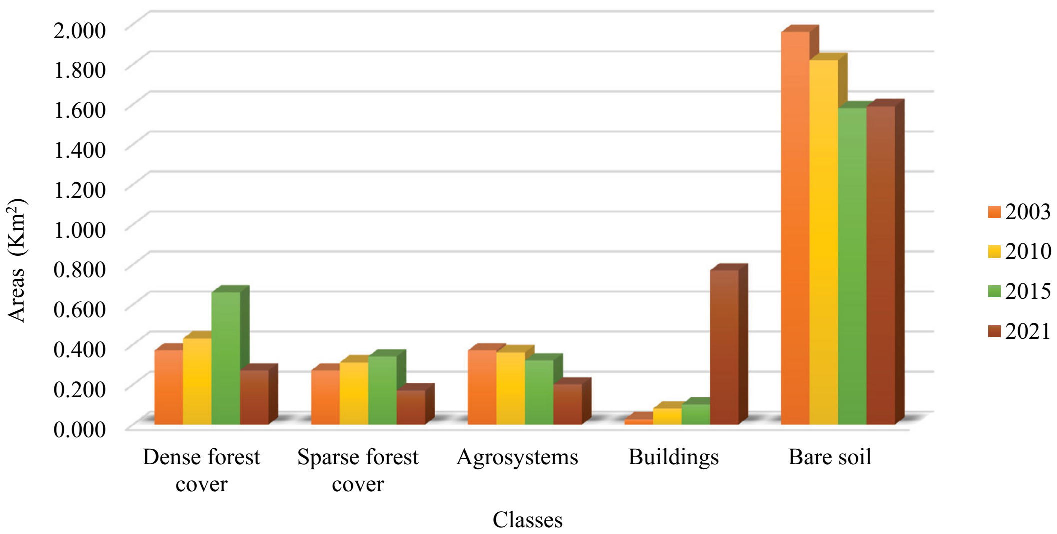


Figure 15. Histogram of the evolution of the areas by class

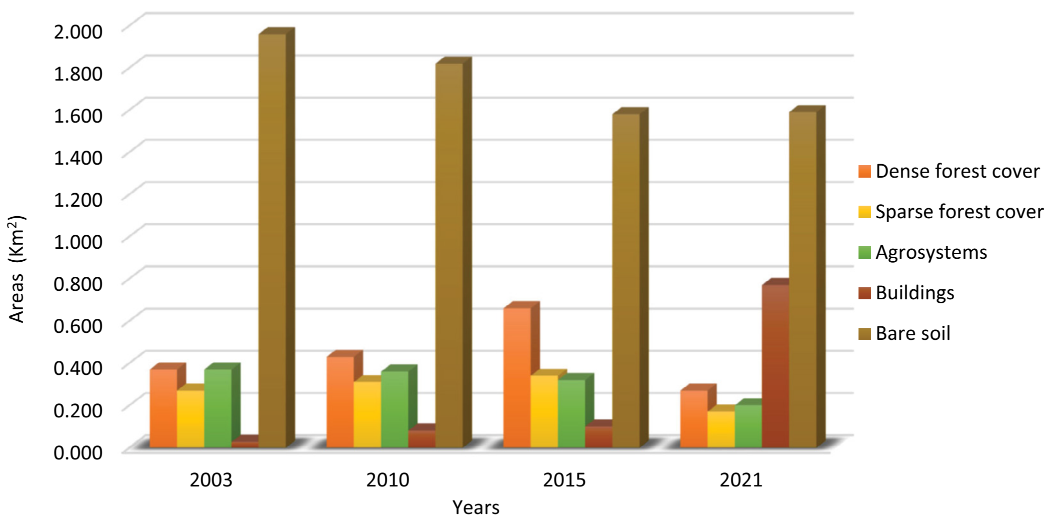


Figure 16. Histogram of the evolution of the areas of the classes according to the year

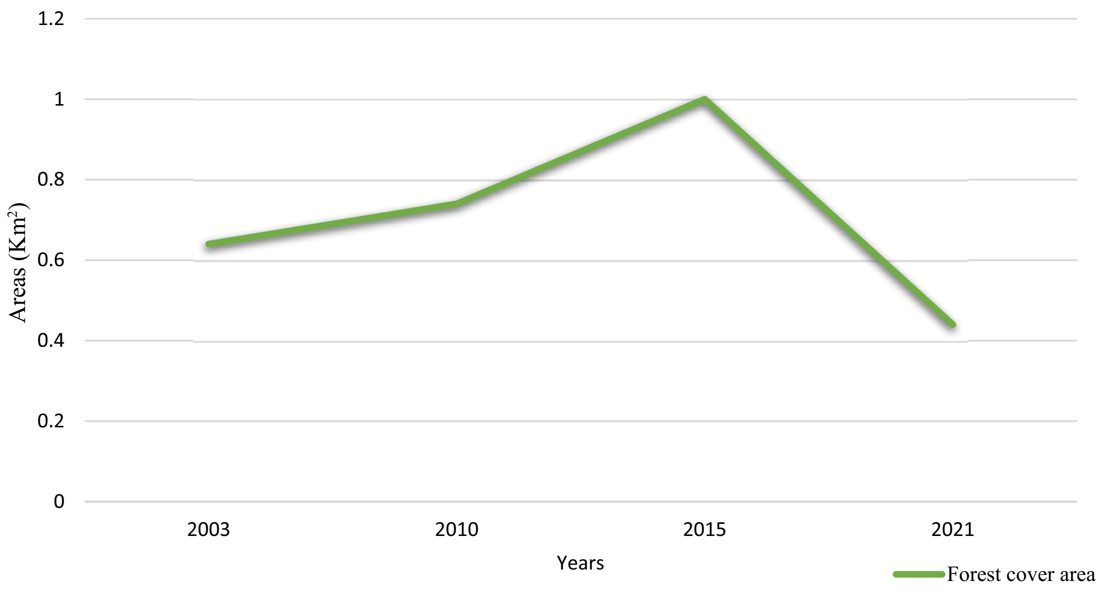


Figure 17. The evolution of forest cover area in the Sfiha-Swani zone (2003–2021)

regions surrounding Sfiha beach. These findings underscore that plant growth patterns vary across both time and geographical locations, with multiple factors contributing to this phenomenon. These factors encompass human-induced activities like fires, excessive grazing, deforestation, and the impact of parasitic attacks, particularly on pines. Additionally, variations in the frequency of dry spells and the occurrence of marine intrusion are also noteworthy explanations for these shifts.

6. Conclusions

This study sheds light on the profound impact of inadequate management practices on vegetation cover in the Sfiha-Swani area, underscoring the pivotal role of remote sensing and GIS in acquiring precise information on land use changes. The endeavor to analyze alterations in vegetation cover from 2003 to 2021 encountered notable challenges, primarily the limitation in accessing high-quality and consistent data over the entire study period. Cloud cover in satellite imagery poses another obstacle, potentially impeding the accuracy of vegetation assessments. The dynamic nature of urbanization and land use changes in the region adds complexity, making it challenging to distinguish between natural and anthropogenic changes. Also, seasonal variations in vegetation introduce further complications, influencing the accuracy of assessments. Finally, the absence of comparable studies in the same region hinders the ability to establish direct comparisons and benchmarks for observed changes. Addressing these multifaceted challenges is crucial for the success and robustness of the study.

The analysis of the obtained results spanning 18 years revealed alarming trends, including a significant loss of 18% of vegetation cover between 2015 and 2021 due to deforestation and urban expansion. The study delineated specific changes in the area, such as a 6% degradation of forest areas (dense and sparse forests), a 24% extension of urbanized areas, a 5% decrease in agricultural areas, and a 13% reduction of bare soil areas. Notably, the decline in agricultural land was linked to urban expansion, driven primarily by forest cover overexploitation and deforestation for tourist infrastructure.

Furthermore, the evaluation of plant chlorophyll activity using the NDVI index indicated a shift in plant conditions, notably experiencing a decline, particularly between 2015 and 2021. This decline suggests a substantial area dominated by severely degraded vegetation, evidenced by NDVI values closely resembling those of bare soil. Parasitic infestations, coupled with elevated pollution levels and soil salinity prevalent in the region, were identified as major contributors to this situation.

In conclusion, this study underscores the efficacy of remote sensing and GIS as formidable tools for scrutinizing vegetation and land use changes. However, the encountered challenges emphasize the need for a comprehensive approach involving technical interventions, measures, and practices to safeguard and rejuvenate vegetation cover in the Sfiha-Swani region.

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