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Spatio-Temporal Dynamics of the Vegetation Cover in a Northern Forest of Morocco: Izarene Forest

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ABSTRACT

The study presents an analysis of the spatiotemporal evolution of vegetation cover in the Izarene forest, using LANDSAT satellite images collected for the years 1984, 2003, and 2022. The methodological approach is based on the use of ArcGIS 10.8 software for processing multispectral images, as well as the calculation of the Normalized Difference Vegetation Index (NDVI), which enables the observation of variations in vegetation cover over time. The findings show that biodiversity is pretty abundant, but they also show that some places with low vegetation density are under a lot of stress. Due in large part to overuse of natural resources, uncontrolled human activity, and environmental factors, these regions seem to be more vulnerable to degradation. However, a decrease in deforestation over the past 20 years is revealed by comparing the two periods (1984–2003 and 2003–2022). The participation of governmental agencies, especially the Department of Water and Forests, through concrete projects like reforestation, forest fire prevention, and awareness-raising campaigns among local communities, is responsible for this progress. In several areas, these measures have stabilized or even improved the state of the vegetation. The analysis emphasizes how crucial sustainable, integrated, and participatory management is to protecting the Izarene forest, which is a significant resource for maintaining the region's ecological balance.

Keywords: Forest; Izarene; Vegetation Cover; Dynamics; Degradation; Morocco

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1. Introduction

The introduction Forests cover a third of the Earth's surface and, by supporting the lives of 1.6 billion individuals, play a crucial role in sustaining life. Indeed, forests harbor 80% of terrestrial biodiversity and serve as a refuge for over half of all invertebrate and vertebrate species on land. Moreover, they protect our soils from erosion, mitigate the consequences of climate warming, provide oxygen, generate a significant portion of human labor, and help feed nearly one billion people[1].

However, worldwide and for several decades, despite their beneficial and vital roles for mankind and the environment, these forests have continuously suffered from actions that threaten their sustainability. These harmful actions, often of anthropic origin, combined with the effects of climate change, exacerbate and accelerate degradation and even deforestation of forest environments.

In the current global context, where natural resources face increasing threats due to both climate change and the consequences of human activities, environmental problems have started to draw the attention of international, national, and even local communities[2].

Forest ecosystems, through their vegetation cover, play a vital role as major absorbers of solar energy and as the most efficient carbon sink for capturing atmospheric CO_2[3]. However, vegetation cover is inherently dynamic: it fluctuates not only seasonally, but also over longer periods. Its development or degradation is closely linked to external influences, whether natural or anthropogenic, which directly affect the hydroclimatic cycle. Understanding the dynamics of vegetation cover is therefore fundamental for the study and management of forest ecosystems.

Similarly, often in a degrading forest, the extent and state of degradation are not the same for all forests. Thus, estimating and monitoring this state or studying forest dynamics is a basic necessity for devising and implementing any strategy aimed at preserving the entire forest[4]. Thus, a better understanding of the dynamics of forest vegetation remains a major concern for the sustainable management of forest ecosystems in semi-arid zones. It allows us to understand the role and benefits of vegetation cover, recognize the specific functions fulfilled by different floristic families, and predict sources of degradation, ultimately informing the development of a protection plan. It is worth noting that one of the main functions of vegetation cover in a forest ecosystem is to reduce erosion, promote carbon storage, improve soil structure, limit the use of inputs, and ensure rational use of forest resources by limiting the impacts on climate change. Vegetation cover also has a profound impact on the course of biogeochemical cycles in the biosphere; it is the first absorber of energy flows received by the sun, which is the only source of energy. Vegetation dynamics is the study of the succession of vegetation cover over time. An understanding of succession is therefore necessary to understand resource protection[3].

Moreover, as with most of the world's forests, despite their essential ecological, economic, and social role, Moroccan forests are undergoing rapid degradation due to human activities (such as overgrazing, tree cutting, and forest fires) and the effects are amplified by climate change. However, in order to improve the ability to anticipate degradation processes and implement sustainable forest management strategies, it is necessary and useful, first of all, to study and understand the dynamics of forest vegetation cover. For this purpose, as noted by Belkaid[5], using the recent evolution of remote sensing, geographic information systems (GIS), and computer technologies, it is now possible to evaluate and monitor the dynamics of vegetation cover and land use at various spatiotemporal scales. This facilitates the analysis of remote sensing data and the use of GIS to identify changes in vegetation condition. In this study, we focus on examining the dynamics of the vegetation cover of the Izarene forest, which is part of the northern Moroccan forest domain. This aim appears useful for contributing to the estimation of degradation evolution in the Moroccan forest domain and, consequently, for better understanding the various facets of Moroccan forest degradation, especially given that Moroccan forest formations face numerous assaults, mainly of anthropogenic origin. According to Alaoui et al.[6], forest ecosystems are primarily negatively affected by overgrazing, deforestation, and fires. However, it should be noted that,to date, few Moroccan forests have benefited from remote monitoring to track their state of evolution or degradation.

2. Materials and Methods

2.1. Study Area

The Izarene Forest, the subject of this study, constitutes a very important national forest heritage that provides the local and national population with a wide variety of products of high economic value. It is located in the Rif Mountains, in the northwest of Morocco, and is bordered to the northwest by the town of Ouezzane, and to the south by the secondary road linking Ouezzane to Zoumi. Most of this forest is located in the Tangier-Tetouan region and is part of the districts of Mokrisset and Ouezzane, including the rural communes of Bni Kolla, Zoumi, and Aïn Beïda. It produces cork, industrial wood, firewood, tannins, medicinal plants, mushrooms and lichens, and is the main source of income for 300,000 inhabitants whose needs are increasing daily and is protected by the Provincial Council of Waters and Forests and the Fight against Desertification, as well as by the DREFLCD in Ouezzane and by the DREFLCD (Regional Directorate of Waters and Forests and Fight against Desertification) of the Rif in Tetouan. Let us add that the Izarene massif is composed of eight surveyed cantons: Izarene (1), Jbel Karker (2), Bousaleh (3), Dhar Douira (4), Dhar Laaroussa (5), Oued Zandoula (6), Mokasseb (7), and Sidi Ali (8), covering a forest area of approximately 11,855 hectares and altitudes ranging from about 350 m to 680 m (**Figure 1**).

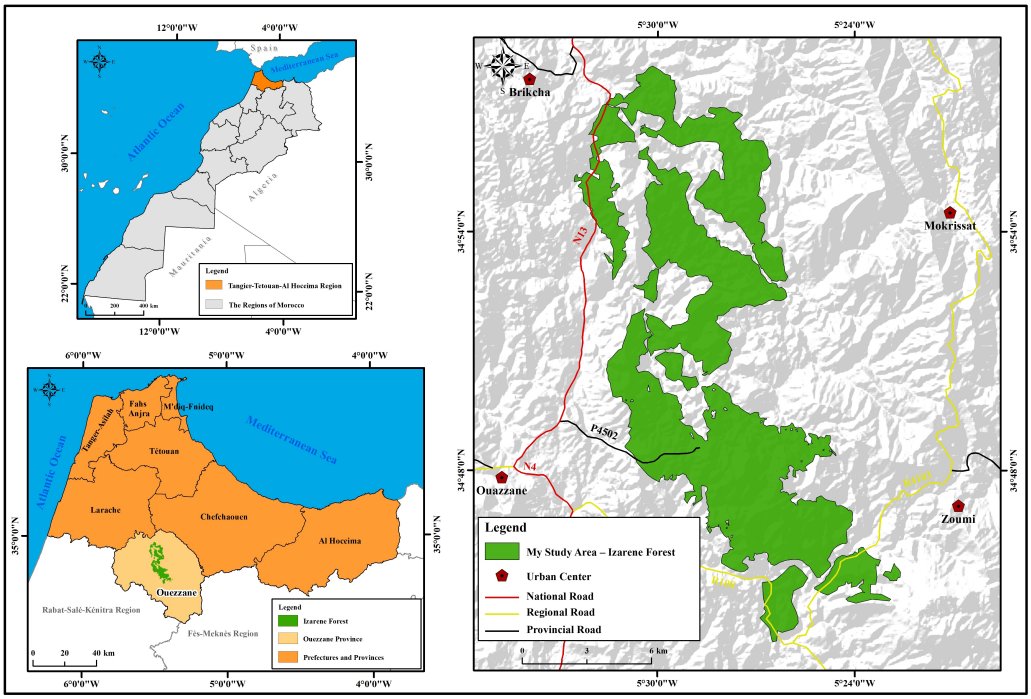


Figure 1. Geographical location of the Izarene forest.

2.2. Study of the Vegetation Cover Structure

The objective of this part of the study is to identify the main plant species that primarily determine the specific structure of the vegetation cover of the forest under study. The methodology chosen to achieve this purpose is the systematic collection and identification of different plants, most often woody, that play a key role in determining the vegetation heterogeneity of the area. So, we selected only the community types of interest to phytosociologists or pastoralists.

2.3. Study of the Dynamics

In this study, we use forest remote sensing techniques across different time periods. In the context of environmental analysis, remote sensing refers to the technology used to detect and record electromagnetic radiation emitted from terrestrial surfaces, oceans, and the atmosphere.

In the environmental context, remote sensing is the technology for recording electromagnetic energies that come from land surfaces, oceans or the atmosphere. With the recent

development of remote sensing, GIS, and computer technology, it is now possible to evaluate and monitor the dynamics of vegetation cover and land use at different spatio-temporal scales[7]. The fields of application of remote sensing have become very varied; there are several types of sensors, with several resolutions: temporal, spectral, and spatial resolution; each platform with its own characteristics is used in a field compatible with these characteristics. Thus, a large number of vegetation indices have been constructed and used for around forty years[8]. They take the form of either very basic expressions (simple difference or simple ratio) or much more complex formulas. The NDVI index, known as the Normalized Difference Vegetation Index, is one of the most widely used indices.

This research focused on the analysis of the diachronic change in vegetation cover by relying on the information provided by the Normalized Difference Vegetation Index (NDVI). This NDVI, also known as the Tucker index, was created by Rouse and Haas (1973) and Tucker (1979). The following equation defines it:

$$NDVI = \frac{(PIR-R)}{PIR+R}$$

where, PIR: Near Infrared; R: Red.

Its values vary from −1 to +1. High values (> 0.3) invariably indicate the presence of vegetation (**Table 1**); the higher these values, the denser the cover. Values below 0.1 indicate less dense covers. Despite NDVI's sensitivity to soil and atmospheric scattering, it remains a good parameter for assessing the amount of vegetation.

Table 1. Classification values according to NDVI[8].

Class	Description	NDVI Value
Bare ground (no vegetation)	Road network, houses, bare ground	−1 to 0.199
Bush	Tropical vegetation composed of shrubs, bushes and herbaceous plants	0.2 to 0.5
Dense vegetation (forest)	An area where the vegetation is very dense	0.5 to 1

The Normalized Difference Vegetation Index (NDVI) is calculated as the difference between the infrared channel (where vegetated surfaces have high reflectance) and the red channel (where mineral surfaces have high reflectance). The resulting channel shows a gradation of vegetation activity that ranges from black (absence of cover) to white (intense chlorophyll activity). NDVI produces an image where each pixel has a value ranging from 0 (no vegetation) to 1 (maximum vegetation). The analysis of the color palette, which spans between these extreme values (which are very rare), informs the observer about the density of the vegetation cover and the amount of green biomass[9–11]. Clouds, water, and snow have a higher reflectance index in the visible spectrum than in the near infrared and a low NDVI. Rocks and bare soil have reflectance indices close to zero[12]. Areas with dense vegetation show NDVI values ranging from 0.6 to more than 1, whereas bare lands approach 0, and water bodies exhibit negative values[10]. Moreover, several studies have shown that NDVI varies according to soil color and moisture conditions, particularly in sparsely vegetated areas[13]. To carry out the spatio-temporal study of vegetation in the Izarene forest, we used three georeferenced multispectral LANDSAT images. The images were acquired respectively on July 17, 1984, July 6, 2003, and July 26, 2022, with cloud cover less than 10%, to ensure data quality. We also used ArcGIS 10.8 software to simplify the visualization, querying, analysis, and organization of geographic data (**Table 2**). The calculation of the Normalized Difference Vegetation Index (NDVI) was performed using the infrared and red spectral bands. The NDVI was calculated on vegetation areas covering an area of 30 m × 30 m, located in the Izarene forest. Atmospheric and geometric preprocessing was applied to ensure the reliability of the results.

Table 2. Satellite image data used for calculating the vegetation cover index (NDVI).

Satellite Type	Product	Date of Capture	Spatial Resolution
LandSat 5	USGS	17/07/1984	30 meters
LandSat 5	USGS	06/07/2003	30 meters
LandSat 8	USGS	26/07/2022	30 meters

This may be an improvement, a decline, or a constancy of the vegetation cover. The acquired images demonstrate, both spatially and quantitatively, the significant vegetation changes that have occurred over time in the study area. The observed changes can be manifested by an advance, a retreat, or a constancy of the vegetation cover.

3. Results and Discussion

3.1. Specific Structure of the Vegetation Cover

Regarding the structure of the vegetation cover, the natural vegetation of the Izarene forest is partly composed of a series of cork oaks occupying the western and southern parts of the forest. Based on the soil characteristics of the different sites, areas with dense cork oak forests, moderate density, and low to very low density have been distinguished [14]. The general characteristics of this vegetation are as follows:

- **Arboreal Stratum:** As shown in the **Figure 2**, this stratum is primarily composed of numerous species, such as Cork Oak (*Quercus suber* and *Quercus faginea*), *Pinus brutia*, *Pinus halepensis*, *Pinus pinaster*, *Pinus mogirabiana*, *Pinus canariensis*, *Eucalyptus gonfo*, *Eucalyptus camaldulensis,* and *Acacia cynaphylla*.
- **Shrub Stratum:** *Erica arborea*, *Arbutus unedo*, *Quercus coccifera*, *Cistus monspeliensis*, *Cistus salviifolius*, *Cistus albidus*, *Myrtus communis*, *Rubus ulmifolius*, *Pistacia lentiscus*, *Phillyrea latifolia*, *Viburnum tinus*, *Rosa sempervirens*, *Crataegus monogyna*, *Rhamnus alaternus*, and *Lonicera implexa*.
- **Herbaceous Stratum:** *Pulicaria odora*, *Ruscus hypophyllum*, *Smilax aspera*, *Brachypodium sylvaticum*, *Poabul bosa*, *Carex distachya*, *Biscutella laevigata*, *Calamintha ascendens*, *Trifolium angustifolium*, *Trifolium campestre*, *Medicago suffruticosa*, *Vicia disperma*, *Agrimonia eupatoria*, *Asplenium dianthumnigrum*, *Geranium rotundifolium*, *Menthapulegium*, *Eryngium tricuspidatum*, *Sherardia arvensis*, and *Hypericum perforatum*.

Reforestation of the massif relies on eucalyptus and various pines (such as *Pinus canariensis*, *Pinus pinaster*, *Pinus brutia*, and *Pinus halepensis*). Secondary species are diversified and include mastic, strawberry tree, Cistus, heather, and Phylale [15].

- **Additional Arboreal Stratum:** *Olea europaea* and *Ceratonia siliqua*.
- **Additional Shrub Stratum:** *Pistacia lentiscus*, *Phillyrea angustifolia*, *Rhamnus alaternus*, *Chamaerops humilis*, *Calycotom villosum*.
- **Additional Herbaceous Stratum:** *Mentha pulegium*, *Arisarum vulgare*, *Rubia peregrina.*

Some Maquis composed of Cistus and Ericaceae are present, replacing the part of the natural vegetation that has been affected by fires. **Figure 2** illustrates the vegetation cover of the Izarene forest showing that Maritime Pine (*Pinus pinaster*) dominates the area, followed by Cork Oak (present in low proportion) in the northern and southern zones. Additionally, *Eucalyptus gonfo* and *Eucalyptus camaldulensis* are present in the southern part of the study area, with diverse vegetation spread throughout the forested zone.

Likewise a predominance of shrubs (secondary species) along the edges, including natural vegetation represented by Dero and Zebboudj (wild olive), basil, and Doum palm, grows almost everywhere, except in areas with acidic soils. This vegetation may spread sporadically or extend over several kilometers. The wild olive (Zebboudj) is pollinated and becomes a source for oil production, facilitating its exploitation by nearby populations for agriculture, grazing, or construction.

Also, it should be noted that the massif has been affected by forest fire episodes since 2004, impacting an area of about 4537.56 ha [16]. The period from June to September is marked by a predominant concentration of these fires, which represent one of the major contributors to the degradation and destruction of forest formations in the region.

As for the density of the vegetation cover of the Izarene forest, the map that resulted from the analysis of Landsat 8 images in 2022 (**Figure 3**) shows that density varies from one zone to another, with areas of low, medium, and high vegetation density. High-density areas are primarily located in topographically elevated zones such as Jbel Mazoura in the south, Jbel Sidi Ali in the center, and Jbel Randa in the northwest. Medium-density vegetation is found in most of the study area, particularly near high-density zones. Low-density vegetation, on the other hand, is located in the oldest mountains and at the forest's periphery, close to inhabited areas.

Note that the expansion of low-density areas occurs at

the expense of the forest. Indeed, most residents in these areas tend to acquire land for their own use, whether for plowing or planting, and later enclose it, incorporating it into private property. Such behaviors contribute to changes in land use, the reduction of vegetation cover, and the decline of forest areas.

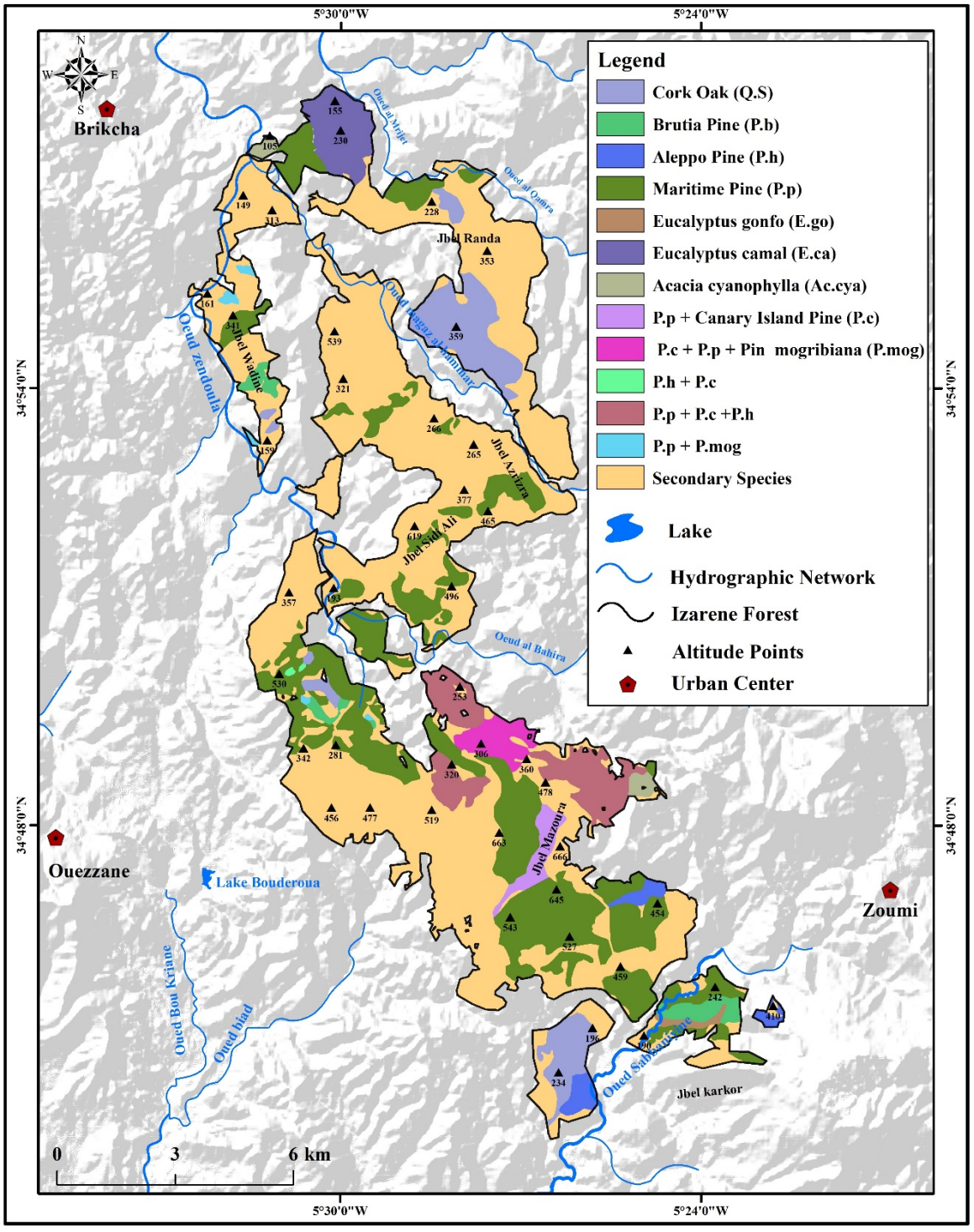


Figure 2. Distribution of vegetation cover in the Izarene forest.

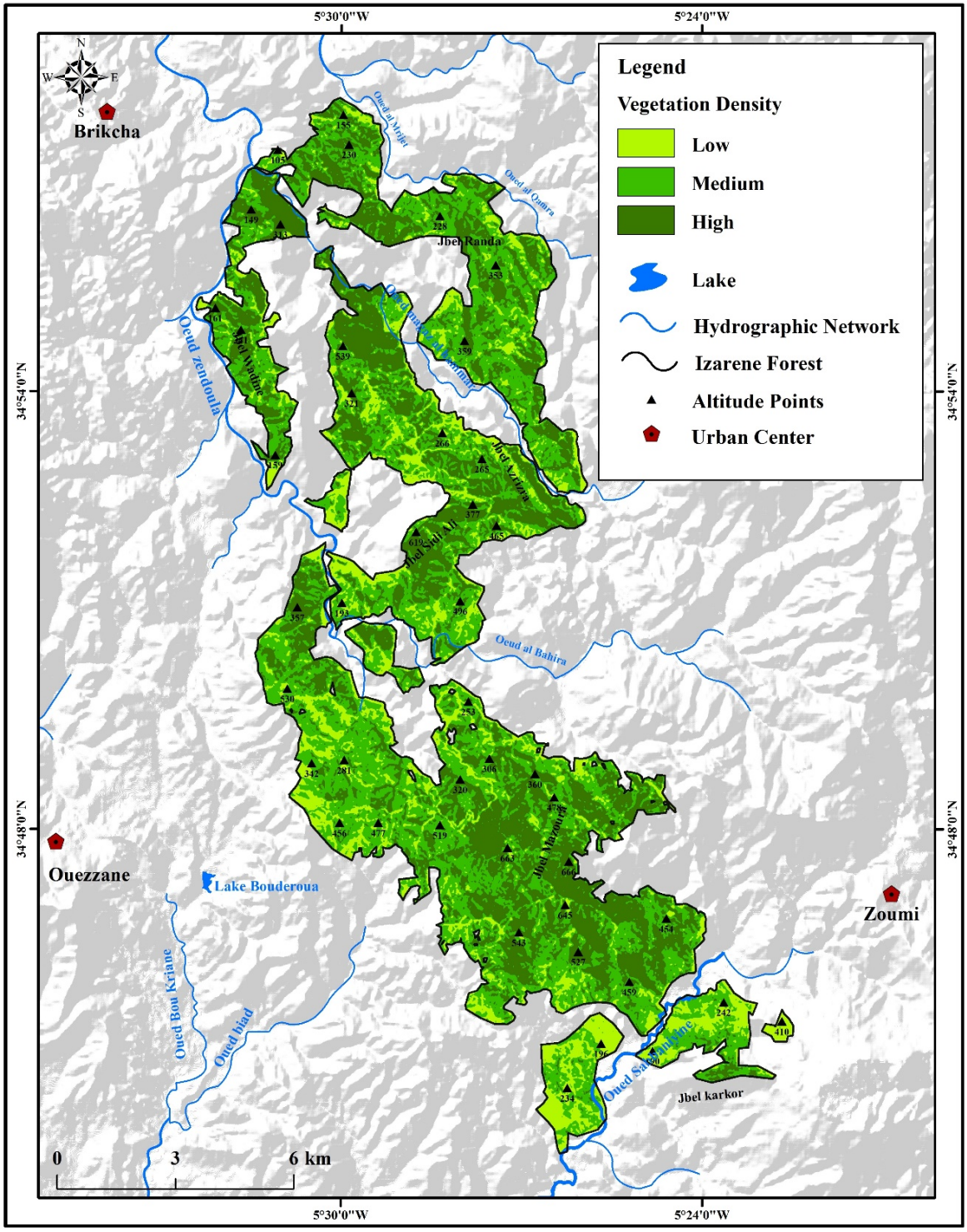


Figure 3. Plant density of the Izarene forest.

3.2. Dynamics of the Izarene Forest (1984–2002 Period)

The analysis of vegetation dynamics underscores the evolving nature of the forest cover. The transformations observed over time are the result of multiple factors [17,18], which can generally be classified into two main categories: endogenous factors, originating from the vegetation itself, and exogenous or ecological factors, driven by external environmental conditions. To examine these dynamics over the period 1984–2022, three satellite maps were analyzed,

illustrating the state of the forest in 1984 (**Figure 4**), 2003 (**Figure 5**), and 2022 (**Figure 6**). These maps were produced from an analysis of Landsat images from 1984, 2003, and 2022.

Moreover, analysis of the three maps allowed us to group the data numerically (**Table 3** and **Figure 7**).

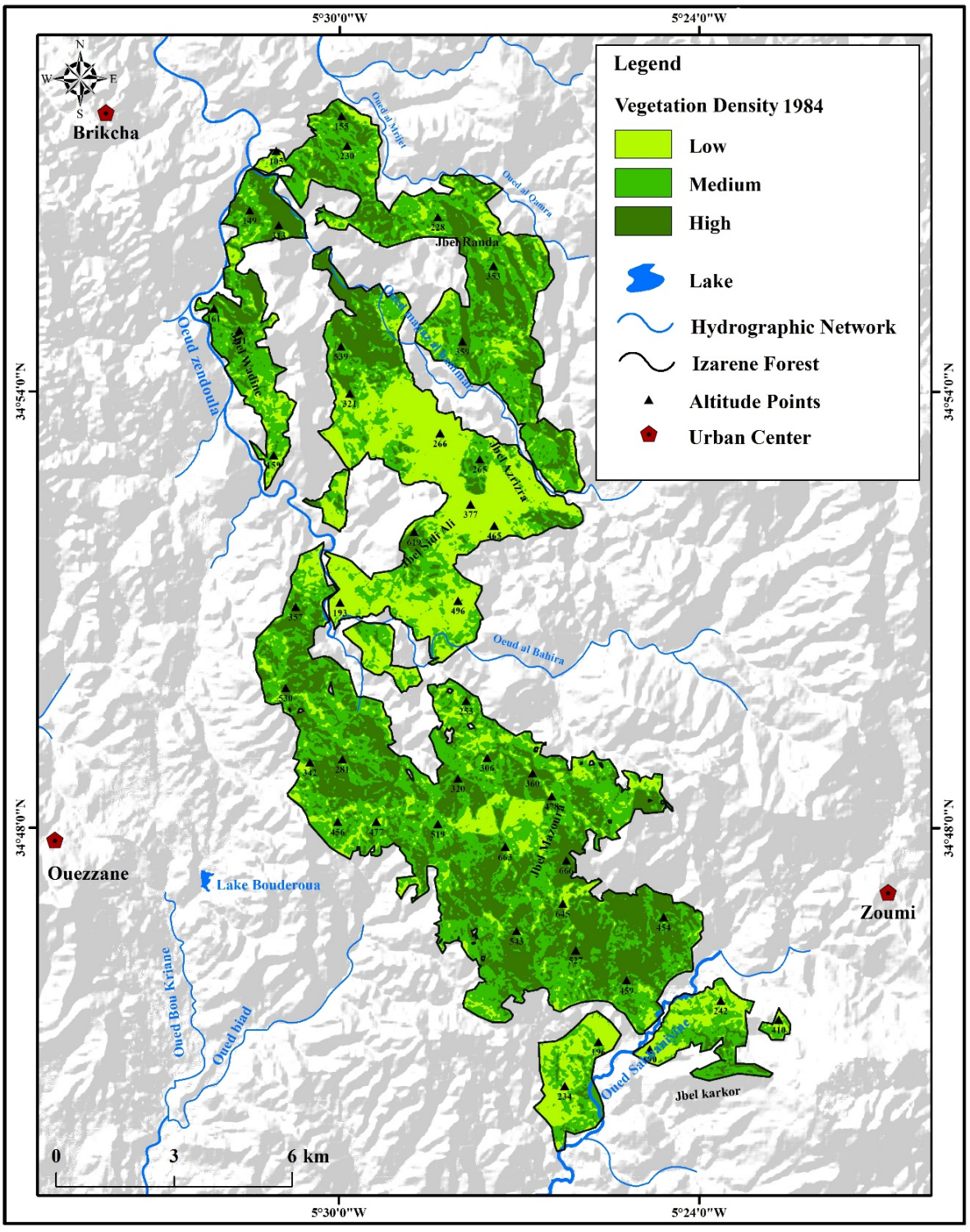


Figure 4. Dynamics of vegetation density in the Izarene forest in 1984.

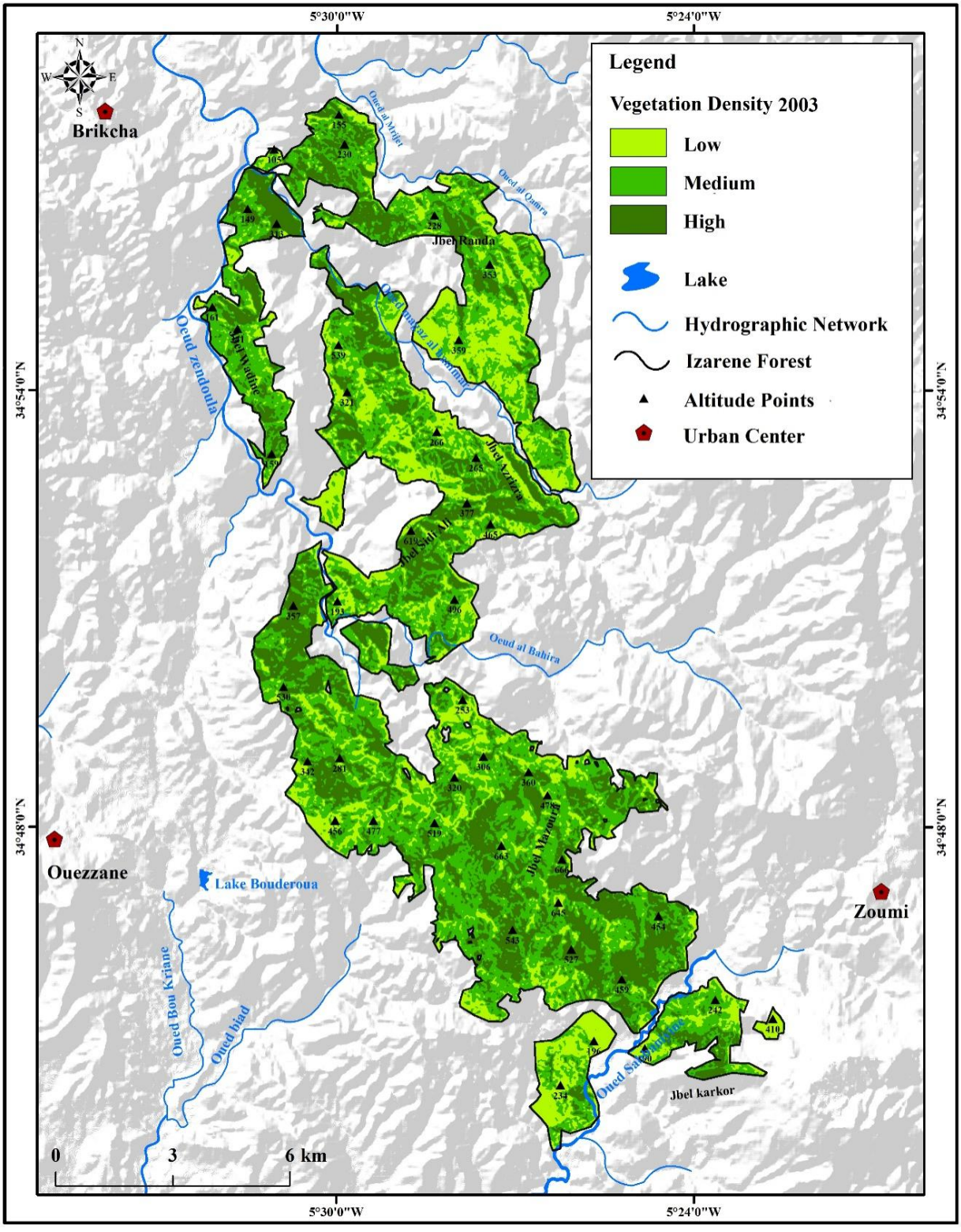


Figure 5. Dynamics of vegetation density in the Izarene forest in 2003.

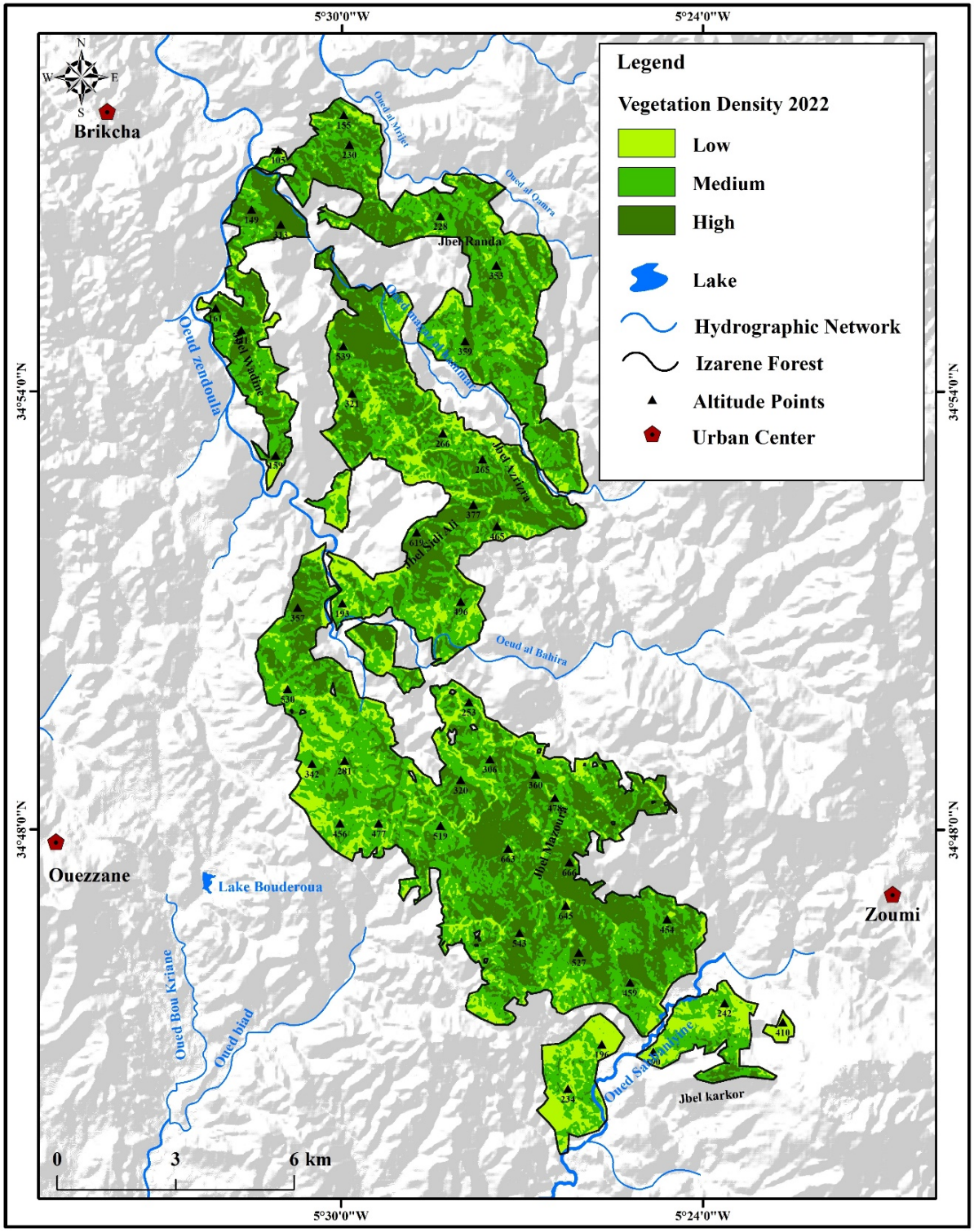


Figure 6. Dynamics of vegetation density in the Izarene forest in 2022.

As shown in **Table 3**, with 41%, 42.5%, and 43.8% of the total covered area in 1984, 2003, and 2022, respectively, medium-density vegetation dominates the forest, and this dominance increased over the 1984–2022 period. Low-density vegetation occupied 28% of the total forest area in 1984, 30% in 2003, and only 21.2% in 2022. High-density vegetation covered 31% of the area in 1984, 26.7% in 2003, and 35% in 2022.

Table 3. Vegetation dynamics between 1984 and 2022.

State of the Vegetation Cover	1984		2003		Variation between 1984–2003 (%)	2022		Variation between 2003–2022 (%)	Variation between 1984–2022 (%)
	Area (km²)	Area (%)	Area (km²)	Area (%)		Area (km²)	Area (%)		
Weak	41	28	45	30.8	+2	31	21.2	−9.6	−6.8
Medium	60	41	62	42.5	+1.5	64	43.8	+1.3	+2.8
High	45	31	39	26.7	−4.3	51	35	+8.3	+4
Total	146	100	146	100	-	146	100	-	-

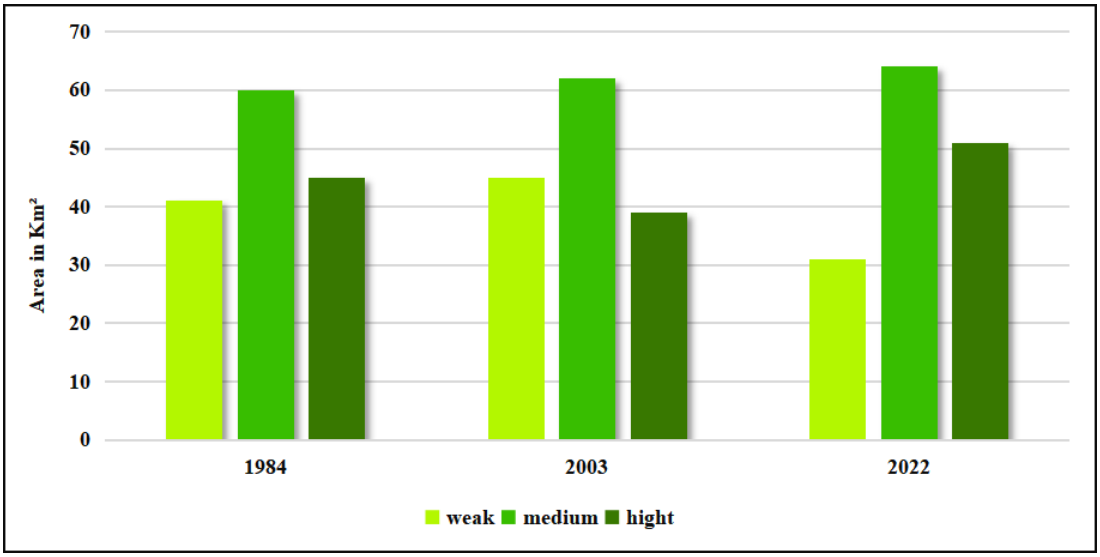


Figure 7. Vegetation dynamics between 1984 and 2022.

Similarly, the frequency distribution of these cover types over the three years (1984, 2003, and 2022) shows that compared to 1984 when 72% of the forest was covered by medium or high density vegetation the condition of the forest slightly degraded, as the high-density portion reduced to 26.7%, even though the overall medium and high-density cover did not change significantly (66.92%). This could indicate a reduction or degradation of the forest during the 1984–2003 period.

In contrast, in 2022, compared to the states in 1984 and 2003, the distribution of vegetation cover types based on density indicates an improvement and recovery of the Izarene forest, likely due to significant restoration efforts undertaken during 2003/2022 by the State and the Directorate of Waters and Forests [6,19–22], especially regarding reforestation, fire prevention, and public awareness.

Furthermore, as with other Rif forest ecosystems, the Izarene forest is subject to multiple anthropogenic pressures [23]. In addition to recurrent fires [6], decreased and irregular rainfall and increased temperatures [23], various human activities such as overgrazing and land clearing [24] contribute to the overexploitation of natural forest resources. As noted in various ecological studies [25–28], these short-term anthropogenic actions are generally responsible for reducing the density and biodiversity of vegetation, and in the long term, they could be the primary cause of forest retreat [29]. It is important to note that the impact of these factors, and their combinations, can vary from forest to forest, depending on local practices and human constraints [30,31]. Additionally, topography, soil type, climate, and climate change are determining factors for the spatial variation in vegetation cover density and dynamics. Moreover, the vegetation cover of the Izarene forest, characterized by a varied associated flora, is dominated by cork oak at various stages of degradation [32]. It experiences a subhumid climate with mild winters, with average annual precipitation of approximately 1000 mm over about 70 days (from November to April). A nearly frost-free, very humid winter follows a dry and hot period of 3 to 4 months [33]. However, the extent and frequency of drought, estimated using the Standardized Precipitation Index (SPI),

differ between the 1984–2003 and 2003–2022 periods. Combined with more intense fire prevention and restoration efforts during 2003–2022, these factors suggest a measure of success in reducing forest degradation in the studied area, although further data is required.

3.3. Estimation of Forest Degradation Based on Vegetation Dynamics

Forests and their products play a central role in addressing crucial economic, social, and environmental challenges. They harbor 80% of terrestrial biodiversity [34], contribute to water purification by absorbing and storing CO_2, and help maintain soil fertility. In order to use forest resources wisely while minimizing the effects of climate change, understanding vegetation dynamics is essential. Sustainable forest management fulfills multiple socio-economic and environmental roles at international, national, and local levels, and is vital for sustainable development. Access to accurate and current information about forest resources is crucial for guiding policies, forestry programs, and development decisions.

Regarding the estimation of degradation in the Izarene forest, results were obtained by analyzing three satellite images representing the forest's state in 1984, 2003, and 2022.

For the negative stable zone, **Table 4** and the associated graphical illustrations for 1984, 2003, and 2022 show that the 1984–2003 period recorded the largest area of the negative stable zone with 11.64% of the total area. In the stable positive zone, the area covered was 61.64% for 1984/2003, 72.60% for 2003–2022, and 63.01% for 1984–2022. This variation indicates an improvement in the stable positive zone during 2003–2022. Conversely, the (growth zone) area was higher during 1984–2003 (17.12%) and lower during 2003/2022 (10.27%).

Table 4. Importance of different degradation states in various areas of the Izarene forest.

Status of Different Types of Forest Areas	State of Degradation of the Izarene Forest					
	Area between 1984/2003		Area between 2003/2022		Difference in Areas between 1984/2003 and 2003/2022	
	In km^2	In %	In km^2	In %	In km^2	In %
Negative stable zone	17	11.64	15	10.27	14	9.58
Positive stable zone	90	61.64	106	72.60	92	63.01
Growth zone	25	17.12	15	10.27	28	19.17
Degradation zone	14	9.58	10	6.84	12	8.22
TOTAL	**146**	**100**	**146**	**100**	**146**	**100**

Regarding overall degradation, the most significant degradation zone covered 9.56% of the total area during 1984/2003 (**Figures 8** and **9**) and only 6.84% during 2003/2022 (**Figures 10** and **11**). However, over the entire 38-year period 1984–2022 (**Figures 12** and **13**), 8.22% of the forest area was classified as degraded, indicating a risk of accelerated degradation that threatens forest sustainability.

There is a correspondence between the total area covered by medium (31%) or high (41%) density vegetation, representing 72% of the total area, and the significant area of the stable positive zone (61.64%) along with the growth zone (17.12%), totaling 78.72% of the overall area. Similarly, the total area covered by medium (43.8%) or high (35%) density vegetation (representing 78.8% of the total area) corresponds with the stable positive (72.60%) and growth (10.27%) zones, totaling 82.87% of the area. This correspondence could confirm the findings of Dahan et al. [35], Laaribya et al. [36], and Faye et al. [37], who indicated that forest degradation generally occurs more readily in areas with lower vegetation density. Additionally, these low-density areas are more easily exploited by local populations for building, livestock enclosures, or agricultural purposes. It should be noted that, according to many authors [35–37], factors influencing vegetation dynamics include both endogenous (arising from the vegetation itself) and exogenous (external) factors. Endogenous succession involves soil transformation and microclimate changes, whereas exogenous succession includes variations in general climate, microclimate, soil, animal population density, and human activity. Thus, for well-founded conclusions regarding both degradation and improvement factors in the Izarène forest, field surveys and observations are essential.

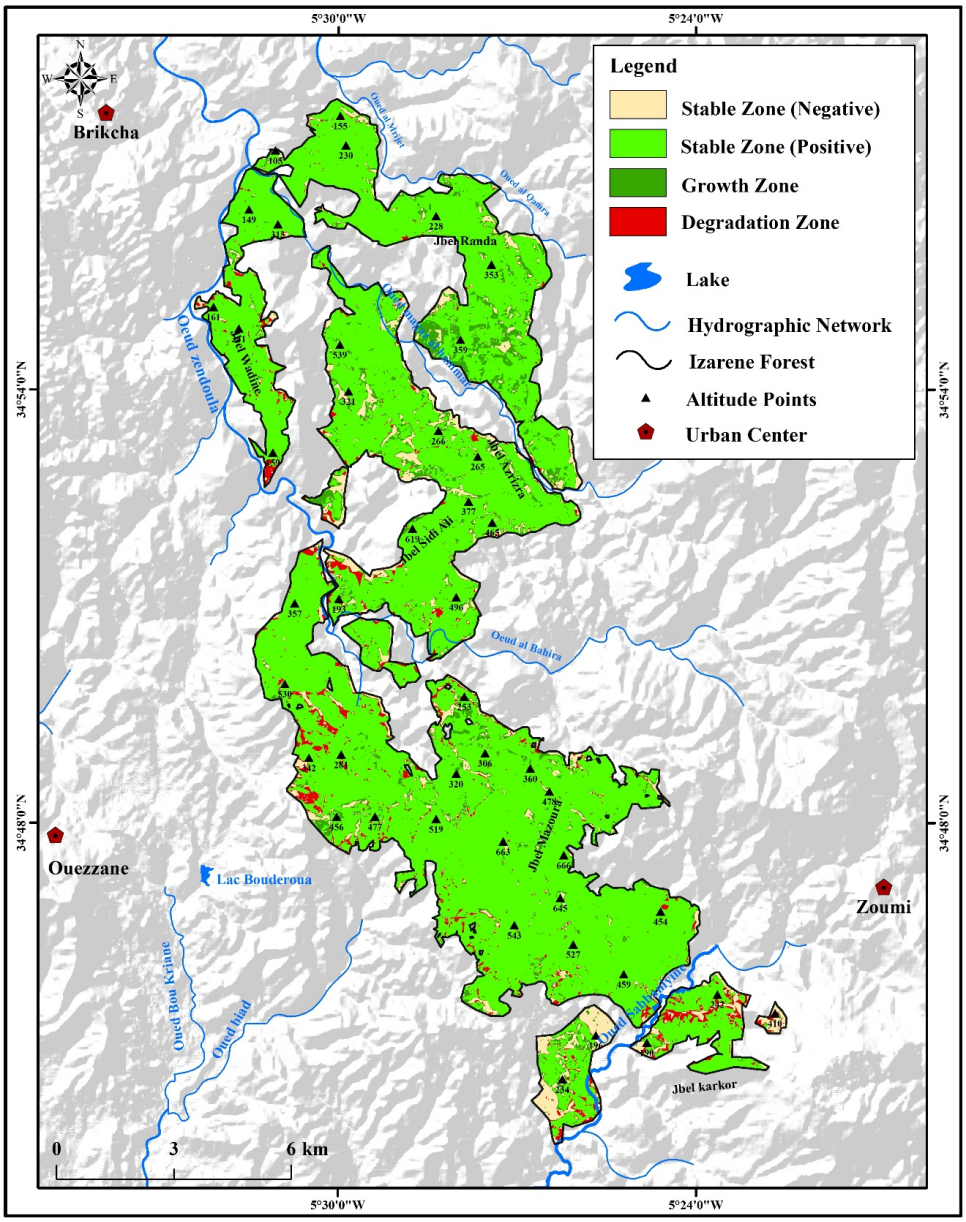


Figure 8. Vegetation degradation between 1984 and 2003.

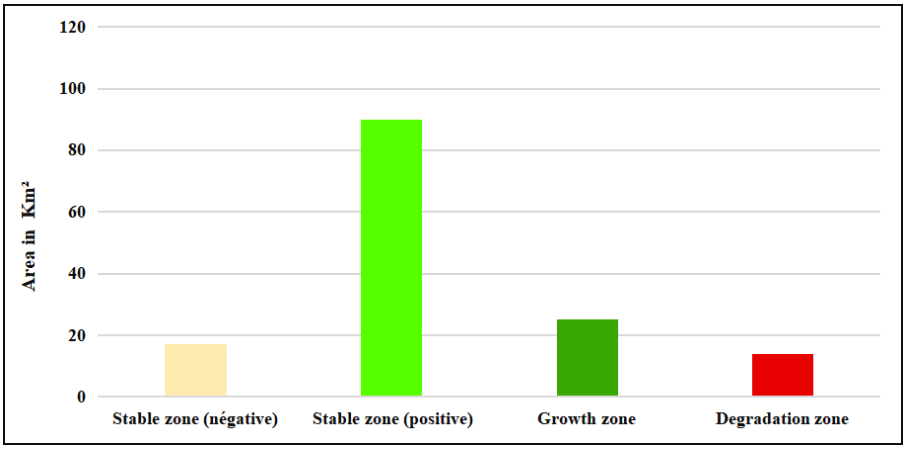


Figure 9. Vegetation degradation between 1984 and 2003.

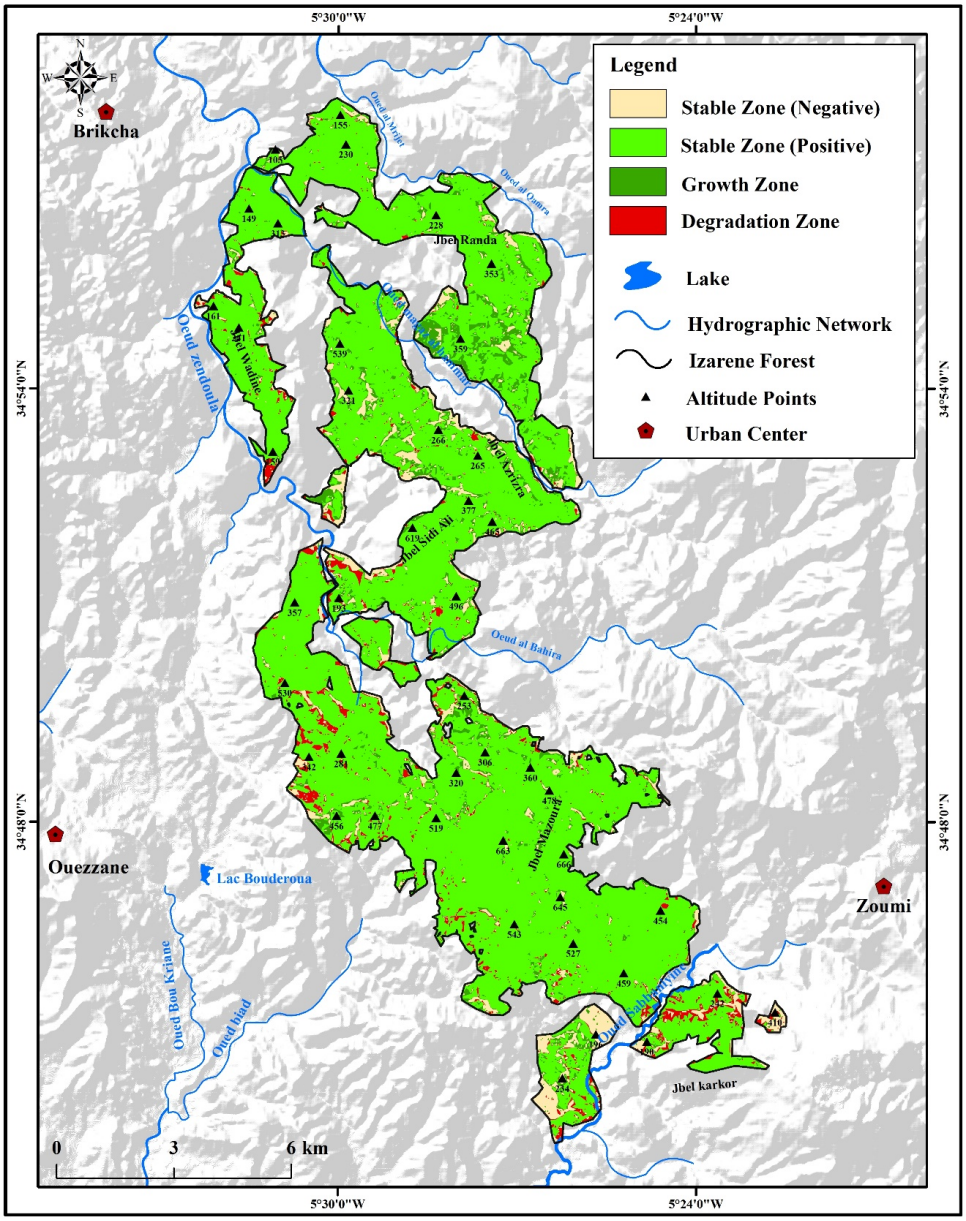


Figure 10. Vegetation degradation between 2003 and 2022.

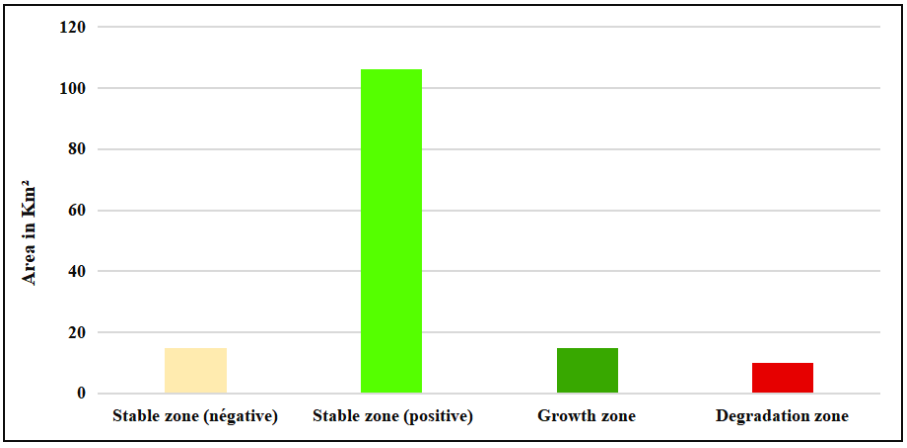


Figure 11. Vegetation degradation between 2003 and 2022.

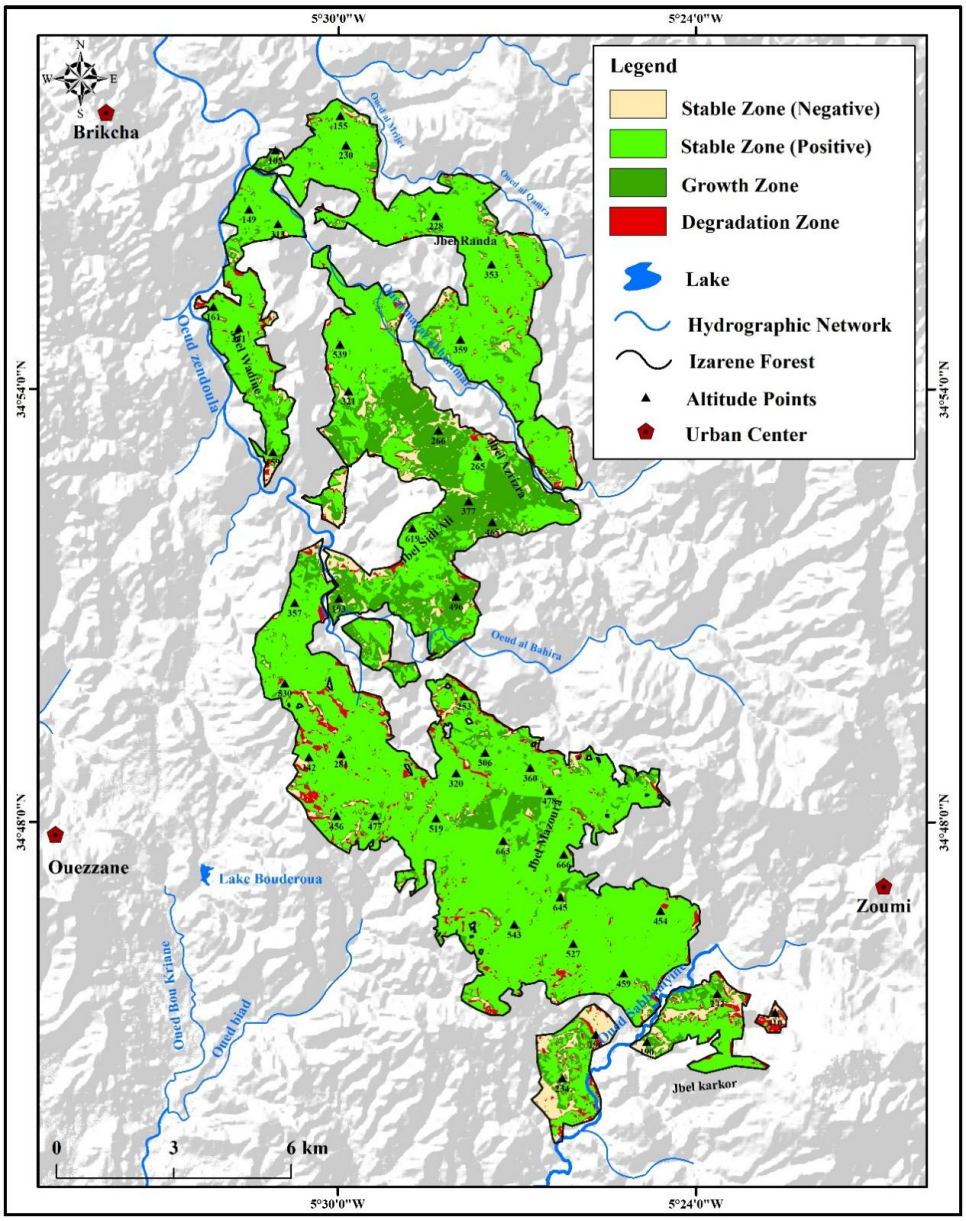


Figure 12. Vegetation degradation between 1984 and 2022.

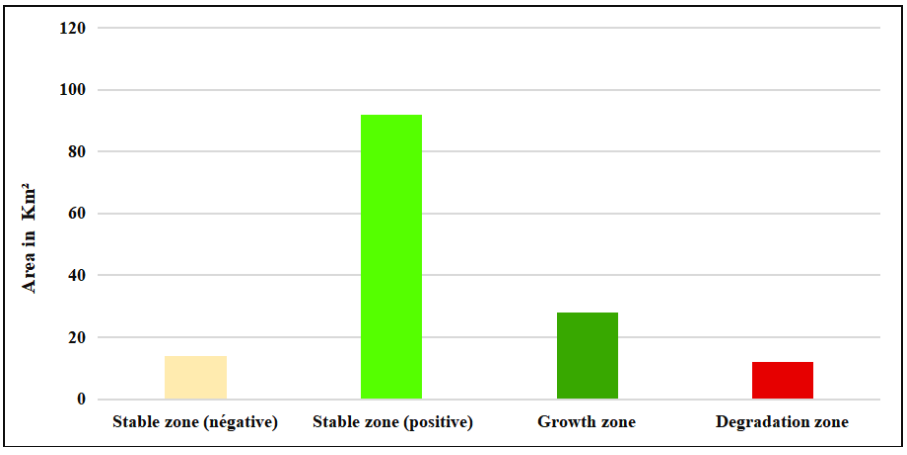


Figure 13. Vegetation degradation between 1984 and 2022.

Furthermore, it is crucial that the change in climatic conditions observed over the past several decades is often accompanied by a decrease in rainfall, both in quality and duration[38]. Its effects affect the quality and quantity of natural resources and accentuate the impacts of human actions on the environment[2].

Thus, forests, which normally play a crucial role in regulating their environment's ecological balance, are facing significant threats. Indeed, these climatic events, often the cause of disasters, could occur more frequently in the future, including excessive droughts, higher temperatures, and overexploitation of forests, which can lead to irreversible degradation of the forest ecosystem. Thus, there is great interest in studying the dynamics of plant cover given the roles it provides to ecosystems, while constituting the first absorber of energy flows received by the sun, the best carbon sinks for storing CO_2 found in the atmosphere[3].

Furthermore, forest cover changes are largely influenced by natural factors, while increasingly impacted by human activities, including sociodemographic factors. These factors include population growth, housing density, the geographic distribution of inhabitants, sources of income, and urban planning.

Rapid population growth is one of the main contributors to deforestation. In several regions such as sub-Saharan Africa, Southeast Asia, and Latin America, population expansion is putting increasing pressure on forest resources. The growing demand for agricultural land is pushing rural communities to convert forests into arable land or pastureland. Moreover, urban growth, combined with rural-to-urban migration and population expansion in urban areas, is causing artificial soil modification, which in turn reduces forest area.

Population density also impacts forest degradation or regeneration. In densely populated areas, the frequent use of wood for activities such as construction, heating, and cooking leads to rapid deforestation.

Similarly, social factors such as education levels, income, and access to services also impact forest management. However, in communities heavily affected by poverty, the need for immediate subsistence takes precedence over resource conservation, favoring unsustainable logging.

The significant impact of public policies and social organization is also noteworthy. Land tenure systems, recognition of the rights of indigenous communities, and decentralization policies can promote more responsible forest management.

Regarding the current state of the forest, even though the rate of deforestation is slowing down, forest ecosystems remain subject to pressure from climate-related stressors, and the demand for forest products continues to increase[39].

Finally, migration, whether within the country or abroad, also influences the stress placed on forest ecosystems. Demographic instability, whether resulting from conflicts, natural disasters, or economic transformations, frequently leads to the creation of new cultivated or forested areas in previously protected regions. These actions can also affect traditional forest management structures.

In short, the study of forest cover dynamics cannot be conducted without considering the socio-demographic context. All forest ecosystems are influenced by factors such as population growth, population concentration, poverty levels, cultural customs, and government initiatives. It is therefore crucial to adopt a comprehensive approach that integrates both environmental issues and human contexts in order to sustainably maintain our forests.

Regarding demographic aspects, the Izarene Forest has undergone significant demographic changes over the decades. Once sparsely populated, this wooded region primarily attracted rural communities who subsisted on agriculture, livestock rearing, and harvesting. Until the mid-20th century, settlements were scattered, consisting of small hamlets at the edges of the forest. However, from the 1970s onwards, several factors contributed to a progressive densification: population growth through natural reproduction, the extension of rural roads, and the rise of crops intended for survival and trade.

Over time, excessive logging and intensive overgrazing have increased the pressure on forest resources. This has led to a gradual degradation of forest cover, disrupting ecological balances. Despite reforestation and sustainable management initiatives, human population growth continues, often in the absence of adequate spatial planning. Currently, the Izarene Forest perfectly illustrates the tensions between human expansion and environmental protection. It underscores the imperative of a comprehensive strategy to reconcile the needs of local communities with the preservation of natural heritage.

Regarding the degradation of the undergrowth and the

reduction in tree density in certain areas of the forest, one of the main causes is the direct use of this undergrowth for cooking or the cutting of trees for charcoal production. Making renewable energy production available to the population, such as from heronian sources, could contribute to maintaining forest density. However, in the area studied, the use of wind, water, or the sun as energy resources remains underdeveloped[40].

Furthermore, Morocco, which recognizes the importance of its forests for sustainable development, biodiversity conservation, and combating desertification, has established a robust legal framework to protect its forests. These regulations, which have evolved over more than a hundred years, seek to balance the preservation of forest ecosystems with the socioeconomic demands of local communities. Based on official texts and national strategies, we examine the main laws and regulations concerning forest preservation in Morocco.

These include:

- Decree of October 10, 1917. This decree serves as the legal basis for the administration of state-owned forests and the user rights granted to local communities.
- Decree of March 4, 1925: This text, revised by the decree of March 28, 1951, regulates the management and preservation of argan forests.
- Law No. 1-76-350, promulgated by decree on September 20, 1976: This text outlines the involvement of local communities in the development of the forest economy. It supports a collaborative management approach by encouraging the establishment of cooperatives and pastoral associations to structure users and empower communities in forest preservation.
- Decree of March 21, 2002: This defines the conditions for compensation for beneficiaries, ensuring a balance between ecosystem protection and the demands of local communities.
- Decree of May 12, 2003: This text establishes fundamental standards for the protection and enhancement of the environment, including forests.
- Law No. 29-05 of 2011: This legislation concerns the protection of natural fauna and flora species and the regulation of their trade.
- Proposed law for 2023. This bill, presented by the Minister of Agriculture, Mohammed Sadiki, introduces a new legal framework for forest protection. It penalizes forest offenses (illegal logging, intentional fires), supervises resource exploitation, and prohibits the use of fire in forests from June 1 to October 31, a period of high fire risk.

In addition to adopting laws, Morocco has implemented national plans to strengthen the protection of its forests:

- Ten-year program (2005–2014): This project aimed to rehabilitate 20,000 hectares of corkoak in the Maâmoura forest, ensure land tenure security in forested areas, and raise awareness among local stakeholders.
- "Forests of Morocco" Plan (2020–2030): This plan is based on four pillars: the involvement of local communities in management, the updating of forest roles, private sector engagement, and institutional change, which includes the creation of two organizations dedicated to forest and national park management.
- Strategic Plan for Fire Prevention and Control: This program focuses on anticipating fire hazards, establishing preventive measures (such as banning fires during the summer months), and collaborating with authorities to minimize damage.

4. Conclusion

A thorough understanding of the biological dynamics of the Izarene forest has been made possible by the spatiotemporal study of the vegetation cover, which was based on NDVI data from LANDSAT satellite imagery between 1984 and 2022. The findings unequivocally show that substantial portions of the forest have remained deteriorated for decades, despite the woodland's remarkable variety and species richness. These results emphasize the forest ecosystem susceptibility, especially in areas with low vegetation densities and higher levels of human demand. Comparing the two primary time periods, 1984–2003 and 2003–2022, however, indicates a noteworthy trend: a recent reduction in the rate of degradation. This development is the direct outcome of deliberate efforts made by government agencies, especially the Directorate of Waters and Forests; it is not a coincidence. Projects, including awareness campaigns aimed at local populations, fire control techniques, and reforestation projects have begun to show noticeable results. Even while this progress is still in its infancy, it is a significant one. It shows how vulnerable forest ecosystems

may be restored or at least stabilized by concerted efforts, governmental will, and community involvement. Thus, the woodland of Izarene serves both a cautionary tale and a testament to resiliency. Its future now hinges on sustaining, bolstering, and growing the efforts already made—in the direction of a sustainable forest management model that strikes a balance between conservation and the requirements of present and future generations.

Author Contributions

Conceptualization, F.-Z.E. and S.L.; methodology, F.-Z.E. and S.L.; software, F.-Z.E. and S.L.; validation, F.-Z.E. and S.L.; formal analysis, F.-Z.E. and S.L.; investigation, F.-Z.E. and S.L.; resources, F.-Z.E. and S.L.; data curation, F.-Z.E. and S.L.; writing—original draft preparation, F.-Z.E. and S.L.; writing—review and editing, F.-Z.E. and S.L.; visualization, F.-Z.E. and S.L.; supervision, F.-Z.E. and S.L.; project administration, F.-Z.E. and S.L.; funding acquisition, F.-Z.E. and S.L. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare that there is no conflict of interest.

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