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Impact of urban dynamics and climate change on forest areas the Maamora forest in the city of Kenitra, Morocco

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Abstract Studies have focused on the issue of drought on one hand, and urban dynamics on the other, as prominent topics in physical geography for the former, which specializes in climate change, and human geography for the latter, which concerns field sciences. This research is part of a series of studies and specifically relates to a wetland area in the western plain, specifically Maamora Forest in the city of Kenitra. This research addresses three main axes: the first axis relates to human factors contributing to the reduction and deterioration of Maamora Forest over the past three decades and analyzes their impact on the forest. This is done by determining the development and dynamics of cork oak through remote sensing data, manifested in the analysis of aerial images from three different periods (1975, 1995, and 2022), complemented by field research throughout the period between 2022 and 2023. The second axis focuses on studying climatic data for the studied area, extending from 1987 to 2019. It highlights the manifestations of climate change, such as a decrease in annual precipitation and an increase in temperatures, and their impacts on the overall forest and specifically on cork oak trees. This is done using the LANG equation. The results indicate that the region has experienced four dry periods, accounting for 87.5% of the total 28 years, which range from 1987/1988 to 1995/1994, 1997/1998 to 2010/2011, 2012/2013 to 2014/2015, and 2016/2017 to 2018/2019. In contrast, the percentage of semi-humid and extremely dry years only accounted for 6.25% each, with an average duration of two years. The third axis relates to monitoring the effects of climate change on the forestry sector, specifically the Maamora Forest, through the use of modern techniques such as remote sensing and spectral plant and water indicators. It aims to understand the role of these technologies in spatial monitoring of factors and phenomena that negatively impact forest areas in general, and the Maamora Forest in particular.

Keywords: urban dynamics, climate change, spectral indicators, Maamora Forest

1. Introduction

In the environmental field, the forest contributes to protecting the soil from erosion and desertification, and absorbs carbon dioxide (Karsenty and Pirard, 2007). It also contributes to the preservation of biodiversity (Slim et al., 2015). It plays an important role in structuring the natural landscape (Benissa et al., 2022). Therefore, it serves as a habitat and fertile land for wildlife, as well as an invaluable genetic repository (Laurance, 1999).

In Morocco, the forest cover spans several geographical areas, particularly the Middle Atlas, High Atlas, Rif, and some coastal regions. It also varies in terms of dominant plant species, and the Maamora Forest is one of the forest areas abundant in Morocco. This forest, which forms the "green lung" for the inhabitants of the Rabat-Salé-Kénitra region, plays an undeniable environmental role. On the other hand, like all forests, the Maamora Forest, which is considered the largest cork oak forest in the world and covers 15% of the total area covered by this tree globally (Alahoual, et al., 2022), has experienced significant deterioration under the threat of various factors that undermine its potential, leading to a decrease in its area and the desertification of the cork oak environment. In this regard, the aim of this study is to identify the climate changes experienced by the city of Kenitra between the years 1975, 1995, and 2022 and analyze their impact on the Maamora Forest, while determining the development and dynamics of the cork oak, using remote sensing and geographic information system techniques, and then studying climatic data in the area from 1987 to 2019, highlighting the aspects of climate change manifested in the decline of annual precipitation and the increase in average annual temperatures.

1.1. The problem of studying

Is there a reduction in the area of Maamora Forest through the processing of aerial images for three different periods (1975, 1995, and 2022)?

How does urban dynamics affect the deterioration of Maamora Forest in general? And the deterioration of cork oak trees in particular?

Did rainfall values remain stable? Or were there changes during the three decades under study?

Did climate changes, especially precipitation and temperature elements, affect the characteristics of Maamora forest? What are those changes? And what are their effects on the studied forest area?

1.2. Study hypotheses

- There are statistically significant differences in the averages of annual rainfall during the studied periods.
- There are statistically significant differences in the averages of annual temperature during the studied periods.

2. Materials and Methods

2.1. Geographical location of Maamora Forest

The Maamora forest (Figure 1) is located in the northwest of Morocco, extending in a rectangular shape with a length of 70 km from west to east, and a width of 40 km from north to south, between the longitude lines 6°.00' and 6°.45' west of Greenwich, and the latitude lines 34°.00' and 34°.25' north of the equator. Maamora belongs to the Rabat-Sale-Kenitra region, stretching from the Atlantic Ocean in the west, separated by sand dunes, to Wadi Buht in the east; and from Wadi Abi-Raqraq in the south to the western plain in the north. It is one of the most important forests in Morocco in general, and in the Rabat-Sale-Kenitra region in particular, covering an estimated area of 131,020 hectares. As for the geographical location of sector A, it belongs to Western Maamora, which in turn belongs to the administrative borders of the city of Kenitra and Sale-Rabat. It is located between the longitude lines 6°30' and 6°45' west of Greenwich, and between the latitude lines 34° and 34°15' north of the equator. In terms of the bioclimatic location, sector A of the Maamora forest is located in a semi-humid bioclimate with a moderate to hot winter, where the average annual rainfall reaches 600 mm.

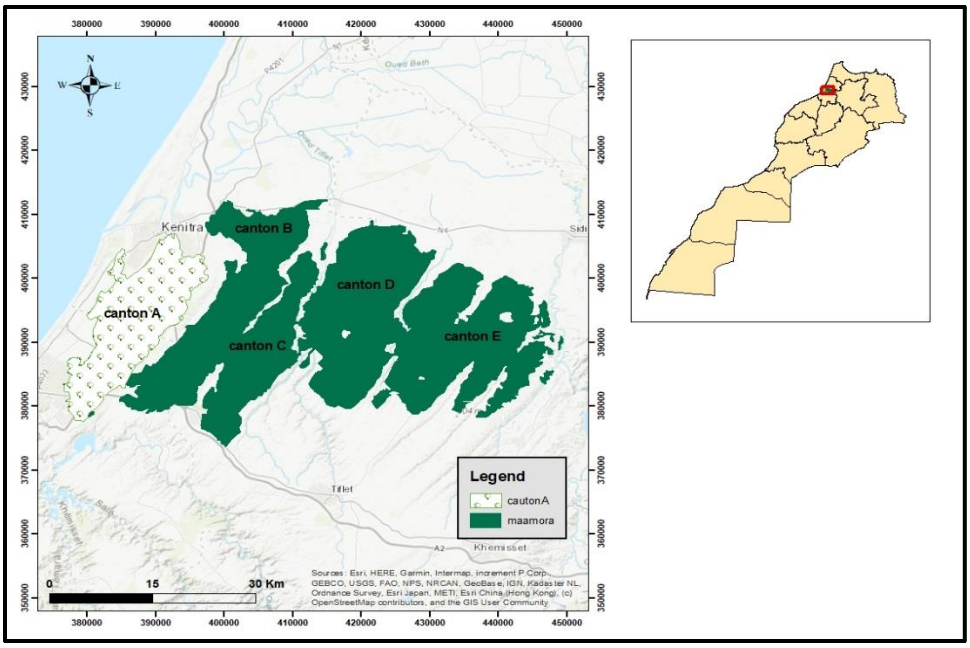

Figure 1 Geographical location of Maamora Forest.
Source: Personal achievement based on topographic maps of Rabat, Fdala, and Fez, scale 1/ 250,000.

Considering that biodiversity in Morocco faces various threats, including human activities such as overgrazing and urban expansion, as well as natural causes such as climate change, parasites, desertification, and the decline of plant formations (Allali, 2022), the Maamora Forest has also not been spared from these factors that have contributed and continue to contribute to the deterioration of a number of plant species within it, with cork oak trees being at the forefront.

And since the Maamora Forest is located in an area that includes the administrative capital Rabat, which is known for its demographic and urban development, as it has depleted its real estate assets, not to mention the economic growth and urban expansion that the city of Kenitra and the population growth that the city of Salé are experiencing. The residents of both cities also take advantage of the forest space for recreation, which is followed by many behaviors that negatively affect the sustainable development of the forest.

All of these factors make those interested in environmental affairs and public and semi-public administrations responsible for managing city affairs, as well as civil society, search for ways to confront them in order to preserve this natural heritage. Hence, the role of geographic information systems and remote sensing comes into play in monitoring the deterioration that the forest has experienced over the past forty years, as well as the impact of climate change on cork oak trees.

3. Results

3.1. The forest cover area in Maamora Forest decreased between the years 1975 and 1990 and 2022.

By processing and analyzing satellite imagery from Landsat satellite for the years 1975, 1990, and 2022 in the Geographic Information Systems (GIS) software ArcGIS 10.3, using the unsupervised classification, it was found that the forest cover in Maamora forest decreased by approximately 56.08% between the years 1975 and 2022 (Figure 2). The number of pixels representing the forest cover was around 278,810 cells in 1975, which decreased to around 145,199 cells in 1990, and reached around 122,443 cells in 2022 (Figure 3). This decrease can be attributed to several factors, both human-induced and natural.

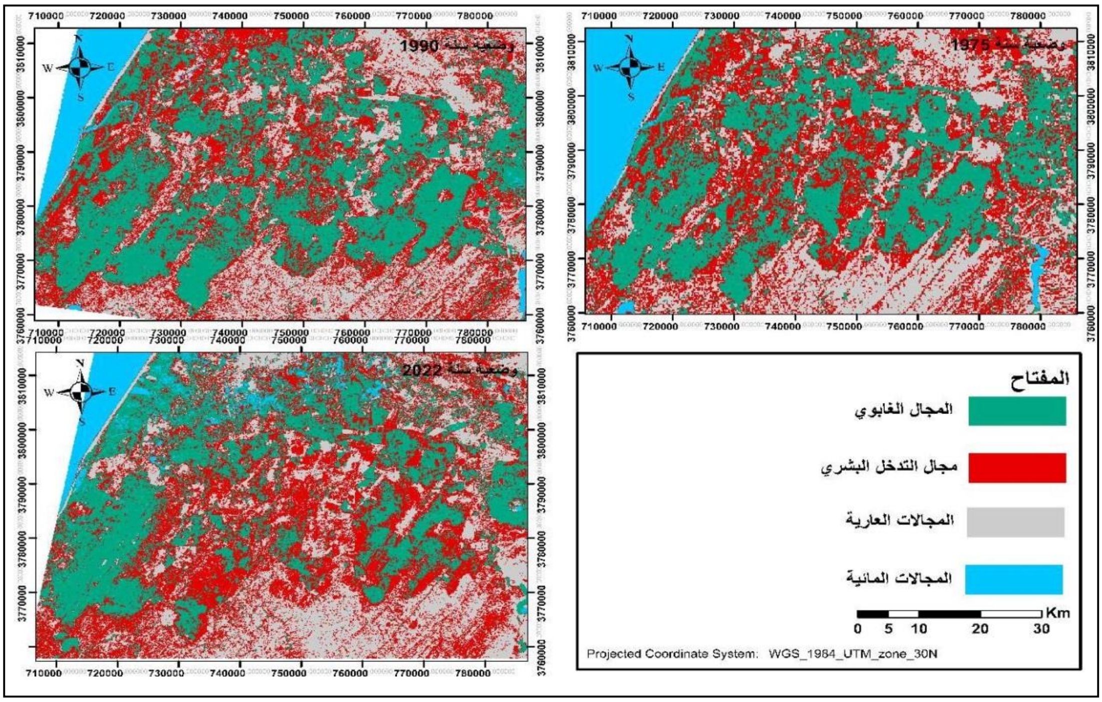

Figure 2 The forest cover decline for the Maamora Forest between the years 1975, 1990, and 2022.
Source: A personal work based on the analysis of satellite imagery from the Landsat satellite provided by the US Geological Survey can be found at https://earthexplorer.usgs.gov.

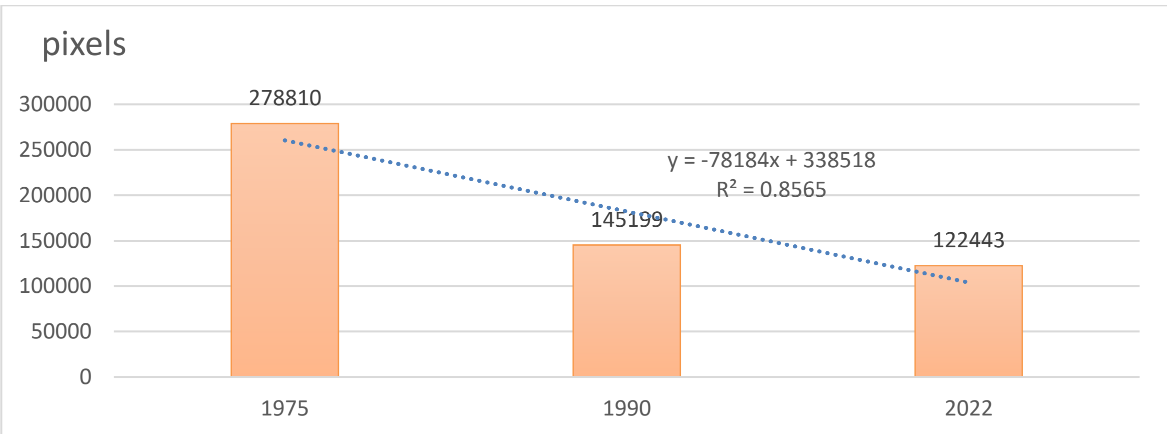

Figure 3 The number of cells representing the forest cover of the Maamora forest declined during the years 1975, 1990, and 2022.

3.2. Forms of human interventions that led to the deterioration of the Maamora forest

- The demographic factor: The demographic pressure in western Maamora is increasing, and this population growth does not align with the needs. Therefore, forest exploitation becomes part of the population's way of life, which has negative effects on the ecosystem.
- Illegal exploitation of cork oak trees: This process is carried out by residents living near the forest, as all their needs for cooking and heating wood are met by cutting down deteriorating wood from the forest, which has a negative impact on an important ecological resource.
- Overgrazing: Approximately 200,000 sheep and 50,000 cattle graze in the forest annually, which constitutes a heavy grazing load that the forest cannot sustain.

3.3. Climate change manifestations observed in the studied region.

3.3.1. Annual average precipitation

Results from Figure 4 indicate that the average amount of rainfall in this area between the years 1987 and 2019 was 459.65 mm, with the highest amount recorded in 1995/1996 reaching 895.30 mm, while the lowest value was 129.5 mm during the year 2011/2012.

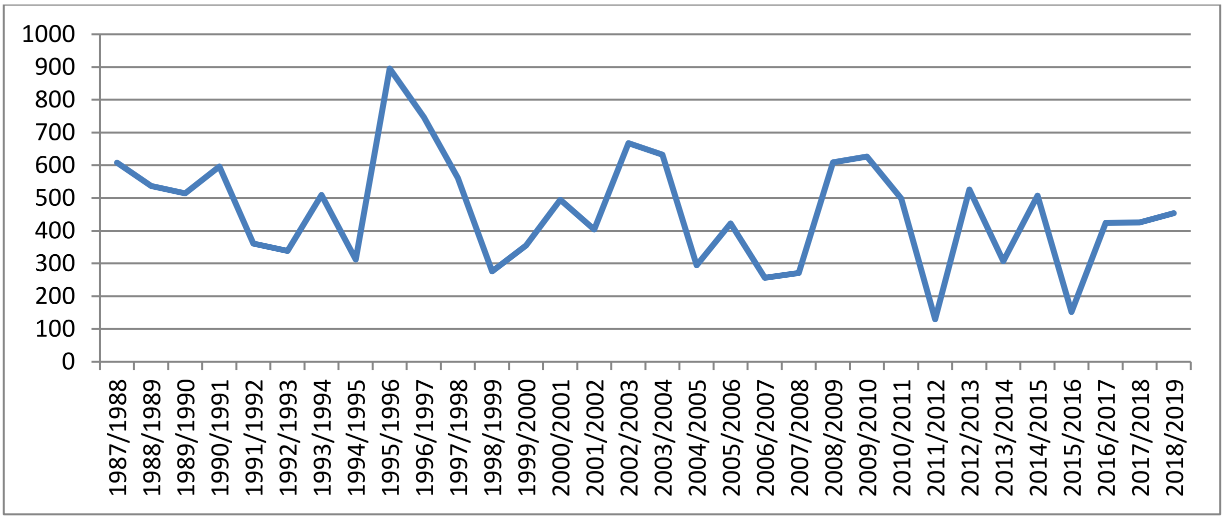

Figure 4 The annual precipitation curve.

On the other hand, it is clear from the Figure 4 that there is a noticeable difference in the amount of annual precipitation during the period from 1987 to 2019. On the other hand, years with precipitation below the annual average are considered dry or severely dry, while those with precipitation exceeding the annual average are considered wet or severely wet (Labhar and Boualam, 2022), according to the recorded amount of precipitation during each year.

The table 1 illustrates the comparison results between the average annual precipitation rates during two periods: from 1987/1988 to 2002/2003 and from 2003/2004 to 2019/2018. The results showed that the average precipitation during the first period had the highest value of 510.89 mm compared to the second period, which had an average precipitation of 408.41 mm.

And when conducting the one-way ANOVA test after confirming the fulfillment of the assumption of homogeneity which was found to be 0.99, meaning that the two periods are homogeneous, it became clear that the significance value is 0.8 at a significance level of 0.05. Therefore, there are no differences between the average precipitation during the two periods under study.

Table 1 statistical and descriptive data for precipitation during the two studied periods.

Statistical data Period	Numbre of years (N)	Mean	Standard deviation	Minimum value	Maximum value	Level of significance	Significance value
First period	16	510,8938	169,45327	276,30	895,30		
Second period	16	408,4112	159,45289	129,50	632,30	0.08	0.05

3.4. Annual average of temperature

On the other hand, a study was conducted on the annual averages of temperature changes in the periods 1987-2019 and represented in the Figure 5. The analysis of this graph indicates that the period 2008-2011 has the highest value ranging between 19.6°C and 19.7°C, while the lowest annual average temperature is 16.8°C recorded during the year 1987/1988.

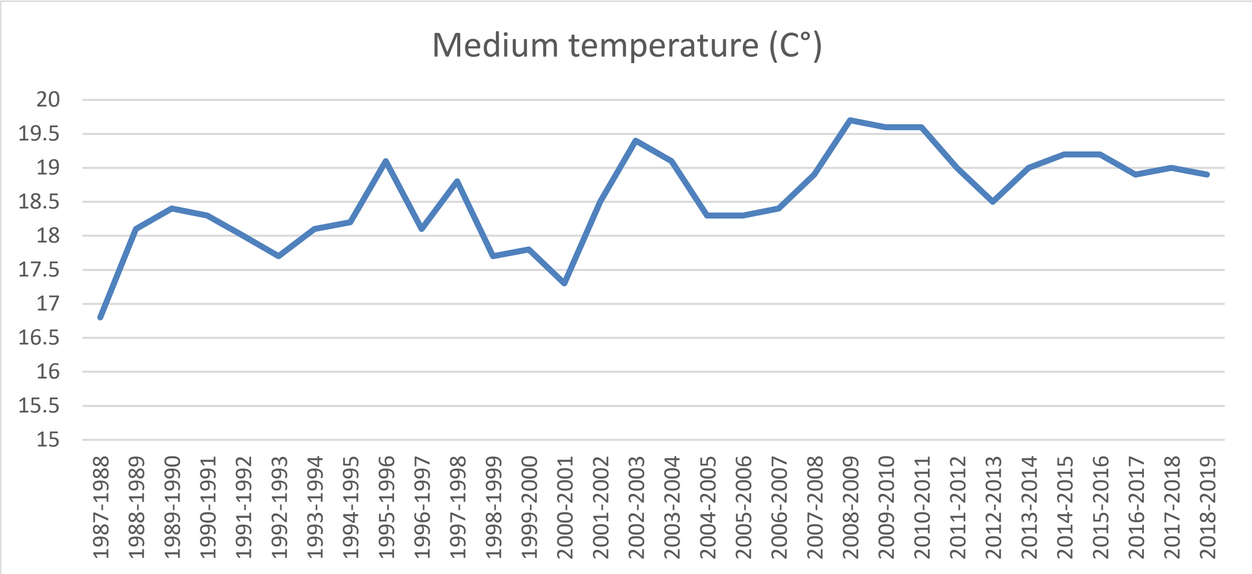

Figure 5 Annual temperature change curve.

And when conducting the one-way ANOVA test after ensuring the assumption of homogeneity, it was found that the significance value equals 0.000 at a significance level of 0.05. Therefore, there are differences between the average temperatures during the two periods under study (Table 2).

Table 2 Statistical and descriptive data for temperature (C°) during the specified periods.

Statistical data Period	Numbre of years (N)	Mean	Standard deviation	Minimum value	Maximum value	Level of significance	Significance value
First period	16	18.144	,6429	16.8	19.4	,000	0.05
Second period	16	18.975	,4405	18.3	19.7		

3.5. The change in rainfall coefficients (frequency of drought)

Is shown in Table 3 and Figure 6. The study area has experienced drought years during the past three decades, with dry years accounting for 87.5%, totaling 28 years, surpassing the percentage of semi-humid years, which only accounted for 6.25% and occurred in only two years. Additionally, severe drought years accounted for 6.25% and also occurred on a biennial basis.

It is evident that climate drought is strongly present within the monitoring station and has a significant impact on the formation of cork oak trees. The sensitivity of these trees increases, and their immunity weakens due to these recurrent and prolonged droughts. This leads to an ecological imbalance and exposes these trees to parasite invasion (Albouanani et al., 2022).

Table 3 most important years of drought experienced by the studied region during the period from 1987 to 2019.

Years From... to...	Number of years					
	Dry	Percentage %	Very dry	Percentage %	Semi-humid	Percentage %
1987/1988 to 1994/1995 and 1997/1998 to 2010/2011 and 2012/2013 to 2014/2015 and 2016/2017 to 2018/2019	28	87.5				
2011/2012 and 2015/2016			2	6.25		
1995/1997					2	6.25

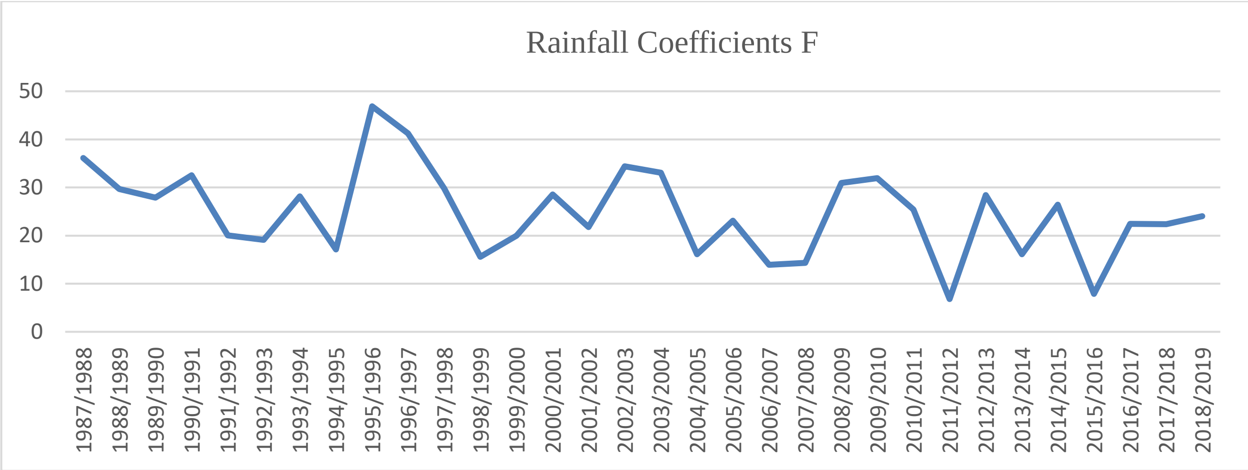

Figure 6 variation of the annual rainfall coefficients.

3.6. The modern development of forest cover formations in region (A) of the Maamora forest between the years 1990, 2000 and 2022.

3.6.1. Analysis and spatial representation of the studied spectral indicators results

- **NDVI Indicator**
- **For the year 1990**

During the year 1990, it is evident that NDVI ranges between 0.03 and 0.33. Overall, it highlights that good vegetation cover is concentrated in the southeast sector (A) of the Maamora forest, where its value ranges between 0.17 and 0.33, with a range of 0.16. On the other hand, poor vegetation cover is concentrated in the northwest sector (A) of the Maamoura forest, where its value ranges between 0.03 and 0.14, with a range of 0.11 (Figure 7).

- **For the year 2000**

In the year 2000, it is evident that the NDVI ranges between 0.02 and 0.34, and geographically, it highlights that the distribution of good vegetation cover has decreased compared to 1990. It is concentrated in the southeastern part of the sector (A) from Maamora Forest, where its values range from 0.13 to 0.34 with a range equivalent to 0.21. It is also evident that the average quality vegetation cover, ranging between 0.11 and 0.13, compensates for a part of the good vegetation cover observed in the year 2000, where the range of the latter reached 0.02, mostly concentrated in the northern part of the sector (A) from the forest. As for the poor vegetation cover, it ranges between 0.02 and 0.11 and is concentrated in the northwestern part of sector A with a range equivalent to 0.09.

- **For the year 2020**

In the year 2020, it is evident that NDVI ranges between 0.02 and 0.47, indicating a noticeable decline in good vegetation cover. It is highly concentrated in the southeastern sector A, with values ranging from 0.20 to 0.47 within a range of 0.27. This decline favors vegetation of moderate quality with values of 0.17 and 0.20 within a range of 0.03. As for the non-good vegetation sector, it is concentrated in the far north and northeast of sector A, specifically in the Maamora forest, with values ranging from 0.02 to 0.17 within a range of 0.17.

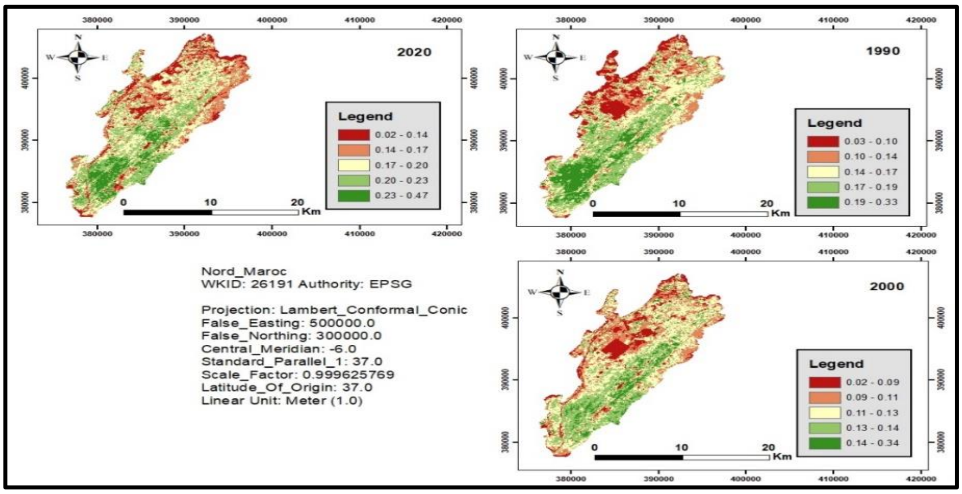

Figure 7 Change in the distribution of NDVI index in the years 1990-2000-2020.

- **SAVI Index**
- **For the year 1990**

When considering the SAVI index as an index that adjusts the NDVI index based on the soil surface factor (USGS, 2023), comparing the maps of the SAVI index and the NDVI index reveals a similarity in the geographical representation of the two indices, with the difference lying in the values taken by the SAVI index in each of the three years. In the year 1990, it is evident that the values taken by the SAVI index range from 0.04 to 0.50, and the higher values of this index are concentrated in the southern sector (A) of the Maamora forest, where values range from 0.25 to 0.50 with a range equal to 0.25. The lower values of the index are concentrated in the northwest of sector (A) of the Maamora forest, with values ranging from 0.04 to 0.21 with a range equal to 0.17 (Figure 8).

- **For the year 2000**

Through comparing the results of the SAVI index between 1990 and 2000, it becomes clear that there is a decline in the spatial distribution of higher values for this index. This decline is observed in the southern and southwestern parts of Sector A, specifically in the Maamora forest. In the year 2000, the values taken by the SAVI index ranged between 0.03 and 0.51, with the higher values concentrated in the far south and southeast of Sector A, ranging from 0.19 to 0.51 with a range of 0.32. As for the lower values of the index, they are concentrated in the far north and northwest of Sector A, ranging from 0.03 to 0.17 with a range of 0.14.

- **For the year 2020**

The decline in the higher values of the SAVI index is still noticeable on the map for the year 2020, especially in the western area of Sector A. The higher values of the index range from 0.30 to 0.70 with a range of 0.40, while the lower values range from 0.03 to 0.26 with a range of 0.23. These lower values are concentrated in the far northwest and parts of the northeast of Sector A.

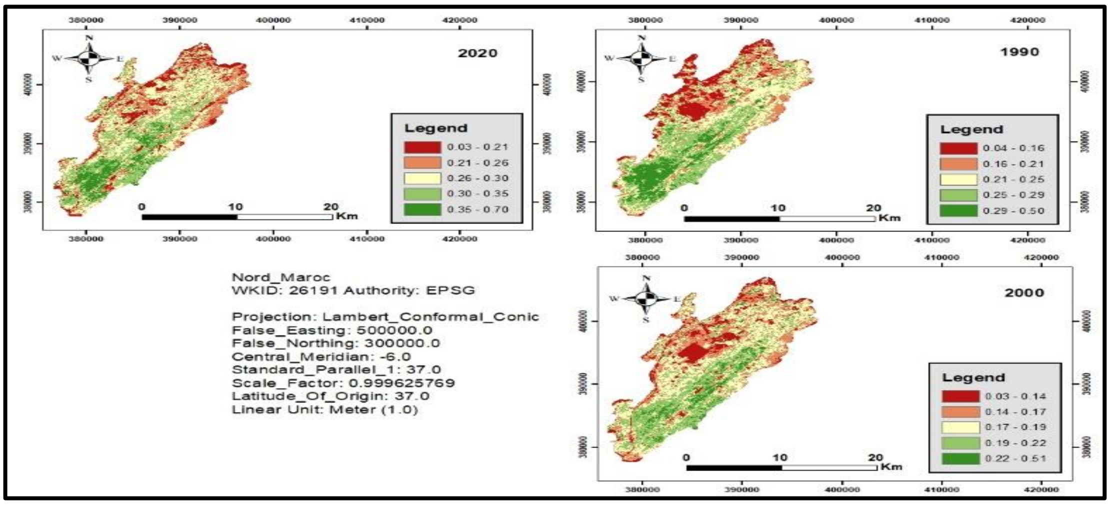

Figure 8 Change in the distribution of the SAVI index in the years 1990-2000-2020.

- **NDMI index**
- **For the year 1990**

Since the NDMI index is an indicator of vegetation water content (USGS, 2023), the results of this index in 1990 were satisfactory compared to 2000 and 2020. The highest values of this index prevail in sector A, which includes the Maamora Forest, with upper values ranging between -0.02 and 0.18, equivalent to a range of 0.2 (Figure 9).

- **For the year 2000**

In the year 2000, the vegetation cover containing water began to recede, concentrating in a few parts of sector A of the Maamora forest, especially in its northern part and the far southwest, with values ranging from -0.05 to 0.16 within a range of 0.21. The water-containing vegetation cover observed in 1990 was replaced by dry vegetation without water, with values ranging from -0.46 to -0.08.

- **For the year 2020**

In the year 2020, there is still a noticeable recession in the vegetation cover containing water, concentrating in the far north and northwest of sector A of the Maamora forest, and also in its south, with values ranging from -0.01 to 0.27 within a range of 0.28. The dry vegetation is concentrated in the east of sector A of the Maamora forest and also in the west, with values ranging from -0.22 to -0.04 within a range of 0.18.

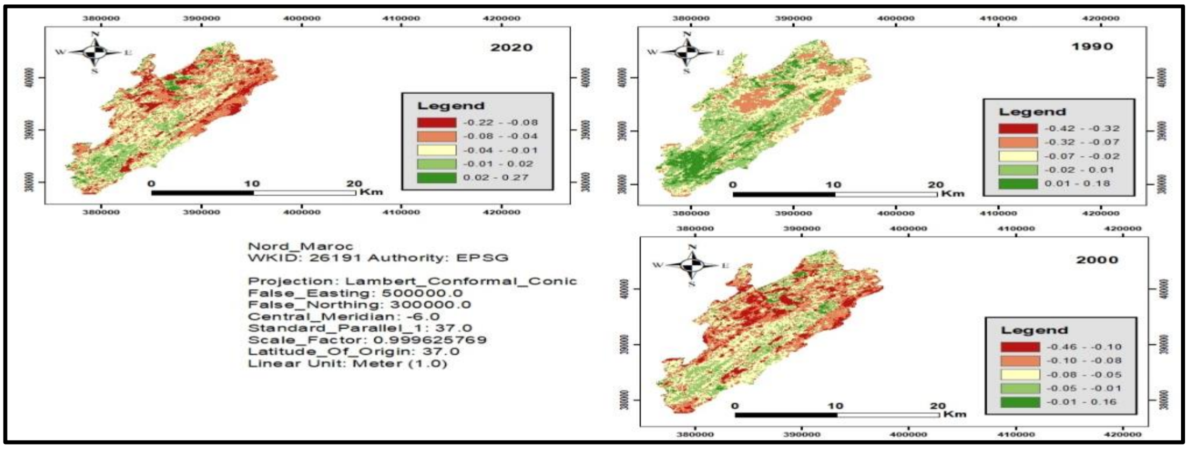

Figure 9 Changes in the distribution of the NDMI index in the years 1990-2000-2020.

4. Discussion

The geographic distribution of forest species is associated with ecological and climatic requirements. The increase in water stress and heat retention will have varying and direct implications on photosynthesis and respiration, affecting the growth season and leading to changes in forest habitats that impact biological interactions (Tabet and Benderradji, 2008).

4.1. Aging of the Cork Oak Trees

Plant life cycles are greatly affected by climate change as it influences their environment, behavior, formation, density, and distribution area. Additionally, it affects their unique phynology (Vache, 2006 in Tabet and Benderradji, 2008). Among the environmental challenges posed by climate change is the early aging of cork oak trees.

Due to the difficulty of adapting to the current environmental conditions characterized by frequent years of drought (Labhar and Boualem, 2022). On the other hand, water stress primarily affects cell growth and differentiation, disrupts gas exchange, alters biochemical and nutritional properties of tree leaves, and hinders the process of photosynthesis. Furthermore, root absorption of minerals decreases due to soil drying resulting from increased temperature (Tabet and Benderradji, 2008).

4.2. Invasion of parasites

Insects are directly affected by changes in temperature and rainfall, and indirectly through the chemical composition of plant tissues (Thuller, 2003, in Tabet and Benderradji, 2008). Increased temperatures lead to the expansion of forest pest activity zones, as it shortens their reproductive cycles and increases their survival rates. Insects have a great ability to move and reproduce (Tardieu et al., 2005, in Tabet and Benderradji, 2008). Therefore, drought creates more favorable thermal conditions for insect growth, reproduction, and resistance. Furthermore, it determines the period during which trees become susceptible to parasitic attacks (Abdendi, 2003). For example, in Morocco, attacks by *Lymantria dispar* on cork oak and attacks by Taumetopoea sp on pine and Atlas cedar trees were devastating during years of drought (El Hassani et al., 2003, in Tabet and Benderradji, 2008).

In an inhabited forest, the subject of this study, insects and parasites constitute about 80% of the animal species in the Maamora forest (Albouanani et al., 2022). If the conditions (drought and water stress) are available, they negatively affect all parts of the cork oak trees (bark, wood, leaves, roots, and fruits) (Slim et al., 2015). Perhaps the biggest destroyer of cork oak trees is the oak processionary moth (*Lymantria Dispar*) as it strips the trees of their leaves and causes severe damage that hinders growth in the upper parts of the trees, eventually leading to their gradual death.

4.3. Soil degradation

Cork oak trees, in general, allow the soil to be enriched with abundant amounts of rapidly decomposing humus, which in turn provides a rich organic material that serves as an important carbon reservoir. Additionally, they supply the soil with an extra amount of moisture, creating favorable conditions for the stability of the entire ecosystem (Alahoual, et al., 2022). On the other hand, soil dryness due to increased temperature stresses the roots in their absorption of organic matter and mineral salts (Tabet and Benderradji, 2008).

5. Recommendation

- Reforestation of the cork oak forest through forest planting;
- Preservation of the forest heritage through awareness campaigns;
- Prevention of overgrazing and prevention of tree cutting;

- Fighting desertification phenomenon;
- Preventing urban expansion at the expense of Maamora forest.

6. Conclusions

This study shows that the Maamora forest has experienced a progressive decrease in its area between the years 1975 and 2022, reaching a percentage of 56.08%. This is due to factors shared by humans, such as deforestation through illegal logging and urban expansion, as well as climate change through years of drought and its severe environmental impacts on cork oak trees. One of the main impacts is continuous aging, in addition to the weak reforestation efforts carried out by relevant authorities to revive deteriorating natural environments within the cork oak field. Not to mention the spread of forest diseases and parasites, such as *Lymantria dispar*, which can worsen and cause more damage under current climate changes. Therefore, it is necessary to take a series of measures to preserve this natural heritage at the local, regional, and national levels.

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Ethical considerations

Not applicable.

Conflict of Interest

Since I am interested in geographical studies, I am studying the impact of climate change on forests.

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