PLANT SCIENCE TODAY
Vol 12(3): 1-11
https://doi.org/10.14719/pst.7120

eISSN 2348-1900

RESEARCH ARTICLE

Study and mapping of the impact of environmental changes on plant cover in Tazekka National Park

Zineb Hazyoun[1]*, Hanae Elharrani[2], Mohammed El Haouari[1,3], Hanan Taybi[2] & Najat Assem[1,4]

[1]Department of Biology, Laboratory of Biotechnology, Conservation and Valorization of Bioresources (BCVB), Faculty of Sciences Dhar El Mahraz, Sidi Mohamed Ben Abdellah University, Fez 35000, Morocco

[2]Laboratory of Natural Substances, Pharmacology, Environment, Modeling, Health and Quality of Life (SNAMOPEQ), Polydisciplinary Faculty of Taza, Sidi Mohamed Ben Abdellah University, Fez 35000, Morocco

[3]Regional Center for Education Careers and Training (CRMEF Fez-Meknes), Taza 35000, Morocco

[4]Polydisciplinary Faculty of Taza, Sidi Mohamed Ben Abdellah University, Fez 35000, Morocco

*Correspondence email - zineb.hazyoun@usmba.ac.ma

Received: 07 January 2025; Accepted: 05 May 2025; Available online: Version 1.0: 30 June 2025; Version 2.0: 03 July 2025

Cite this article: Hazyoun Z, Elharrani H, El Haouari M, Taybi H, Assem N. Study and mapping of the impact of environmental changes on plant cover in Tazekka National Park. Plant Science Today. 2025; 12(3): 1-11. https:/doi.org/10.14719/pst.7120

Abstract

Since the beginning of the 20th century, Morocco has experienced an increase in its annual average temperature of around + 1.5 °C. This warming is observed throughout the Tazekka National Park (TNP) territory, which is our study's subject, located in the northernmost part of the Middle Atlas, near the city of Taza. This mountainous park covers an area of 13737 ha with an altitude between 1400 m and 1980 m (the summit of Tazekka). However, this massif, which offers a great variety in landscape and diversity of forest stands, is threatened due to anthropogenic and climatic factors. In this context, analyzes of Landsat images from 2010 to 2020 have enabled us to follow the evolution of natural plant formations in different stations of TNP. This work aims to highlight the spatio-temporal changes of plant groups in the park over 2010-2020, by studying the normalized vegetation index (NDVI). The obtained results in the form of GIS using the ArcGis software have shown that climate change strongly influences the plant biodiversity of the studied park.

Keywords: climate change; GIS; NDVI; plant biodiversity; Tazekka National Park

Introduction

Morocco is among the five most floristically rich and diverse countries in the Mediterranean basin. This remarkable biodiversity is primarily attributed to its unique geographical position in the Atlantic Ocean, the Mediterranean Sea, the Sahara Desert and multiple mountain ranges that create favourable ecological conditions (1, 2). The country hosts approximately 4500 plant species, with an exceptionally high rate of endemism in mountainous regions (3). However, Moroccan ecosystems are increasingly vulnerable to the impacts of climate change, posing a significant threat to their stability and long-term sustainability. Recent studies have underscored the alarming effects of climate change on Moroccan forests, particularly those dominated by key species such as the Atlas cedar (*Cedrus atlantica*), cork oak (*Quercus suber*), cypress (*Cupressus* spp.) and argan tree (*Argania spinosa*). These forests face significant degradation, with the risk of transitioning into pre-forest, steppe, or even desert ecosystems (4, 5). Climate projections indicate a substantial decline in precipitation and a rise in average temperatures across North Africa, further accelerating the process of aridification (6).

Morocco has implemented various conservation measures to counter these threats, including establishing ten national parks, including Tazekka National Park (TNP) in the eastern Middle Atlas. Despite these efforts, TNP is under increasing ecological pressure. This park, characterized by a diverse mosaic of landscapes and forest ecosystems, is significantly affected by two significant factors: human activities and climate change (7, 8). Furthermore, overgrazing, deforestation and unsustainable agricultural practices contribute to habitat fragmentation, exacerbating the effects of climate variability (9). These pressures endanger the survival of many plant species, some of which are already at risk of extinction. Climate change, in particular, is expected to intensify bioclimatic constraints, potentially exceeding the adaptive capacity of many species in the face of new environmental conditions (10, 11).

Recent research in Morocco's semi-arid and mountainous zones has revealed growing climate-related pressures on plant ecosystems. Research documented significant vegetation decline in the Oued Lahdar watershed, linking this degradation to decreasing rainfall patterns and soil deterioration (12). Research indicates that Morocco's Tensift region captured measurable climate-driven vegetation changes, indicating these ecological transformations may occur nationwide as plant communities adapt to warming temperatures and altered precipitation regimes (13). These studies demonstrate climate change's tangible impacts on Morocco's fragile ecosystems. In contrast to other research, this study evaluates the progressive effects of climate change on the biodiversity of Tazekka National Park. This location has received little attention in the scientific literature, as a ten-year examination of NDVI data was combined with GIS-based spatial modelling. Our research offers fresh perspectives on the spatiotemporal dynamics of vegetation, which is essential for future conservation planning in Moroccan protected areas.

In contrast to other research, this study evaluates the progressive effects of climate change on the biodiversity of Tazekka National Park. This location has received little attention in the scientific literature, by combining a ten-year examination of NDVI data with GIS-based spatial modeling. Our research offers fresh perspectives on the spatiotemporal dynamics of vegetation, which is essential for future conservation planning in Moroccan protected areas. In contrast to other research, this study evaluates the progressive effects of climate change on the biodiversity of Tazekka National Park. This location has received little attention in the scientific literature, by combining a ten-year examination of NDVI data with GIS-based spatial modeling. Our research offers fresh perspectives on the spatiotemporal dynamics of vegetation, which is essential for future conservation planning in Moroccan protected areas.

In this context, the present study seeks to evaluate the impact of climate change on the vegetation cover of TNP and propose strategies to mitigate these risks. To achieve this, we employ advanced geospatial analysis techniques, including aerospace remote sensing and computer-based data processing, to monitor vegetation dynamics and identify vulnerable areas. Through satellite imagery, remote sensing enables large-scale and long-term monitoring of vegetation changes, making it an essential tool for assessing the effects of climate fluctuations (14). Additionally, vegetation indices such as the Normalized Difference Vegetation Index (NDVI) facilitate the detection of changes in plant cover and health status (15). The integration of Geographic Information Systems (GIS) further enhances spatial analysis by allowing the cross-referencing of climatic, soil and topographic variables, providing a comprehensive understanding of ecosystem dynamics (16). Combining these analytical tools, this research aims to generate valuable insights for conservation planning and the sustainable management of TNP's unique ecosystems. The findings will contribute to ongoing biodiversity conservation efforts and inform the development of adaptive strategies to mitigate the adverse effects of climate change on forest ecosystems in Morocco and beyond.

Material and Methods

Geographical context of the study area

The study area is attached to the province of Taza. It constitutes the northern end of the Eastern Middle Atlas, dominating the hallway of the South-Rifain. It is a park with an altitude between 1400 and 1980 m, the highest point being the summit of the Tazekka massif (Fig. 1). It offers a tremendous floristic diversity, both by its remarkable forest formations and by its large number of vascular plant species. The vegetation of the massif is distributed according to its affinity to the different bioclimates present in the various stations of the park (17).

Geological data

The Tazekka National Park covers the south-west regions of Taza, the northern part of the Middle Atlas and dominates the southern Rifain hallway. The north part of the Middle Atlas chain can be divided into three geologically distinct parts:

The primary massif of Tazekka (summit of Tazekka), the middle atlas tabular cause of secondary (summer centre of Bab Boudir) and the folded Middle Atlas of the secondary (Bou Iblane to the west of the park) (18).

Edaphic data

Tazekka National Park covers the northern part of the Middle Atlas and dominates the southern Rifain hallway (19). From a pedological point of view, soil types encountered in the massif are calcimagnesic soils, browned soils, fersiallitic soils and soils with little evolution (20).

Methodology

To follow the spatio-temporal evolution of phytobiodiversity in Tazzeka National Park, we have used Landsat satellite images, with a resolution of 30 m, from the Landsat 8OLI (Operational Land Imager), Landsat 4-5 TM (Thematic Mapper) and Landsat 7 ETM + (Enhanced Thematic Mapper Plus) sensors over 10 years from 2010 to 2020 (Table 1). The methodology adopted in this study consists in georeferencing the images, combining the spectral bands, classifying the plant groups and recognizing the chlorophyll activities of the vegetation (Fig. 2).

The NDVI extracted from satellite imagery, developed by Rousse and collaborators (1974), is the most used for ensuring follow-up environmental. This index is generally recognized as being a reliable indicator of the state of vegetation. It is constructed from an image's red and NIR (near infrared) bands. It exploits the reflectance characteristics of plants, which absorb wavelengths around 650 nm and more or less reflect those in the near infrared (between 700 and 900 nm) depending on their chlorophyll activity. The index is then defined as follows:

$$\mathrm{NDVI} = \frac{\rho ir - \rho r}{\rho ir + \rho r} \qquad \text{(Eqn. 1)}$$

With:

ρir: reflectance in the near infrared band

ρr: reflectance in the red band

The result of an NDVI takes the form of a new image. Values are between -1 and +1. NDVI values are close to 1 for forest areas, zero value for bare soils and negative value for water surfaces. The Normalized Difference Vegetation Index (NDVI) continues to be a robust tool for assessing vegetation health and biomass dynamics. Its effectiveness has been particularly demonstrated in Morocco's arid ecosystems,

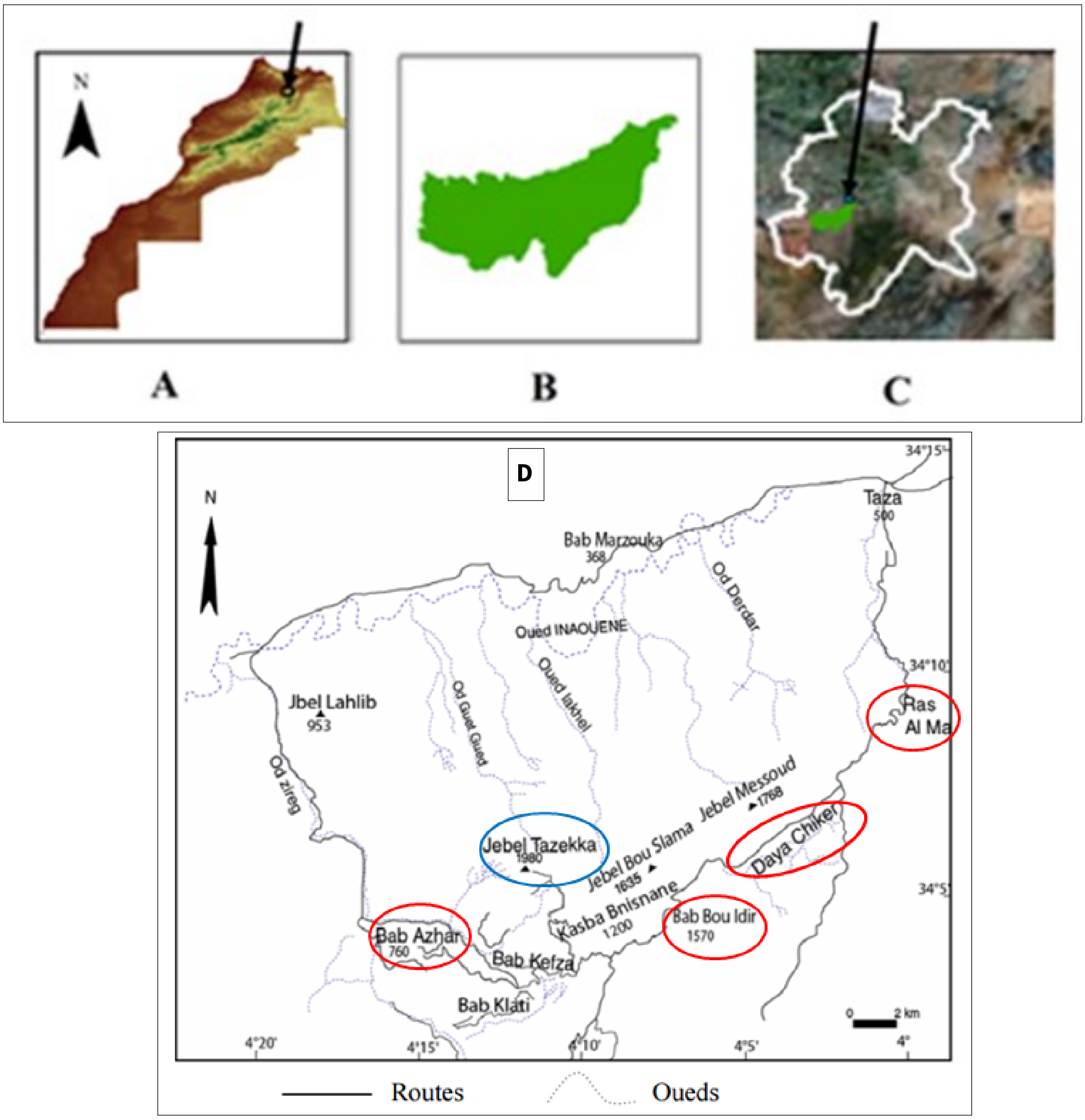

Fig. 1. Geographical location of the study area with modifications. A) Situation of Tazekka National Park (TNP) in Morocco; B) TNP limit; C) Situation of the TNP in the Taza region; D) Study stations.

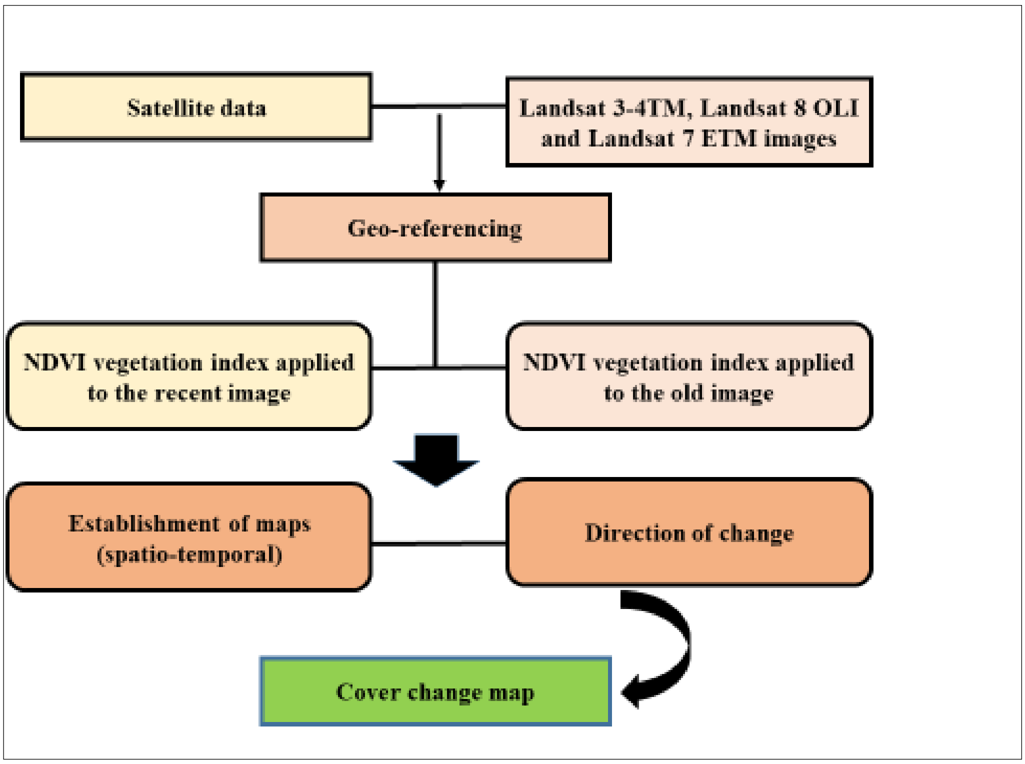

Fig.2. Methodology of work.

Table 1. Characteristics of the satellite images used in this study

Year	Month/day of acquisition	Type of sensor
2010	04-September	Landsat 4-5
2011	07-September	TM
2012	03-October	Landsat 7
2013	14-October	ETM +
2014	17-October	
2015	18-September	
2016	06-October	
2017	09-October	
2018	10-October	Landsat 8 OLI
2019	13-September	
2020	15-September	

where researchers have successfully applied NDVI-based monitoring systems. A notable 2021 study by Lang and colleagues demonstrated this application by correlating NDVI datasets with rainfall patterns to evaluate pastureland productivity in eastern Morocco, highlighting the critical role of remote sensing in tracking environmental changes (21).

Results and Discussion

Climatic data

The study of a given region is always preceded by a study of essential climatic parameters (precipitation, temperatures, etc.).These parameters influence the spatiotemporal distribution of vegetation, so knowledge of climatic conditions is crucial in defining and assessing the distribution of the plant cover in the study area (22).

The relief of (TNP) is an obstacle to the humid westerly winds, which allows it to receive most of the moisture they carry. Compared with the surrounding rainfall regimes, the park is characterized by average annual precipitation and relative humidity of the atmosphere, which are distinctly important (23). Indeed, Table 2 shows the annual mean precipitation and temperatures of the Taza station from 2010 to 2020.

The analysis of Table 2 established a clear distinction between the temperatures and rainfall recorded at Taza Station throughout the research period. It seems that height, exposure and geographic location significantly impact precipitation dispersion, impacting plant species distribution within the TNP (24). The ombrothermic diagram (Fig. 3) shows an alternation of two wet and dry periods. The latter's duration reaches more than 3 months in the Taza station, strongly influencing the vegetation cover of different park stations.

The atmospheric conditions of the study area, often characterized by a clear sky and are free of all obstacles. So, the images obtained are sharp and don't require any prior processing. This advantage has made it possible to have precise estimates very close to reality. Cloud cover, disease and bad weather are sources of error that could reduce accuracy (25).

NDVI is an indicator of the mass of plant cover it contains and its state of health or strength of growth. The reflectance of the vegetation cover strongly depends on the illumination direction, observation and wavelength. Hence, vegetation is denser when the NDVI is between 0.3 and 1. On the other hand, clear and moderately dense vegetation is seen when

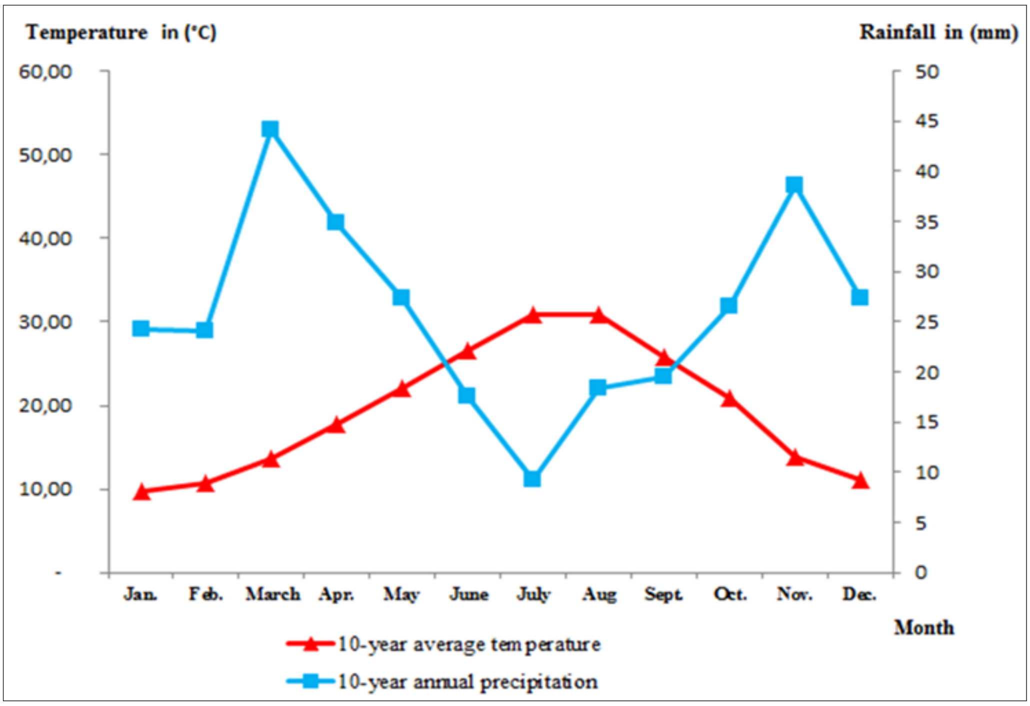

Fig. 3. Ombrothermic diagram of BAGNOULS and GAUSSEN of Taza station (**Period**: 2010-2020).

Table 2. Average precipitation and temperature at the Taza station (2010 to 2020) (10)

	Jan.	Feb.	March	Apr.	May	June	July	Aug	Sept.	Oct.	Nov.	Dec.
Annual average temperature (°C)	9,77	10,68	13,59	17,82	22,14	26,50	30,91	30,86	25,77	20,86	13,86	11,14
Annual average rainfall (mm)	24,27	24	44,09	34,91	27,27	17,54	9,18	18,36	19,45	26,45	38,64	27,36

the NDVI is between 0 and 0.3 (Table 3 and Fig. 4). The obtained NDVI results indicate that the study area does not have a homogeneous vegetation density in the different stations and between the years of study. There are parts of bare soil where very weak vegetation has been detected. Dense vegetation (maximum NDVI), sparse vegetation (average NDVI) and weak vegetation (minimum NDVI) have been identified (Fig. 4). The maps in Fig. 5 represent images of the NDVI from 2010 to 2020 obtained using the ArcGis software in TNP. Indeed, there is a substantial difference between the minimum and maximum values for each studied period. However, the minimum values for each type of sensor used are very close to each other, indicating that the minimum vegetation cover is more or less stable. This difference may be due to factors external to the plant cover, such as the influence of the atmosphere, the spectral contribution of soils and the water content of plants.

The maps in Fig. 5 show that NDVI depends on vegetation density and chlorophyll activity. The black area indicates a negative NDVI value, which necessarily means the absence of vegetation; the grey areas are probably scattered vegetation. Its low reflectance is due to water stress, diseases, end-of-season period for crops and matorrals etc. The white areas indicate dense vegetation. The maps in Fig. 6-8 result from integrating the maps in Fig. 5 using the ArcGis program. These maps show how vegetation has changed over ten years (2010–2020) due to climate change based on Landsat satellite pictures taken at several stations in TNP. Every map shows how chlorophyll changed during two years.

The maps in Fig. 6 demonstrate a noticeable difference between the four TNP sites over several years of study. Regarding the Ras al Ma station, we saw in 2011 and 2012 that the predominant hue in this area is black, which accounts for the nearly complete lack of vegetation. This is accompanied by a slight vegetative evolution, represented by the holm oak's blue colouring. 2013 saw the emergence of the red hue, indicating a more notable vegetative retreat. For Bab Boudir station, In 2011 and 2012, the colouring gradually disappeared and was replaced with blue, suggesting a vegetative evolution. The red tint, which indicates a more pronounced vegetative regression in this area, first appeared in 2013.

Regarding Jbel Tazekka Station, between 2011 and 2013, we observed the following colour patterns in this area: white, pale blue and black, with white predominating. Consequently, the black colouring explains the nearly complete absence of vegetation in the exact location over the three years of study, the light blue colouring shows a weak evolution of the vegetation dispersed throughout the region and the white colouring shows that the vegetation cover remains stable without any progression.

For Bab Azhar station, we observe that there are two hues present here: red and white, with a few faint blue dots. Fig. 7 indicates that the four TNP stations differ significantly from one another. Indeed, we have observed an increasing amount of red colouring in this area, which helps explain why the vegetation is exhibiting a more pronounced regressive dynamic. At Ras Al Ma station, we observed a predominance

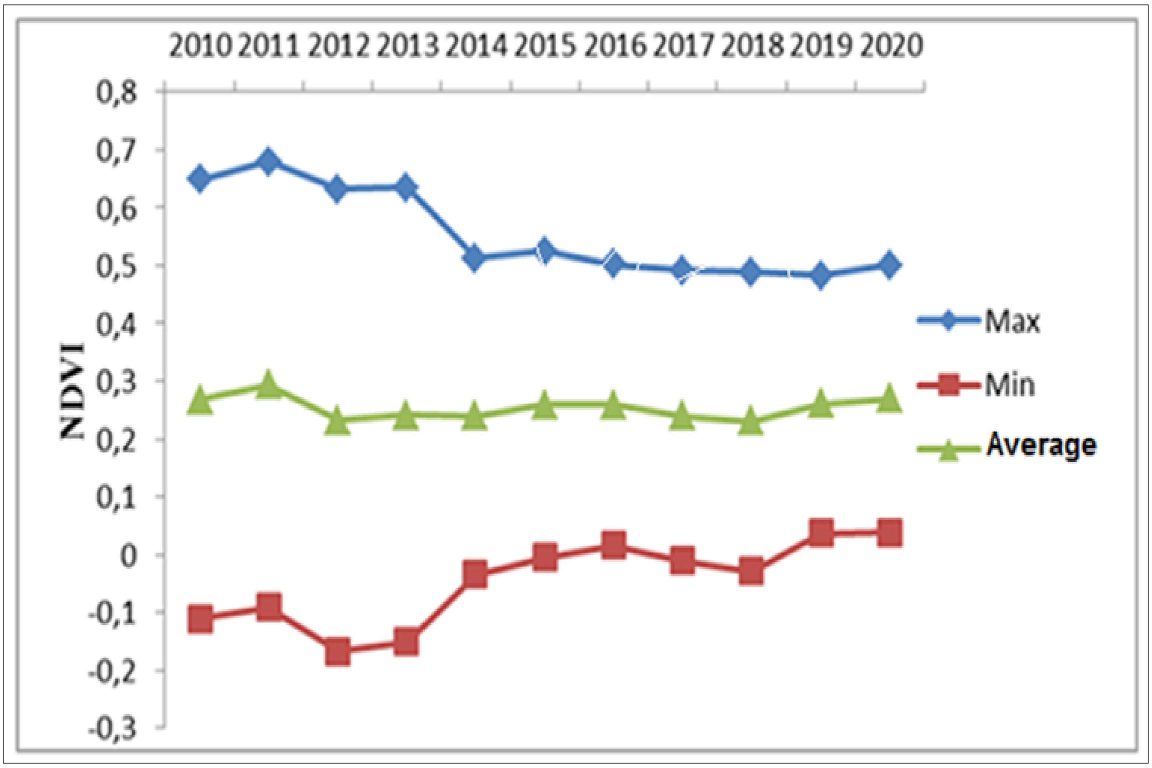

Fig. 4. Evolution of the NDVI between the years studied (from 2010 to 2020) in TNP.

Table 3. Values of NDVI (2010-2020) in TNP

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Max	0,648	0,678	0,632	0,634	0,513	0,523	0,502	0,491	0,489	0,483	0,500
Min	-0,111	-0,090	-0,167	-0,151	-0,034	-0,005	0,016	-0,010	-0,028	0,037	0,038
Average	0,268	0,293	0,232	0,241	0,239	0,259	0,259	0,240	0,230	0,260	0,269

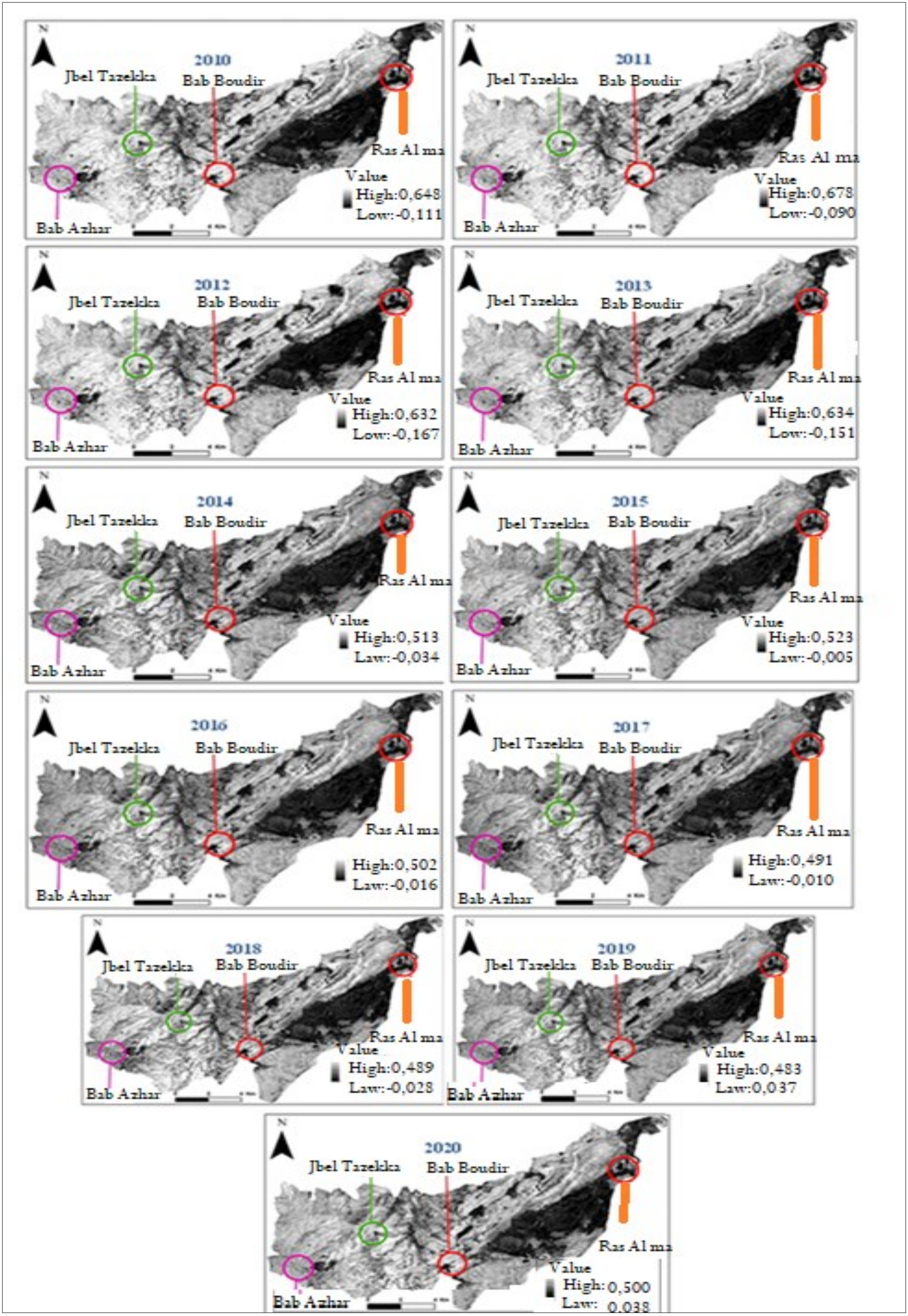

Fig. 5. Images of NDVI from 2010 to 2020 in TNP.

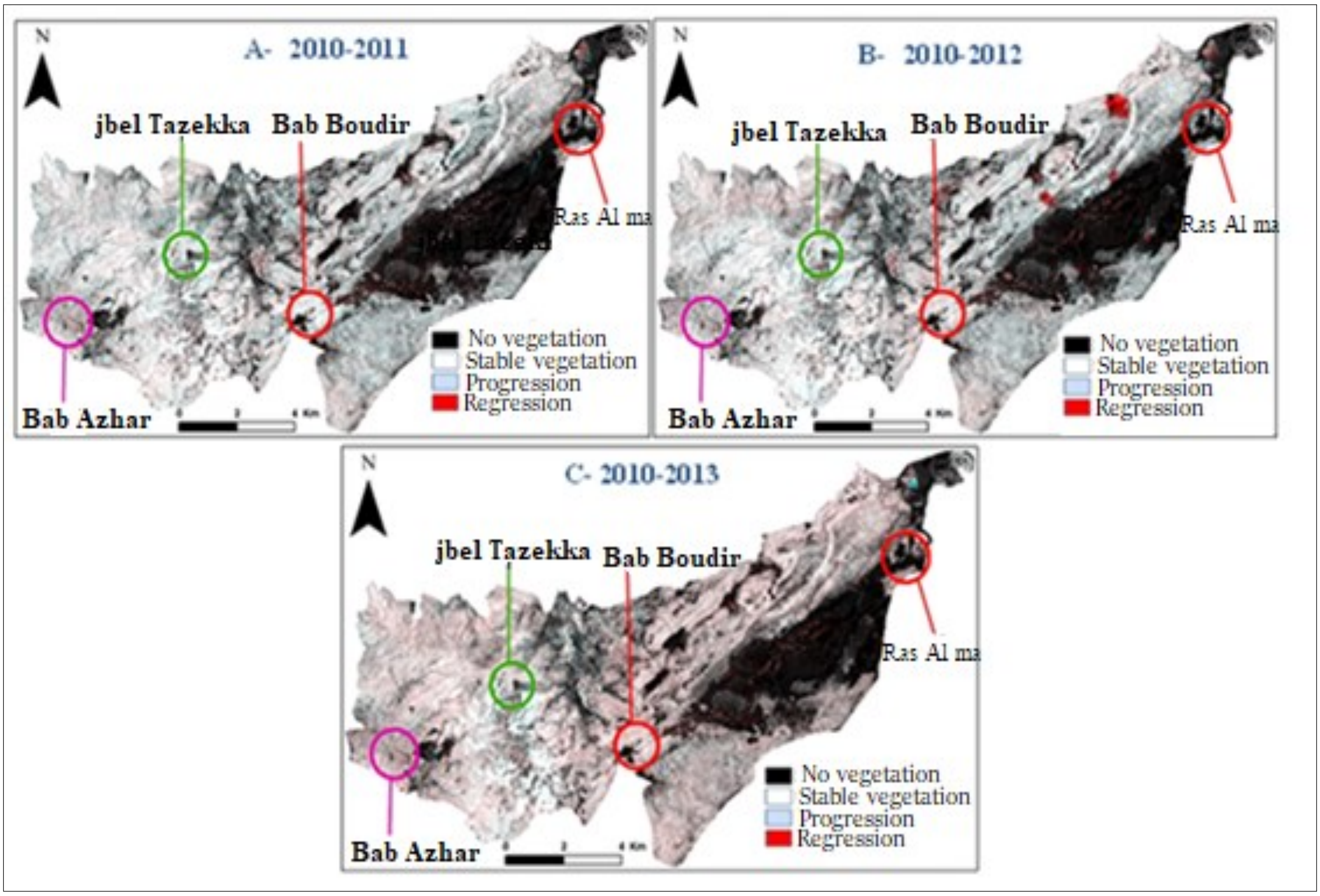

Fig. 6. Vegetation distribution in the TNP between 2010 and 2013 due to climate change (ArcGis).

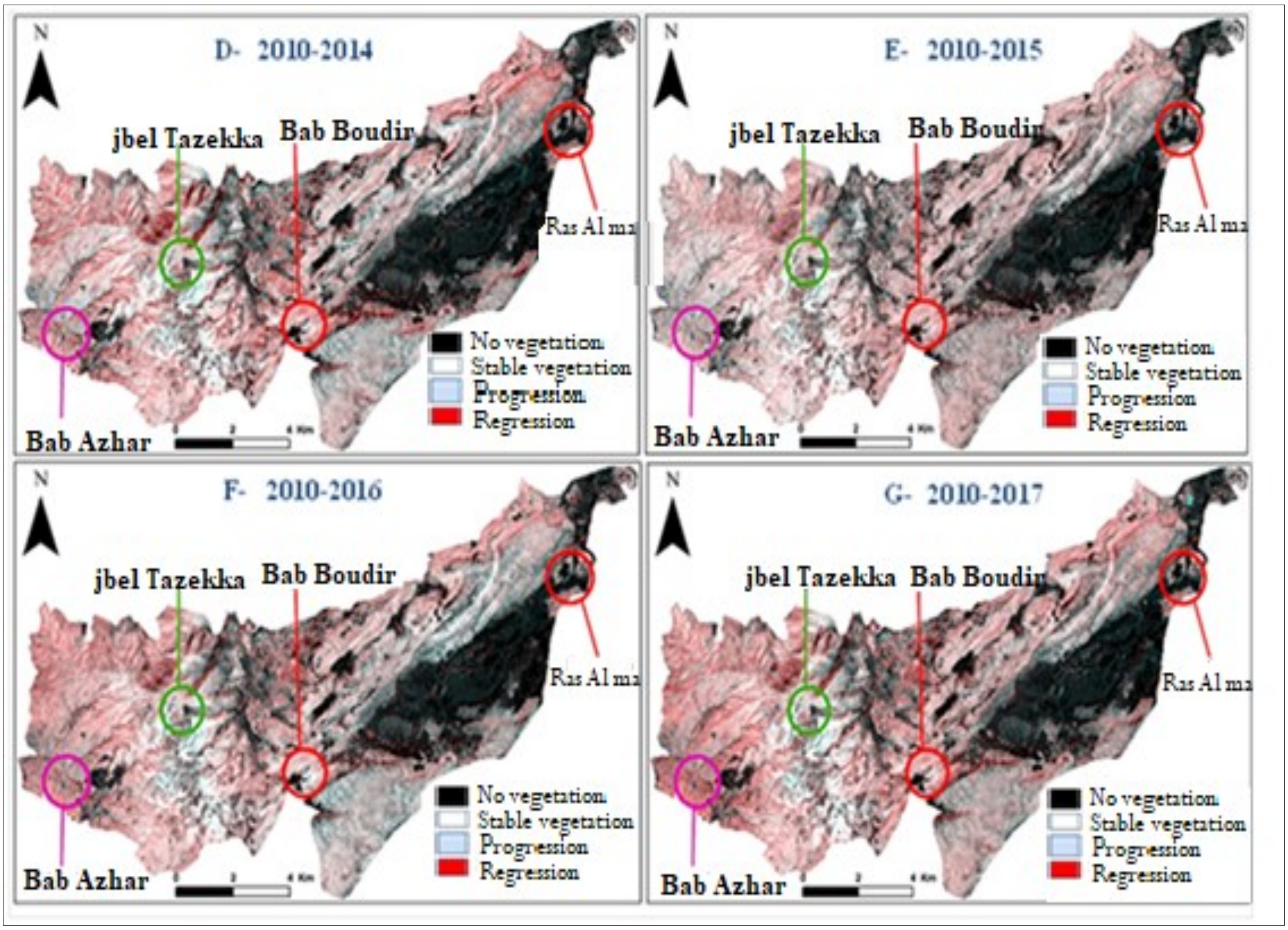

Fig. 7. The distribution of vegetation at TNP level under the influence of climate change between 2010, 2014, 2015, 2016 and 2017 (ArcGis).

of black and blue colours, indicating a balance between geological evolution and the absence of vegetation. At Bab Boudir, we observed the presence of black and red colours, along with a small area of light blue, indicating a regression accompanied by vegetative progression. At the Jbel Tazekka station, we observed the presence of white and red colours. The white colour suggests that the vegetation remains stable, showing neither progression nor regression, while the red colour indicates a slight recession affecting the vegetation cover throughout the area. Meanwhile, for the Bab Azhar area, we noticed a dominance of red, which means the vegetation has receded in this station. We also showed a small spot of light blue (the presence of cork oak). According to Fig. 8, there is a noticeable difference among the four TNP stations. Specifically, the red coloring becomes increasingly prominent in this area in the first two maps (H, I) which is replaced by the light blue and white coloring in the J map, which explains why there is a regression of the vegetation cover on the one hand and an evolution and a stability of the vegetation on the other hand in the whole region.

As a result, between 2010 and 2012, the vegetation cover of these stations saw a more noticeable stability, as shown by the colour white. A dynamic regression of the entire vegetative region is visible in all stations from 2013 to 2019, as denoted by the red colouration. By 2020, all stations exhibit a progressive evolution of the vegetative land, which is denoted by the blue colouring. Thus, human activity and climate change, particularly in terms of temperature and precipitation, are to blame for both the regression and the vegetative progression. To better explain this regression in the TNP, we calculated the chlorophyll evolution in this area (Fig. 9).

According to Fig. 9, the periods 2010-2016, 2010-2017 and 2010-2019 are the most influenced by climate change. Indeed, TNP presents high percentages of vegetation cover regression with 34.91 % (3800 ha) during the period 2010-2016, 50.39 % (5647 ha) for 2010-2017 and 41.48 % (4647 ha) for 2010-2019. Concerning the period 2010-2015, the regression is 31.27 % (3516 ha), while for 2010-2014 it is 32.55 % (3647ha). The regression of plant cover was about 21 % during the periods 2010-2011, 2010-2012, 2010-2013 and 2010 -2020. These results agree with those obtained in Fig. 6-8. As everywhere else, the TNP forest estate is subject to both natural constraints and intense anthropogenic pressure, which, in addition to fires, is the leading cause of forest resource degradation.

As a result, remote sensing techniques have effectively highlighted the observed degradation of forest ecosystems. Additionally, the use of GIS enables the creation of maps showing the evolution of land use according to various spatial and temporal scales and the issuance of early warnings in drought based on multiple spatial indices, such as the vegetation index by normalized difference (NDVI). This research has indicated that the NDVI helps distinguish between evergreen and seasonal forest types and for savannah, dense forest, non-forest environments and agricultural fields (26). Indeed, the value of this index provides information relating to the primary production of vegetation (27). The changes observed in include the increase in temperatures, the decrease in precipitation and the

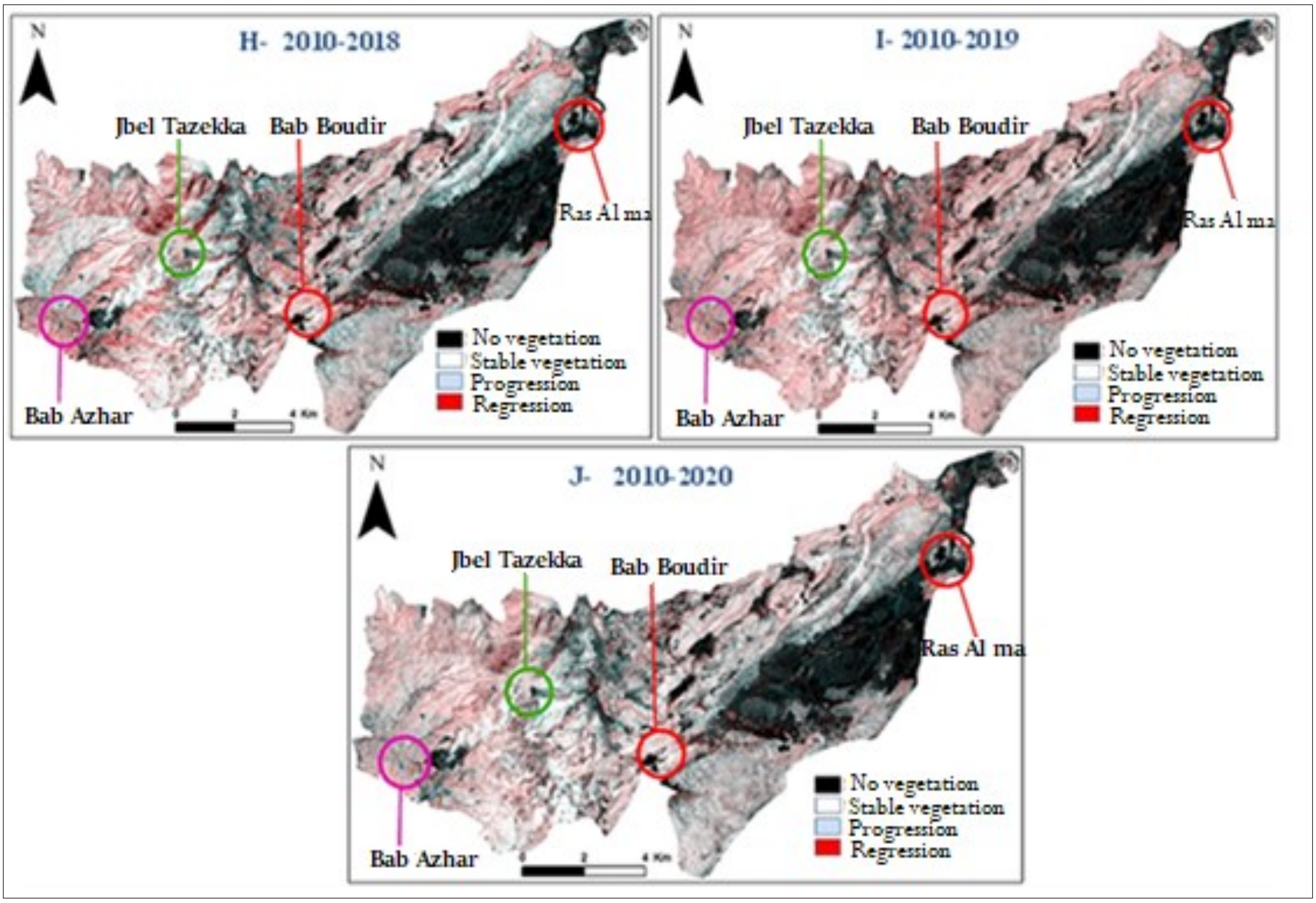

Fig. 8. Vegetation distribution in the TNP between 2010 and 2020 due to climate change, as ArcGis shows.

Fig. 9. Chlorophyll evolution in Tazekka National Park as a function of the surface area during the years 2010-2020.

succession of years of droughts, sometimes severe, have exerted negative effects on the forest plant cover, already fragile, due to the increased pressure on the resources. These impacts are ecological, with a lack of natural regeneration combined with an aging of these populations, a modification of the distribution areas species and therefore of the landscapes and a high vulnerability to diseases (28). The NDVI, which represents the photosynthetic activity of plants, can be directly linked to meteorological factors such as rainfall, which plays a crucial role in the plant growth cycle (29). Thus, the variation in chlorophyll activity intensity measured by the NDVI can be linked to rainfall distribution throughout the year (30, 31). Climate change, this global phenomenon, caused changes in natural environments. However, the speed of change and the accentuation of bioclimatic constraints will significantly induce the loss of species or groups of species that will not have enough time to adapt to the new physical conditions imposed (22). Therefore, validating this study with more precise measurements in the field would be necessary. According to a study carried out on the TNP by the German international cooperation agency for development (GIZ), on the reduction of climate risks for sustainable development, climate change should induce, at the level of phytobiodiversity, a decrease the abundance of species, a loss of natural habitats for the entire territory and the modification of the distribution areas of species and natural habitats (22). As a result, the disruption of the earth's natural ecosystems brought on by climate change would likely increase and eventually result in the extinction of plant species. Under the influence of human activities, warming has recently reached a speed not seen in more than a millennium. Indeed, the research shows a severe change in ecosystems on 5 to 19 % of continental surfaces (32). Furthermore, the more rapid the changes, the more societies and ecosystems are forced to adapt (33). Also, environmental factors, particularly climatic factors, play a crucial role in the development and distribution of species (34). Furthermore, the annual loss of approximately 13 million hectares of forests worldwide is primarily due to human activities and global climate change (35).

Variations in the distribution of vegetation also affect the climate. For instance, in high northern latitudes, warming -related vegetation growth tends to decrease surface albedo, increasing warmth in these areas(36, 37). Indeed, the direct actions of climate change on the physiology of organisms are well documented and many mechanisms of action have been identified. However, for many plants, the climate has indirect effects (38, 39). Also, climate change and increasing temperatures are reflected in biodiversity, such as the movement of certain species towards cooler regions or vice versa (40). The combined effect of excessive and inappropriate anthropogenic actions seriously disrupts ecosystem dynamics, affecting biodiversity, species distribution and the balance of natural environments and agrosystems (41). It reduces agricultural productivity, impoverishes biological diversity and compromises food security (42).

The vegetation degradation patterns identified in Tazekka National Park align with broader ecological trends observed across Morocco. Research revealed comparable forest decline in Morocco's central plateau, demonstrating how combined climatic and human factors drive ecosystem deterioration (43). Research indicates that watershed-scale analysis in the Dades region, which recorded significant NDVI fluctuations, providing further evidence of Moroccan ecosystems' heightened sensitivity to climate stressors(44).

Conclusion

The study highlights the significant impact of climate change on the distribution of plant species within Tazekka National Park (TNP) over the past decade. Using ArcGIS software, it was evident that climate alterations directly influence the park's vegetation cover, which could lead to changes in ecosystem composition and functioning. These shifts may affect plant biology and behaviour, potentially contributing to the extinction of certain species. To mitigate these effects, it is crucial to implement sustainable development strategies by strengthening environmental protection conventions, particularly those related to biodiversity, climate change and wetlands. Additionally, regular monitoring of natural resources through high-resolution satellite imagery and raising awareness about the importance of trees, fire risks and alternative energy sources will help preserve TNP's plant heritage. Promoting agroforestry practices and educating the public on sustainable resource management will minimize environmental pressures and ensure the park's long-term ecological health.

Acknowledgements

We want to thank HIFDHI Said (Head of the Department of Development Studies and Planning at the North-East regional directorate for water and forests and the fight against desertification in Taza) for his help.

Authors' contributions

NA conceived and designed the study and wrote the original manuscript draft. ZH was involved in the creation of maps and contributed to data analysis. HE carried out map development and assisted in analyzing the data. MEH helped in writing sections of the manuscript and contributed to the discussion of the data. HT supported manuscript writing and participated in data interpretation and discussion. All authors read and approved the final version of the manuscript.

Compliance with ethical standards

Conflict of interest: The Authors do not have any conflicts of interest to declare.

Ethical issues: None

References

1. Convention on Biodiversity (CBD). Fourth national report on biodiversity – Morocco [internet]; 2010 [cited 2025 Apr 27]. Available from: https://www.cbd.int/doc/world/ma/ma-nr-04-fr.pdf
2. Médail F, Quézel P. Biodiversity hotspots in the Mediterranean basin: Setting global conservation priorities. Conserv Biol. 1999;13(6):1510–13. https://doi.org/10.1046/j.1523-1739.1999.98467.x
3. Fennane M, Ibn TM, Mathez J. Flore pratique du Maroc. Rabat: Travaux de l'Institut Scientifique, Série Botanique. 1999;1
4. RAC-SPA. Climate change in the Mediterranean: Trends and impacts on biodiversity; 2013 [cited 2025 Apr 27]. Available from: https://www.rac-spa.org/sites/default/files/doc_cop/c_clim_fr.pdf
5. Benabid A. Flore et écosystèmes du Maroc: Évaluation et préservation de la biodiversité. Paris: Ibis Press; 2000
6. IPCC. Climate change 2021: The physical science basis. Intergovernmental Panel on Climate Change[internet]; 2021 [cited 2025 Apr 27]. Available from: https://www.ipcc.ch/report/ar6/wg1/
7. Policy Center for the New South. Climate and biodiversity situation in North Africa [internet]; 2020 [cited 2025 Apr 27]. Available from: https://www.policycenter.ma/publications/la-situation-du-climat-et-de-la-biodiversite-au-maghreb
8. Chebli Y, Fennane M, Rhazi L. Climate change impact on biodiversity in the Middle Atlas, Morocco. J Mediterr Ecol. 2022;21(3):45–58.
9. El Abbassi A, Khalfaoui B, Bourhim K. Human pressures and climate change effects on the Moroccan forest ecosystems. Environ Sci Policy. 2017;74:49–57.
10. Prevention Web.net. Climate change and its impacts in North Africa [internet]; 2014 [cited 2025 Apr 27]. Available from: https://www.preventionweb.net/files/changements_climatiques-214.pdf
11. Huang J, Yu H, Guan X, Wang G, Guo R. Accelerated dryland expansion under climate change. Nat Clim Chang. 2016;6(2):166–71. https://doi.org/10.1038/nclimate2837
12. Khalis M, sadiki A, Jawhari F, Mesrar H, Azab E, Gabouri AA, et al. Effects of climate change on vegetation cover in the Oued Lahdar basin, Northeastern Morocco. Plants. 2021;10(8):1624. https://doi.org/10.3390/plants10081624
13. Akensous Y, Al Sabri A, Al-Akad S, Hakdaoui M. Climate change impact on vegetation dynamics in the Tensift region, Morocco. Int J Environ Sci Dev. 2021;21(11):326–31. https://doi.org/10.18178/ijesd.2021.12.11.1357
14. Pettorelli N, Vik JO, Mysterud A, Gaillard JM, Tucker CJ, Stenseth NC. Using the NDVI to assess ecological responses to environmental change. Trends Ecol Evol. 2005;20(9):503–10. https://doi.org/10.1016/j.tree.2005.05.011
15. Zribi M, Baghdadi N, Holah N, Fafin O. New indices for monitoring vegetation by remote sensing. Remote Sens Environ. 2016;186:234–46.
16. Gharbia SS, Mahfoud M, Bouziane H. GIS-based assessment of climate vulnerability in the Middle Atlas region. Appl Geogr. 2020;116:102179.
17. Rachid A. The Neogene basins of the southern Rif furrow and the North eastern Rif (Morocco). [Thesis]. Fez: Univ. Sidi Mohamed Ben Abdellah; 1997 .p. 333
18. Fougrach H, Badri W, Malki M. Rare and endangered vascular flora of the Tazekka massif. Bull Inst Sci Rabat. 2007;29:1–10.
19. DEFCS/BCEOM-SECA. Tazekka National Park, plan director for development and management. Vols. 1 and 2. Rabat: Morocco; 1994.
20. AEFCS, BCEOM/SECA. Plan of management of Tazekka National Park. Vols. 1 and 2. Rabat: Water and Forestry and Soil Conservation Administration; 2017
21. Lang Y, Mahyou H, Tychon B. Estimation of rangeland production in the arid oriental region (Morocco) cobining remote sensing vegetation and rainfall indiced challenges and lessons learned.. Remote Sens. 2021;13(11):2093. https://doi.org/10.3390/rs13112093
22. DREFLCD NE. Study for the development of the plan development and management of Tazekka National Park. Mission I: State of play; 2018. p. 319
23. Mounsif M, Mokhtari N. Development of a sustainable use plan for the rangelands in the area of the Tazekka National Park; 2010. p. 53
24. DREFLCD NE. Study for the development of the plan development and management of Tazekka National Park. Mission I: State of play; 2022
25. Huete A, Didan K, Miura T, Rodriguez E, Gao X, Ferreira LG. Overview of the radiometric and biophysical performance of the MODIS vegetation indices. Remote Sens Environ. 2002;83(1–2):195–213. https://doi.org/10.1016/S0034-4257(02)00096-2
26. Pettorelli N, Vik JO, Mysterud A, Gaillard JM, Tucker CJ, Stenseth NC. Using the satellite-derived NDVI to assess ecological responses to environmental change. Trends Ecol Evol. 2005;20(9):503–10. https://doi.org/10.1016/j.tree.2005.05.011
27. Pettorelli N, Ryan S, Mueller T, Bunnefeld N, Jedrzejewska B, Lima M, Kausrud K. The Normalized Difference Vegetation Index (NDVI): unforeseen successes in animal ecology. Clim Res. 2011;46:15–27. https://doi.org/10.3354/cr00936

28. El Mazi M, Houari A, El-Fengour M. Contribution of remote sensing and GIS to monitor the temporal and spatial dynamics of the Jebel Outka montanha forest (Central Rif, Morocco). J Geogr Territ Plan. 2017;11:171–87. https://doi.org/10.17127/got/2017.11.008

29. Jiang Z, Huete AR, Chen J, Chen Y, Li J, Yan G, Zhang X. Analysis of NDVI and scaled difference vegetation index retrievals of vegetation fraction. Remote Sens Environ. 2006;101:366–78. https://doi.org/10.1016/j.rse.2006.01.003

30. Serrano L, Filella I, Peñuelas J. Remote sensing of biomass and yield of winter wheat under different nitrogen supplies. Crop Sci. 2000;40:723–31. https://doi.org/10.2135/cropsci2000.403723x

31. Wang J, Rich PM, Price KP. Temporal responses of NDVI to precipitation and temperature in the central Great Plains, USA. Int J Remote Sens. 2003;24:2345–61. https://doi.org/10.1080/01431160210154812

32. Warszawski L, Friend A, Ostberg S, Frieler K, Lucht W, Schaphoff S, et al. A multi-model analysis of risk of ecosystem shifts under climate change. Environ Res Lett. 2013;8:044018. https://doi.org/10.1088/1748-9326/8/4/044018

33. Chavaillaz Y. The speed of climate change and its implications for the perception of future generations [Thesis]. Paris-Saclay: University Paris-Saclay; 2016. p. 274

34. Gourari B. Study and mapping of the vegetation of Djebel Medjounes (Hautes Plaines Sétifiennes, North Tellien) [Thesis]. Sétif 1: University of Sétif 1; 2023. p. 468

35. Villeneuve C. Forests and humans: A shared destiny. Quebec: Ministry of International Relations of Quebec; 2009. p. 101

36. Falloon PD, Dankers R, Betts RA, Jones CD, Booth BBB. Role of vegetation change in future climate under the A1B scenario and a climate stabilization scenario, using the HadCM3C Earth system model. Biogeosci. 2012;9:4739–56. https://doi.org/10.5194/bg-9-4739-2012

37. Port U, Brovkin V, Claussen M. The influence of vegetation dynamics on anthropogenic climate change. Earth Syst Dyn. 2012;3:233–43. https://doi.org/10.5194/esd-3-233-2012

38. Mykrä H, Heino J, Muotka T. Scale-related patterns in the spatial and environmental components of stream macroinvertebrate assemblage variation. Glob Ecol Biogeogr. 2007;16(2):149–59. https://doi.org/10.1111/j.1466-8238.2006.00272.x

39. Victorer L, Robert K, Robinson LF, Taylor ML, Huvenne VAI. Species replacement dominates megabenthos beta diversity in a remote seamount setting. Sci Rep. 2018;8:4152. https://doi.org/10.1038/s41598-018-22296-8

40. Octavian-Adrian S. Adaptation and mitigation to climate change as a vector for maintaining inequality [Thesis]. Liège: University of Liège; 2021

41. Belaid AM. Climate risks and their impacts on the environment [Thesis]. Oran: University of Oran; 2015. p. 184

42. Ralantoarisoa H. Impacts of climate change on rice yield in the municipality rural area of Merintsiatosika [Thesis]. Antananarivo: University of Antananarivo; 2016

43. Dallahi M, Boujral A, Meliho M, Orlando CA. Assessment of forest dieback in Moroccan central plateau using spectral vegetation indices. J For Res. 2022;34:793–808. https://doi.org/10.1007/s11676-022-01525-x

44. Nafouri R, El Hichou A. NDVI analysis using Landsat 8 OLI in the Dades watershed (High Atlas, Morocco). AS Acad Proc. 2023;12(4):444.

Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

Reprints & permissions information is available at https://horizonepublishing.com/journals/index.php/PST/open_access_policy

Publisher's Note: Horizon e-Publishing Group remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc
See https://horizonepublishing.com/journals/index.php/PST/indexing_abstracting

Publisher information: Plant Science Today is published by HORIZON e-Publishing Group with support from Empirion Publishers Private Limited, Thiruvananthapuram, India.