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Impact of climate variability and soil physicochemical parameters on phytobiodiversity on four wetland sites in Taza province (Morocco)

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ABSTRACT

Understanding how ecological factors influence plant communities is essential for biodiversity conservation, especially in regions experiencing climatic and anthropogenic pressures. In this context, the present study explores the floristic diversity of four wetland sites in Taza province (Morocco): Oued M'Soun, Ras-El-Ma, Oued Elbared, and Lac Tameda. These sites, representative of the region's ecological variability, offer a valuable opportunity to assess the relationship between environmental conditions and plant distribution. Floristic surveys were conducted in March 2024 using 10 m² plots, complemented by physico-chemical soil analyses (granulometry and pH), satellite-derived vegetation indices, notably the normalized difference vegetation index (NDVI), and statistical analyses including principal component analysis (PCA) and hierarchical classification. The NDVI was employed to assess vegetation vigor and spatial distribution patterns at each station, providing a quantitative complement to field observations. The results reveal significant differences among the stations in terms of precipitation, temperature, soil type, pH, and NDVI values, all of which shape the composition and health of local vegetation. A high level of plant diversity was observed, with dominant families including Asteraceae, Lamiaceae, and Rosaceae. Some species, such as *Scolymus hispanicus* and *Carduus pycnocephalus*, were present at all four sites, highlighting their ecological adaptability, whereas others, like *Juniperus thurifera* and *Nerium oleander*, were restricted to specific habitats. The PCA and classification analyses distinguished three floristically distinct groups of stations, structured according to environmental gradients, including vegetation vigor inferred from NDVI. These findings underscore the uniqueness of Taza's flora within semi-arid Mediterranean ecosystems and emphasize the need for conservation strategies adapted to the pressures threatening these natural habitats.

Keywords: Floristic inventory, environmental factors, plant diversity, NDVI, PCA, conservation.

INTRODUCTION

Floristic diversity is a key element in the analysis of ecosystems, as it reflects the complex interaction between plant species and the environmental factors that condition them. In the Mediterranean region, this diversity is accentuated by marked ecological gradients, particularly in terms of climate, topography and edaphic conditions (Quézel et al., 2003).

Morocco is a biodiversity hotspot where more than 4,200 vascular species have been identified. It is situated at the intersection of various biogeographical influences, including Mediterranean, Saharan, Atlantic, and Euro-Siberian, of which almost 879 are endemic (Fennane et al., 1999; Fennane et al., 2005). The Taza region, a transition zone between the Rif and the Middle Atlas, offers remarkable ecological diversity, ideal for floristic distribution studies. Natural environments are shaped by heterogeneous abiotic factors such as soil type, pH, granulometry, rainfall and temperature variations (Lucie, 2008; Mathieu et al., 2009).

Advances in remote sensing technologies have enabled the use of vegetation indices like the Normalized Difference Vegetation Index (NDVI) to quantitatively evaluate vegetation health and spatial distribution across extensive regions (Rouse et al., 1974). In Mediterranean ecosystems, NDVI is particularly valuable for tracking vegetation dynamics, identifying the effects of climate-related stressors such as drought, and evaluating anthropogenic impacts on vegetation cover (Pérez-Harguindeguy et al., 2021; García et al., 2020; Zhang et al., 2019; Mekonnen et al., 2022).

The dynamics, composition, and structure of plant communities are all directly impacted by these factors. Comparing the floristic composition of four representative wetland stations in Taza province (Oued M'Soun, Ras-El-Ma, Oued Elbared, and Lac Tameda) is the goal of the current study. While analyzing the associated ecological parameters. The approach adopted combines classic botanical inventory methods (Braun-Blanquet, 1932), soil physico-chemical analyses and statistical tools (Principal Component Analysis., PCA), to identify the ecological gradients underlying the spatial distribution of species (Friedman et al., 2004). To our knowledge, this is the first study to combine floristic inventory and environmental analysis using a multivariate statistical approach in this region, which enhances its scientific value. This research is part of a descriptive and functional ecology framework aimed at enriching knowledge of Moroccan flora and contributing to the conservation of Mediterranean ecosystems, which are increasingly threatened by climate change and anthropogenic pressures (Benabid, 2000; Tison et al., 2014).

MATERIALS AND METHODS

Geographical context of study stations

As part of this floristic study, four wet stations located in the province of Taza were selected for their ecological diversity and their representativeness of the main types of natural environment in the region. The regions of Oued M'Soun, Ras-El-Ma, Oued Elbared and Lac Tameda stand out for their diversified geographical and environmental characteristics, conducive to analysis of the distribution of local flora in relation to environmental conditions. Below (Table 1) is a geographical presentation of each station.

METHODOLOGY

Climatic Data

Climatic data for the year 2024 (Precipitation and temperature), were obtained for each study site from the National Agency for Water and Forests of Taza. These data were used to characterize the local climatic conditions that may influence floristic composition across the stations.

Soil study

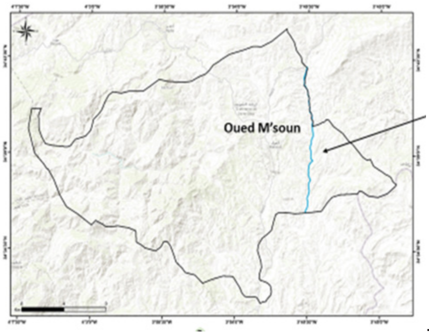
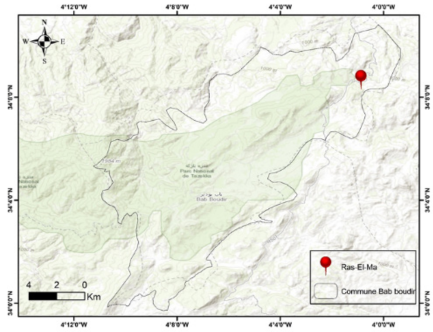
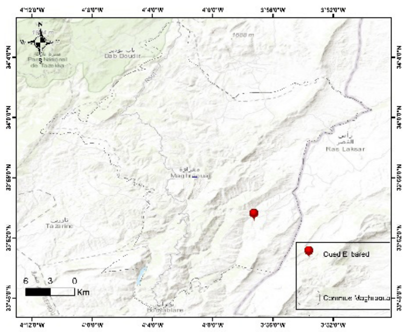
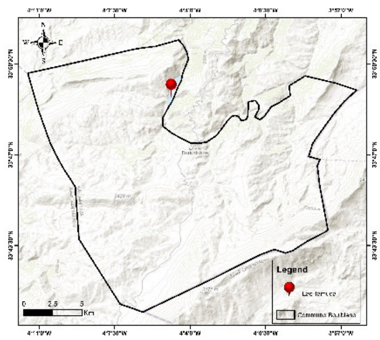
In this study, soil samples were taken from a depth of 0 to 20 cm at each site to analyze their physico-chemical properties. Granulometry was determined by separating the coarse elements (diameter > 2 mm) from the fine fraction (diameter < 2 mm), a necessary step in assessing soil texture (Lucie, 2008). The granulometric analysis of the fine soil was carried out by dry sieving, enabling the proportions of fine and coarse sand to be quantified. In addition, pH was measured using a pH meter (Mathieu et al., 2009) on a solution prepared with a soil/water ratio of 1/5.

Normalized Difference Vegetation Index

In this study, we used Landsat satellite images with a spatial resolution of 30 m, obtained from the Landsat 8 OLI (Operational Land Imager) and Landsat 4–5 sensors. These data enabled us to monitor changes in natural vegetation cover within the study sites (Figure 1).

The Normalized Difference Vegetation Index, first developed by Rouse et al. (1974) from satellite imagery, is one of the most widely used

Table 1. Geographical location of the study sites

Oued M'Soun Station The Oued M'soun station is located in the commune of Aknoul, in the center of Gzenaya Al Janoubia (Taza province), with latitude (N) 34°21' and longitude (W) 03°15' 	Ras-El-Ma Station The Ras-El-Ma (Ras-El-Oued) station is located south of the town of Taza, in the Bab Boudir commune, at latitude (N) 34°08' and longitude (W) 04°01'. 
Oued Elbared Station The Oued El Bared station is located in the Fès-Meknès region, Taza province in northeastern Morocco, in the Maghraoua commune, with latitude (N) 33°57' and longitude (W) 03°54'. 	Lac Tameda Station Lac Tamda is a natural lake in the rural commune of Maghraoua, province of Taza, with latitude (N) 33°49' and longitude (W) 04°04'. 

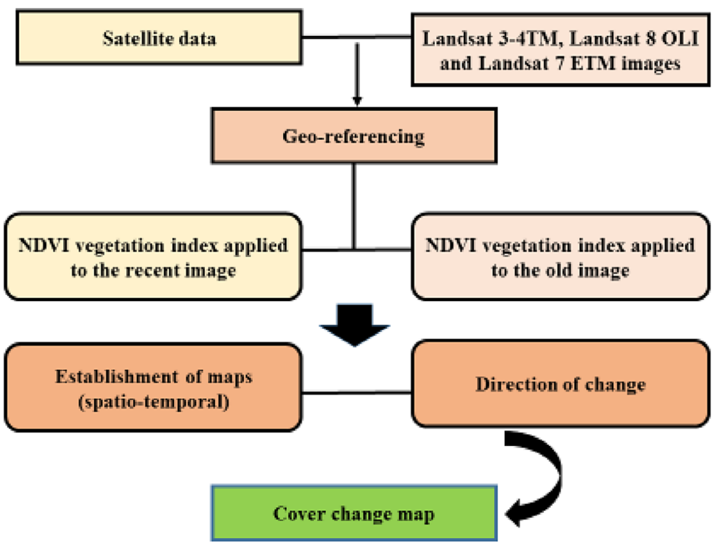


Figure 1. Methodology of work

tools for environmental monitoring. It is generally recognized as a reliable indicator of vegetation condition. NDVI is calculated using the red and near-infrared (NIR) bands of satellite images, taking advantage of the spectral reflectance properties of plants. Vegetation strongly absorbs red wavelengths (~650 nm) due to chlorophyll, while reflecting NIR wavelengths (700–900 nm) to a degree that depends on photosynthetic activity. The index is defined as:

$$NDVI = \frac{pir - pr}{pir + pr} \quad (1)$$

where: ρ_{NIR} is the reflectance in the near-infrared band and ρ_{R} is the reflectance in the red band.

The result is a new image in which NDVI values range from −1 to +1: values close to +1 indicate dense forest cover, values near 0 correspond to bare soil, and negative values are typically associated with water bodies.

Floristic inventory

At each station studied, floristic surveys were carried out during March 2024 using the 10 m² fixed plot method, chosen to best represent the ecological heterogeneity of the site. This method enables a systematic and repeatable approach to floristic diversity, taking into account plant cover and species frequency (Braun-Blanquet, 1932). Online databases and botanical references (Flore d'Afrique du Nord, Flore vasculaire du Maroc) were used to identify plants (Fennane et al., 2005).

Statistical analysis tools

Principal Component Analysis was performed using SPSS software. As a reminder, PCA is a multi-criteria classification method, which synthesizes all the information provided by the different variables on a 2-axis factorial plane or on a multi-dimensional space (3 or more) used to classify individuals and/or variables into relatively homogeneous point clouds.

This method yields several indicators reflecting correlations and variabilities between individuals and variables. These indicators inform us about possible cause-and-effect relationships that may arise with each change in the parameters of the tests and experiments carried out.

Individuals and variables belonging to the same point cloud block show relatively homogeneous features and similarities (low intra-group variability). On the other hand, scattered or distant point clouds show very heterogeneous specificities (resulting in very high inter-group variability). In this study, the individuals correspond to the 4 stations (Oued M'Soun, Ras-El-Ma, Oued Elbared and Lac Tameda), while the variables represent the botanical families identified according to the four stations studied.

RESULTS AND DISCUSSION

Climatic data

Climatic analysis of the study stations in 2024 (Figures 2 and 3) reveals significant variations in mean annual precipitation and temperature. The Ras-El-Ma station stands out for both hot and humid conditions, with the highest mean temperature (18.49°C) and the highest rainfall (26.58 mm). Lac Tameda, on the other hand, although

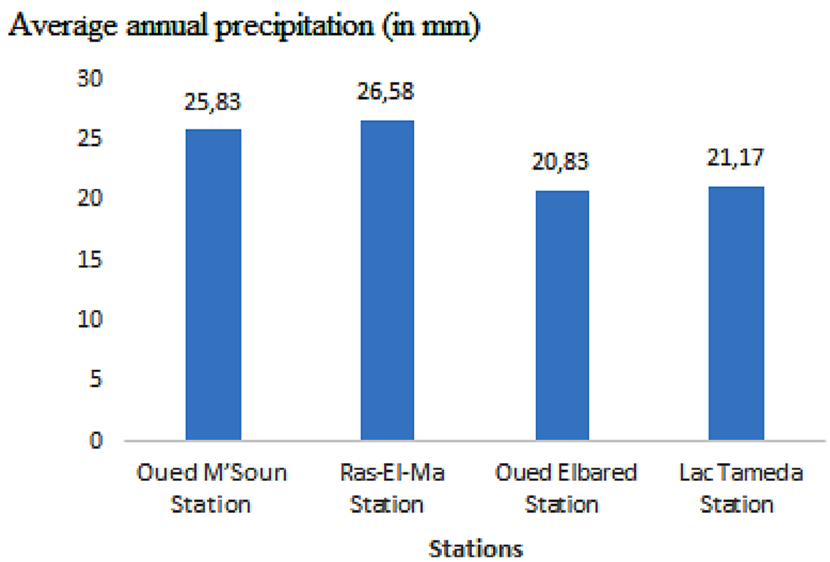


Figure 2. Average annual precipitation (mm) in 2024 at the studied stations (Source: National Agency for Water and Forests, Taza)

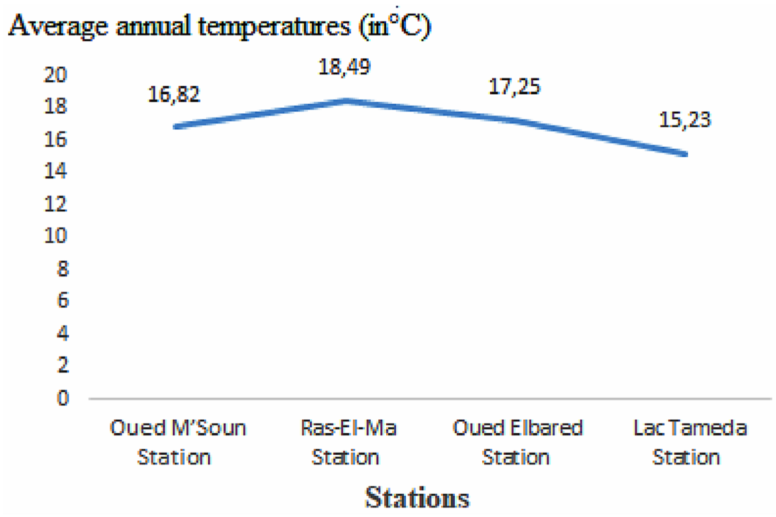


Figure 3. Average annual temperatures (°C) recorded in 2024 at the various stations studied (Source: National Agency for Water and Forests, Taza)

recording moderate rainfall (21.17 mm), has the lowest average temperature (15.23 °C), suggesting a cooler climate. The Oued Elbared station, with the lowest rainfall (20.83 mm) and a relatively high temperature (17.25 °C). Finally, Oued M'Soun has an intermediate climate, with (25.83 mm) rainfall and an average temperature of (16.82 °C).

Granulometry

A granulometric analysis by dry sieving was carried out on samples taken from four separate stations: Ras El Ma, Lac Tamda, Oued El Bared and Oued M'soun. The aim was to determine the distribution of granulometric fractions, notably coarse sand (200-2000 µm), fine sand (50-200 µm) and fines (< 50 µm, including silt and clay).

- Ras El Ma
  - Coarse sand: 63.3%.
  - Fine sand: 32.4%.
  - Fines (< 50 µm): 4.35%.
  - Texture: Coarse sand, in compliance with NF X 31-107 ("predominantly coarse sand").
  - Properties: High permeability, low water and nutrient retention.
- Lac Tameda
  - Coarse sand: 72.37%.
  - Fine sand: 25.64%.
  - Fines (< 50 µm): 1.99%.
  - Texture: Similar to Ras El Ma, classified as "predominantly coarse sand".
- Oued El Bared
  - Coarse sand: 92.78% (very marked predominance)
  - Fine sand: 6.72
  - Fines (< 50 µm): 0.53%.
  - Texture: Extremely coarse, almost devoid of fine elements.
- Oued M'soun
  - Fine (< 50 µm): 81.46% (majority)
  - Fine sand: 16.44
  - Coarse sand: 2.09% (almost absent)
  - Texture: Fine (silty-clayey), suggesting better water retention and higher potential fertility.

The Ras El Ma, Lac Tameda and Oued El Bared stations have predominantly coarse sandy soils, characterized by high permeability and low water retention capacity. Oued M'soun, on the other hand, is characterized by a fine texture, more conducive to nutrient accumulation and water retention.

This granulometric variability could influence the agronomic and ecological properties of the soils studied.

pH

Analysis of soil pH (Table 2) at the study sites shows slight but significant variations, which may influence local floristic composition. The Oued M'Soun station has a pH of 8.36, indicating an alkaline soil, while Lac Tameda and Oued Elbared have pH values of 8.09 and 7.93 respectively, corresponding to slightly alkaline soils. On the other hand, the Ras-El-Ma station, with a pH of 7.6, is close to neutral.

Table 2. Soil pH values measured at various study sites

Stations	Oued M'soun	Ras-El-Ma	Oued Elbared	Lac Tameda
pH	8,36	7,6	7,93	8,09

Spatial variability of NDVI and influence of precipitation in 2024

The NDVI maps for 2024 (Figure 4) show marked heterogeneity between stations. Maximum values range from 0.48 (Lake Tamda) to 0.555 (Ras-El-Ma), reflecting differences in vegetation cover density and vigor. Ras-El-Ma has the highest NDVI, indicating dense and active vegetation. Oued Elbared also has a high value (0.549), suggesting good plant productivity despite a drier climate. Oued M'Soun has a maximum NDVI of 0.492 and stands out with a positive minimum (0.022), which could indicate the absence of areas completely devoid of vegetation. Finally, Lake Tamda, with a maximum NDVI of 0.48 and a minimum of -0.187, appears to have areas with less dense or sparse vegetation.

A comparison between NDVI and average annual precipitation reveals a general trend toward an increase in maximum NDVI with increasing precipitation. Ras-El-Ma, which has the highest precipitation (26.58 mm), has the highest maximum NDVI (0.555), reflecting the positive impact of available water on plant productivity. Oued M'Soun (25.83 mm) also has moderate NDVI values. However, some stations, such as Oued Elbared, buck this trend:

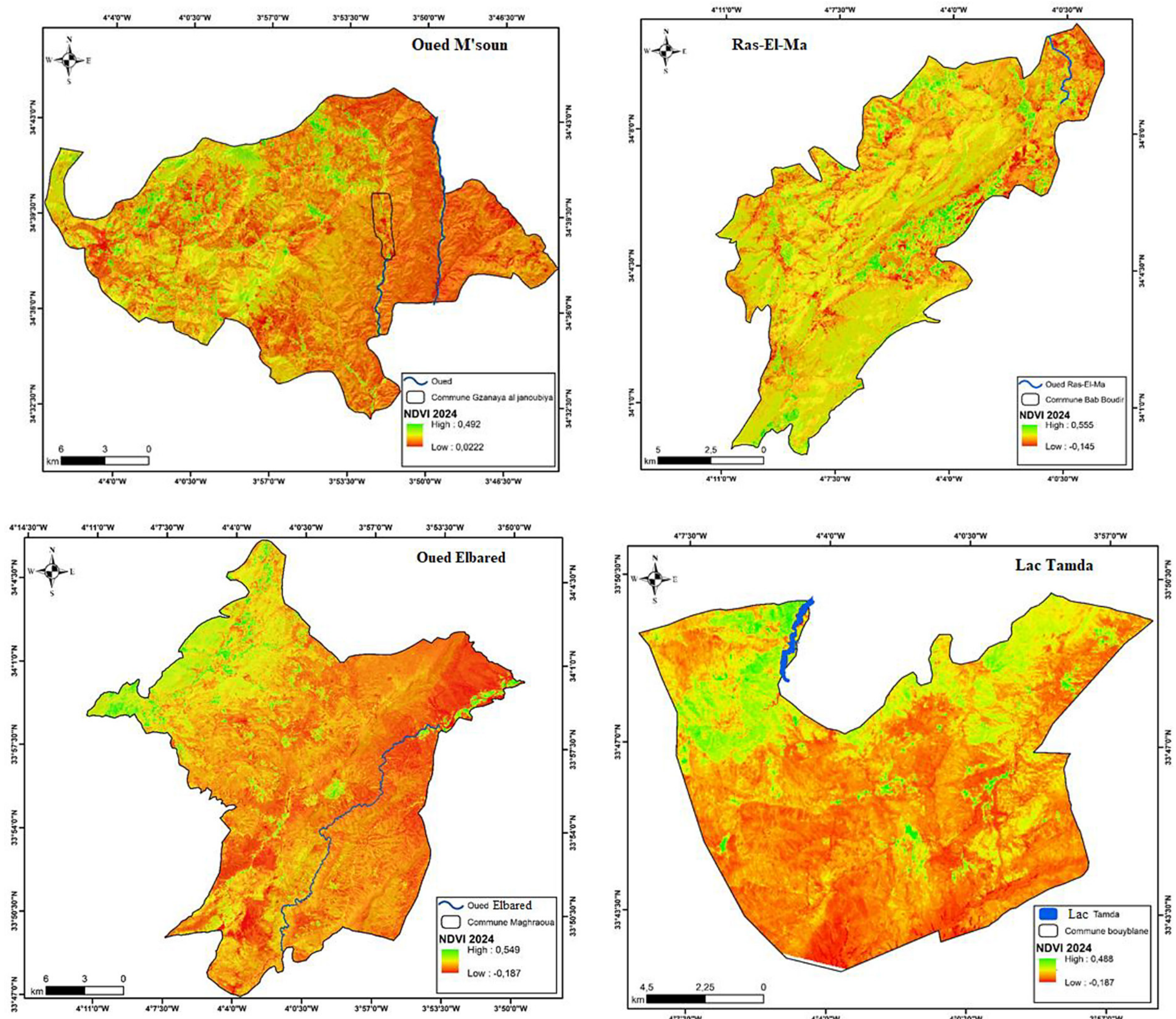


Figure 4. Spatial distribution of vegetation according to NDVI in 2024 in the four wetland in Taza province (Morocco)

Table 3. Distribution of plant species observed at Oued M'soun, Ras-El-Ma, Oued Elbared and Lac Tameda

Stations	Oued M'soun	Ras-El-Ma	Oued Elbared	Lac Tameda
Species inventoried	*-Pinus halepensis* *-Salvia rosmarinus* *-Pistacia lentiscus* *-Nerium oleander* *-Cistus albidus* *-Ononis natrix* *-Teucrium polium* *-Mentha rotundifolia* *-Rosa agrestis* *-Antirrhinum australe Rothm* *-Saccharum officinarum* *-Juniperus oxycedrus*	*-Scolymus hispanicus* *-Lactuca serriola* *-Hedara helix* *-Melia azedarach* *-Crepis bursifolia* *-Veronica beccabunga* *-Rosa galica* *-Carex cuprina* *- Anchusa officinalis* *-Ehrharta dressée* *-Salvia officinalis* *-Urtica dioica* *-Umbilcus rupestris* *-Fraxinus excelsior* *-Vinca major* *-Carduus pycnocephalus* *-Malva sylvestris* *-Papaver rhoeas* *-Convolvulus althaeoides* *-Malva neglecta* *-Nerium oleander*	*-Herniaria hirsuta* *-Trachelium caeruleum* *-Chenopodiastrum murale* *-Campanula celsii* *-Pistacia lentiscus* *-Carduus pycnocephalus* *-Phoenix dactylifera* *-Juniperus thurifera* *-Salvia rosmarinus* *-Ampelodesmos mauritanicus* *-Pinus halepensis* *-Sonochus tenerrimus*	*-Origanum onites* -Quercus ilex *-Juniperus thurifera* *-Cedrus atlantica* *-Scolymus hispanicus* *- Chamaerops humilis* *- Papaver rhoeas* *- Onopordum acaulon* *- Picnomon acarna* *- Isatis tinctoria* *- Mentha villosa* *- Rosa agrestis* *-Antirrhinum australe Rothm* *-Crataegus azarolus* *-Astragalus sempervirens*

despite the lowest rainfall (20.83 mm), its maximum NDVI remains high (0.549), which could be explained by favorable local factors such as proximity to a water table or the presence of suitable perennial vegetation. Lac Tamda, with moderate rainfall (21.17 mm) but a lower NDVI, illustrates the importance of edaphic constraints and local characteristics in regulating vegetation cover.

Climatic variables, particularly precipitation and temperature, have a strong influence on vegetation dynamics, as they directly determine water supply and the photosynthetic potential of plants. Several studies have shown that increased precipitation is usually associated with higher NDVI values, which indicate denser and more productive vegetation (Mahcer et al., 2024; Zhao et al., 2024). Conversely, prolonged periods of drought can cause a sudden drop in "greening" and a decrease in biomass, as was observed during the severe drought of 2023 in the Amazon (Jiménez et al., 2024). However, the link between climate and vegetation is not necessarily linear: In some scenarios, high NDVI values may persist despite low rainfall, thanks to the presence of groundwater, soils that retain water well, or drought-resistant plant species (Bianchini, 2025; Zhang et al., 2024). Furthermore, the impacts of climate on vegetation can vary depending on altitude, topography, and land use practices. This highlights the importance of multidimensional methods that combine satellite data with environmental factors (Mahcer et al., 2024).

Floristic inventory of the Oued M'soun, Ras-El-Ma, Oued Elbared and Lac Tameda stations

The plant species inventoried at the various stations studied (Oued M'soun, Ras-El-Ma, Oued Elbared and Lac Tameda) are listed in Table 3.

Common floristic distribution between the stations studied

Floristic analysis revealed the presence of several common species (Table 4) at several of the study sites, testifying to certain ecological similarities between these sites. Two species, *Scolymus hispanicus* and *Carduus pycnocephalus* (Asteraceae), were found at all four study sites, suggesting wide distribution and good adaptation to the region's different environmental conditions. Four other species, *Pinus halepensis* (Pinaceae), *Salvia rosmarinus* (Lamiaceae), Rosa agrestis (Rosaceae) and Antirrhinum australe (Plantaginaceae), were observed at three or two stations, reflecting a certain floristic continuity between Oued M'soun, Oued Elbared and Lac Tameda. Similarly, *Papaver rhoeas* (Papaveraceae), *Juniperus thurifera* (Cupressaceae) and *Nerium oleander* (Apocynaceae) were found at two stations each. This floristic repetition between stations highlights shared ecological gradients,

Table 4. Classification of plant species common to several study sites

Scientific name: *Pinus halepensis* Common name: Aleppo pine/white pine  Photo Taken on March 20, 2024	Classification (Quézel et al., 2003). Reign: Plantae Sub-reign: Tracheobionta Division: Pinophyta Class: Pinopsida Subclass: Pinidae Ordre: Coniferales Family: Pinaceae Gender: *Pinus* Species: *halepensis*
Scientific name: *Salvia rosmarinus* Common name: Rosemary  Photo Taken on March 20, 2024	Classification (Quézel et al.,1993). Reign: Plantae Sub-reign: Virdaeplantae Division: Magnoliophyta Class: Equisetopsida Subclass: Magnoliidae Ordre: Lamiales Family: Lamiaceae Gender: *Salvia* Species: *rosmarinus*
Scientific name: *Nerium oleander* Common name: Pink oleander  Photo Taken on March 20, 2024	Classification (APG III, 2009) Reign: Plantae Sub-reign: Virdaeplantae Division: Magnoliophyta Class: Magnoliopsida Subclass: Magnoliidae Ordre: Gentianales Family: Apocynaceae Gender: *Nerium* Species: *oleander*
Scientific name: *Rosa agrestis* Common name: Small-leaved/sweet-briar  Photo Taken on March 20, 2024	Classification (Tison et al., 2014) Reign: Plantae Sub-reign: Tracheobionta Division: Magnoliophyta Class: Magnoliopsida Subclass: Rosidae Ordre: Rosales Family: Rosaceae Gender: *Rosa* Species: *agrestis*

Scientific name: *Antirrhinum australe Rothm* Common name: Snapdragon  Photo Taken on March 20, 2024	Classification (Rothmaler, 1956) Reign: Plantae Sub-reign: Tracheobionta Division: Magnoliophyta Class: Equisetopsida Subclass: Asteridae Ordre: Scrophulariales Family: Scrophulariaceae Gender: *Antirrhinum* Species: *australe Rothm*
Scientific name: *Papaver rhoeas* Common name: Poppy  Photo Taken on March 21, 2024	Classification (Hequet et al., 2009) Reign: Plantae Sub-reign: Tracheobionta Division: Magnoliophyta Class: Magnoliopsida Subclass: Magnoliidae Ordre: Papaverales Family: Papaveraceae Gender: *Papaver* Species: *rhoeas*
Scientific name: *Scolymus hispanicus* Common name: Golden Thistle  Photo Taken on March 20, 2024	Classification (Tison et al., 2014) Reign: Plantae Sub-reign: Viridaeplantae Division: Streptophyta Class: Equis etopsida Subclass: Magnoliidae Ordre: Asterales Family: Asteranae Gender: *Scolymus* Species: *hispanicus*
Scientific name: *Carduus pycnocephalus* Common name: Plymouth Thistle  Photo Taken on March 20, 2024	Classification (Tison et al., 2014) Reign: Plantae Sub-reign: Viridaeplantae Division: Streptophyta Class: Equisetopsida Subclass: Magnoliidae Ordre: Asterales Family: Asteranae Gender: *Carduus* Species: *pycnocephalus*

Scientific name: *Juniperus thurifera* Common name: Thuriferous juniper  Photo Taken on March 20, 2024	Classification (Mao et al., 2010) Reign: Plantae Sub-reign: Pracheobionta Division: Pinophyta Class: Pinopsida Subclass: Cupressidae Ordre: Pinales Family: Cupressaceae Gender: *Juniperus* Species: *thurifera*

particularly in terms of climate, soil type or similar anthropogenic disturbances

The species identified at the sites studied have well-documented ecological requirements, reflecting their adaptation to Mediterranean conditions. *Pinus halepensis*, a typically Mediterranean species, thrives on calcareous soils, poor in organic matter but well drained, with a neutral to slightly alkaline pH, and is particularly suited to arid to semi-arid climates marked by dry summers and mild winters (Quézel et al., 2003; Barbero et al., 1990). *Salvia rosmarinus* (formerly *Rosmarinus officinalis*), characteristic of thermoxeric environments, thrives on shallow sandy-limestone to rocky soils (pH 6.5-8.5), and is drought-resistant thanks to its sclerophyllous foliage (Escudero et al., 2000; López et al., 1997). *Juniperus thurifera*, xerophilous and orophilous, preferentially colonizes calcareous or dolomitic rocky substrates (alkaline pH) in dry montane areas, tolerating both cold and drought (Terrab et al., 2008 ; Médail et al., 1999). Among nitrophilous species, *Carduus pycnocephalus* and *Scolymus hispanicus* (Asteraceae) prefer disturbed, nutrient-rich environments with clay-loam soils (neutral to slightly acid pH), typical of agricultural or ruderal areas (Zohary, 1973; Pignatti, 2005) *Papaver rhoeas*, a common messicolous plant, is found in light to medium, well-drained soils (neutral to alkaline pH), associated with crops or recent disturbances (Jauzein, 1995 ; Le Houérou, 1995).

Finally, *Nerium oleander*, a riparian species, requires deep, moist silty-clay soils (neutral to basic pH), depending on watercourses for its water supply in dry Mediterranean climates (Le Houérou, 1995). These specific adaptations underline the diversity of ecological strategies deployed by Mediterranean flora in response to local climatic and edaphic constraints.

Edaphic specialization is a key factor in species distribution, with many cases of endemism linked to specific substrates such as limestone, gypsum, or serpentine soils (Ibanez et al., 2022).

Furthermore, research conducted near the thermal springs of Aïn El Haouamed and Aïn Hamra in eastern Morocco has revealed that soil properties particularly its texture (clay-loam vs. loam-sand) and slightly basic pH play a decisive role in the structure and richness of spontaneous vegetation. These characteristics particularly influence nutrient availability and soil electrical conductivity (Mouchane et al., 2024).

Distribution of plant species by botanical family in the study areas

Floristic analysis by botanical family (Figure 5) reveals a clear predominance of Asteraceae, accounting for 17.8% of species recorded. This family, typical of Mediterranean environments, is well adapted to semi-arid climatic conditions.

Lamiaceae, with 13.3% of species, are in second place; they stand out not only for their species richness, but also for their constant presence at all the stations studied (Oued M'Soun, Ras-El-Ma, Oued Elbared and Lac Tameda), reflecting their strong ecological adaptability. Rosaceae (8.9%), followed by Poaceae and Cupressaceae (6.7% each), Pinaceae, Apocynaceae, Malvaceae and Papaveraceae, each representing 4.4%, contribute to enriching the plant stand structure. Finally, the 15 other families, each represented by a

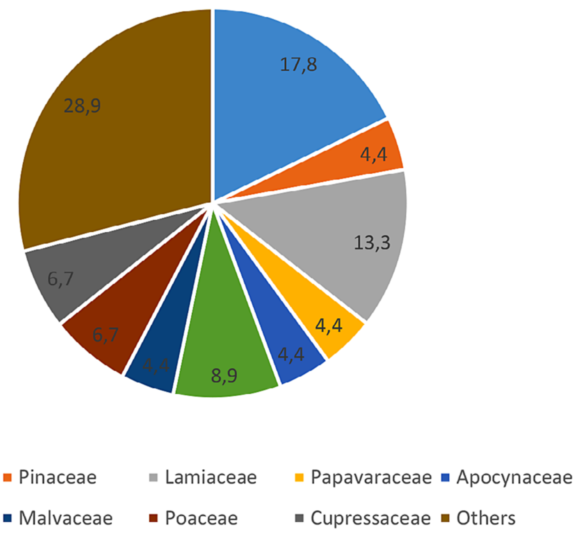


Figure 5. Distribution of plant species by botanical family in the study areas (in %)

single species, make up 28.9% of the total, underlining the great floristic and ecological diversity of the environments studied. The dominance of Asteraceae in the areas studied, one of the most diverse botanical families in the world (Heywood et al., 2007), is explained by their great ecological plasticity and their adaptation to Mediterranean ecosystems, where they play a key role in plant successions and the colonization of disturbed environments. Their ability to thrive in poor soils and under variable water regimes makes them characteristic species of the semi-arid regions of the Maghreb (Le Houérou, 1995).

Lamiaceae, also well represented, confirm their affinity with Mediterranean bioclimates (Quézel et al., 3003), thanks to their xerophilic, aromatic traits and resistance to water stress, as well as their efficient reproductive strategy. On the other hand, the presence of less abundant families, such as Poaceae and Cupressaceae, as well as a diversity of rare species (each family being represented by a single species), reflects ecological heterogeneity between stations. This floristic diversity highlights the combined influence of complex environmental factors, including topography, microclimates and human disturbance (Pignatti, 2005), underlining the specificity and richness of these Mediterranean ecosystems.

Statistical analysis

Principal component analysis and hierarchical clustering revealed distinct groupings between the stations studied on the basis of floristic composition. These groupings reflect significant disparities in the distribution of botanical families, probably influenced by local ecological conditions.

The results obtained gave rise to a multivariate analysis in which the first two principal components summarized around 79.87% of the total information (Table 5 of total variance explained). This high percentage justifies the interpretation of the first two factorial axes, as shown by the graph of variables and the graph of individuals (Figures 6 and 7).

Table 5. Total variance explained for the different botanical families

Component	Initial eigenvalues			Sum of squares of rotation factors		
	Total	% of variance	% cumulative	Total	% of variance	% cumulative
1	13,609	50,406	50,406	13,378	49,548	49,548
2	7,956	29,465	79,871	8,187	30,323	79,871
From the 3rd to the 27th component	5,450	20,129	100,000			

Note: We have compiled this summary table from the table of eigenvalues, which reflect the variability of the principal components.

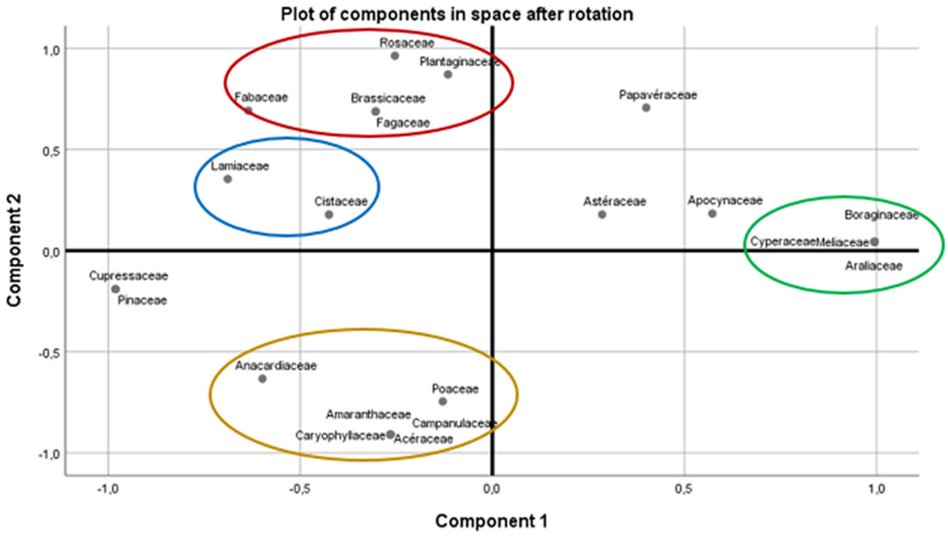


Figure 6. Variable graph

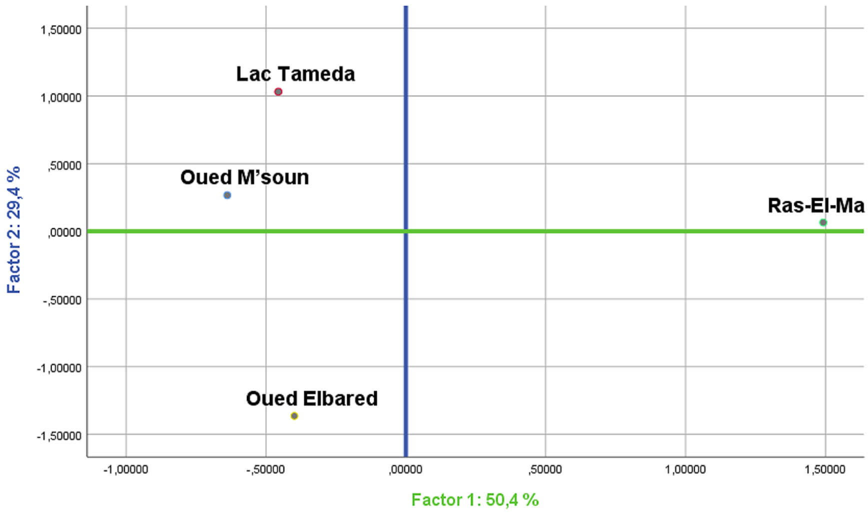


Figure 7. Scatter plot of individuals

The graph of variables (botanical families) shows that certain families such as Rosaceae, Fabaceae, Brassicaceae, Papaveraceae and Plantaginaceae make a significant contribution to Component 2, while families such as Asteraceae, Apocynaceae, Boraginaceae or Araliaceae are more closely correlated with Component 1. Conversely, families such as Anacardiaceae, Poaceae, Caryophyllaceae or Campanulaceae are far from the positive axes, indicating very specific floristic profiles.

The graph of individuals (stations) reveals a clear ecological structuring:

- The Ras-El-Ma station is strongly associated with Component 1, reflecting its particular floristic richness.
- Lac Tameda stands out for its strong contribution to Component 2.
- Oued Elbared and Oued M'soun appear further back on both axes, reflecting a more homogeneous or less diverse floristic composition.

Thus, the proximity of a station to certain botanical families reflects a strong ecological link, while its distance from them indicates a weak floristic affinity with them.

Finally, the ascending hierarchical classification (Figure 8) distinguishes three main groups:

- The first group includes Ras-El-Ma and Lac Tameda, which are only a short distance apart. These two stations are therefore very close floristically.
- The second group is made up solely of Oued Elbared, which has its own particular characteristics, allowing it to stand out moderately.

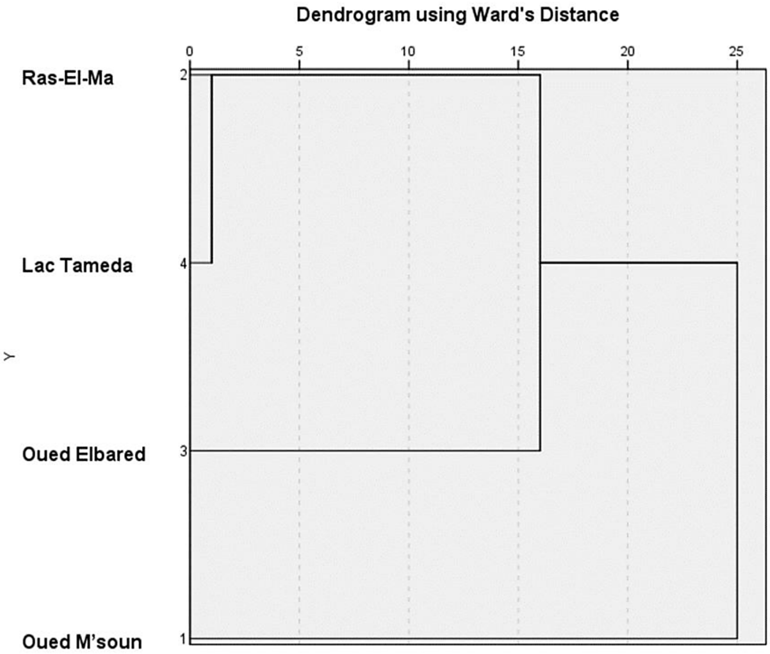


Figure 8. Hierarchical classification dendrogram

- The third group, more isolated, is represented by Oued M'soun, reflecting a marked ecological and floristic specificity.

This structuring reflects the existence of significant inter-station variability, probably linked to abiotic factors such as soil type and climatic conditions (temperature and rainfall).

The combined approach of principal component analysis and hierarchical ascending classification (HAC) is particularly relevant for deciphering the complex organization of Mediterranean plant communities. As pointed out by Legendre & Legendre, this methodology effectively reduces the dimensionality of the data while preserving the essential structures, with in our case almost 80% of the variance explained by the first two axes – a remarkable result that authorizes a sound ecological interpretation (Jolliffe, 2002).

The differential distribution of botanical families in factor space, notably the polarization of Asteraceae on axis 1 and Rosaceae on axis 2, reveals non-random patterns that reflect distinct ecological niches (Borcard et al., 2011). The overall architecture of the plant communities observed results from the complex interaction of multiple environmental gradients. As demonstrated by Quézel & Médail (2003) and Blondel et al (2010) in Mediterranean ecosystems, these gradients integrate both abiotic factors (nature of substrate, water regime) and biotic factors (interspecific competition). The ecological singularity of the Oued M'soun station, clearly identified by HAC, could be explained by particular edaphic conditions or geographical isolation, in line with the speciation models described by Médail & Diadema. Conversely, the floristic proximity between Ras-El-Ma and Lac Tameda suggests a homogenization of microclimatic conditions or a shared evolutionary history.

From a functional point of view, these results corroborate the work of Lavorel et al on the differential response of functional traits to disturbance in Mediterranean environments. The particular resilience of Asteraceae, clearly visible in our PCA, fits into the conceptual framework developed by Le Houérou concerning drought avoidance strategies. This multivariate analysis thus not only provides an operational station typology for conservation (Margules et al., 2000), but also allows us to pose testable hypotheses on the mechanisms of plant community assembly in a Mediterranean context.

CONCLUSIONS

The flora analysis carried out in the province of Taza, covering the four sites of Oued M'Soun, Ras-El-Ma, Oued Elbared and Lac Tameda, revealed a remarkable floristic richness and significant ecological diversity. Observation of the species present showed a significant influence of abiotic factors such as soil type, pH and local meteorological conditions (temperature and rainfall). Principal component analysis revealed a distinct floristic organization between sites, reflecting the impact of particular environmental characteristics on vegetation composition.

Species such as *Scolymus hispanicus* and *Carduus pycnocephalus*, found at all sites, show a remarkable ability to adapt to the different environments examined. Others, on the other hand, seem more specific and can act as ecological indicators of local conditions, such as *Juniperus thurifera* in mountainous areas or *Nerium oleander* in humid environments.

Important supplementary data on vegetation strength and spatial distribution throughout the study sites was made available by the incorporation of satellite-derived vegetation indices, especially the normalized difference vegetation index. By emphasizing differences in plant cover and health associated with environmental gradients, NDVI data validated field findings. In semi-arid Mediterranean habitats, where plant communities are heavily influenced by seasonal and climatic fluctuation, this remote sensing method works well for tracking vegetation dynamics.

This study corroborates that the plant diversity of the Taza area, although localized, illustrates semi-arid Mediterranean ecosystems. It also highlights the need to protect these natural environments in the face of increasing dangers linked to climate change, excessive resource depletion and urbanization. Understanding local floristic dynamics is therefore crucial to developing sustainable management strategies aimed at preserving biodiversity and appreciating Morocco's natural heritage.

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