Assessment of the spatio-temporal dynamics of agricultural lands in relation to rainfall variability in the Tadla plain (Morocco)

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Abstract. The Tadla Plain, situated in central Morocco under semi-arid climatic conditions, represents a key agricultural area at the national scale, yet it is highly exposed to climate-related constraints, particularly fluctuations in rainfall and increasing stress on irrigation water resources. Building on earlier findings that documented a 21% reduction in cultivated land between 2013 and 2023, this study examines vegetation dynamics during the subsequent period from 2023 to 2025, marked by a notable recovery in precipitation. Vegetation conditions were evaluated using the Normalized Difference Vegetation Index (NDVI) derived from Landsat 8 imagery, in conjunction with rainfall records obtained from the NASA database. Field surveys were conducted to support and validate the remote sensing analysis. The results indicate a clear improvement in vegetation status across the Tadla Plain, with high-density vegetation areas increasing from 5.9% to 11.4% of the total surface area. In parallel, zones with moderate vegetation cover expanded from 24.6% to 29.2%. These changes closely coincide with a substantial rise in annual rainfall, which increased from an average of 240.38 mm in 2023 to 402.43 mm in 2025. The findings underline the strong dependence of agricultural systems in the Tadla Plain on climatic variability and demonstrate the effectiveness of satellite-based indicators as valuable tools for supporting sustainable land and water resource management.

1 Introduction

The Tadla Plain, located in central Morocco, is characterized by arid to semi-arid climatic conditions, where limited and irregular rainfall strongly constrains agricultural productivity. Over the past decade, the region has experienced persistent drought episodes that have significantly reduced surface water availability, weakened vegetation development, and lowered reservoir storage capacity. According to the Emberger pluviometric classification,

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these climatic constraints have increased pressure on irrigated agriculture, particularly within the Tadla irrigation scheme, which plays a strategic role in national crop production [2, 4].

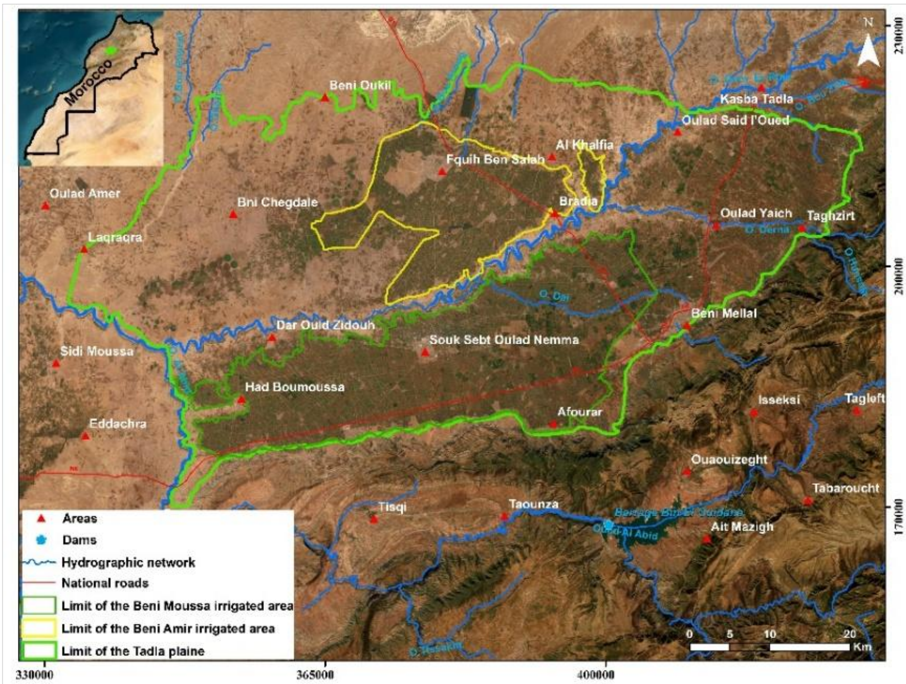
In parallel, the growing dependence on groundwater abstraction, combined with climate variability, has exacerbated land degradation processes and intensified competition over water resources. These dynamics pose serious risks to the ecological sustainability of cultivated areas and threaten the long-term contribution of the Tadla Plain to Morocco's food security [1, 3, 5, 8].

Against this background, the present study investigates recent variations in vegetation cover across the Tadla Plain during the period 2023–2025. This analysis follows a documented decline of approximately 21 % in cultivated land between 2013 and 2023 [6]. Vegetation dynamics are assessed using the Normalized Difference Vegetation Index (NDVI) derived from Landsat 8 satellite imagery, in combination with precipitation data provided by NASA and supported by field observations. This multi-source approach enables an evaluation of vegetation response to recent increases in annual rainfall, while accounting for the vulnerability of local natural resources.

2 Presentation of the Tadla plain

The Tadla region extends over nearly 3,200 km² on the northern foothills of the Atlas Mountains and is shaped by the east–west course of the Oum Er-Rbia River. Rather than forming a uniform plain, the area presents a heterogeneous geomorphology, with sections of the river locally entrenched into the landscape, which explains its frequent classification as a so-called "pseudo-plain". It is divided into two main parts: to the north-northwest, the phosphate plateau corresponding to the Béni-Amir Plain, lying on a Paleozoic basement overlain by Cretaceous and Eocene limestone; and to the south-southeast, the Béni-Moussa Plain, located at the foot of the Middle and High Atlas. These areas have undergone structural subsidence linked to a sub-Atlas depression, subsequently filled with lacustrine and colluvial Quaternary deposits 20–30 m thick, and exhibit a general east-to-west slope.

The plain extends approximately 125 km in length, with a maximum width of 50 km and altitudes ranging from 315 to 750 m. Two irrigated perimeters have been established: Béni-Amir (33,000 ha), irrigated with slightly saline water from the Oum Er-Rbie, and Béni-Moussa (69,500 ha), supplied with high-quality water from the Bin-El-Ouidane reservoir, which was at only 6 % capacity on 12 February 2024 (Oum-Er-Rbie Hydraulic Basin Agency).



Map. 1. Location of the Tadla plain

3 Methodology

To carry out this study, a geospatial approach was adopted following several methodological steps. First, Landsat 8 satellite images corresponding to May 2023 and May 2025 were downloaded and processed from the official USGS Earth Explorer platform. The choice of May was because this period corresponds to the peak of vegetative development in the Tadla plain. Subsequently, the NDVI was calculated to characterize vegetation vigor, and a classification of areas with high and low vegetation density was performed.

$$NDVI = (PIR-R)/(PIR+R) \text{ [7]}$$

Regarding precipitation data (Fig. 1), information from the NASA POWER database was adopted in the absence of long-term, consistent records from local meteorological stations. The robustness of this dataset was evaluated by comparing annual rainfall totals for the year 2020 obtained from the Béni Mellal weather station (412.4 mm) with corresponding values extracted from the NASA POWER platform at the same location (417.69 mm). The minimal difference observed between the two datasets supports the suitability of NASA POWER data for climatic analysis in the study area.

To capture spatial variability across the Tadla Plain, five observation points were systematically distributed throughout the region. In addition, field investigations were carried out concurrently to corroborate satellite-based interpretations and to validate the outputs of the geospatial analyses.

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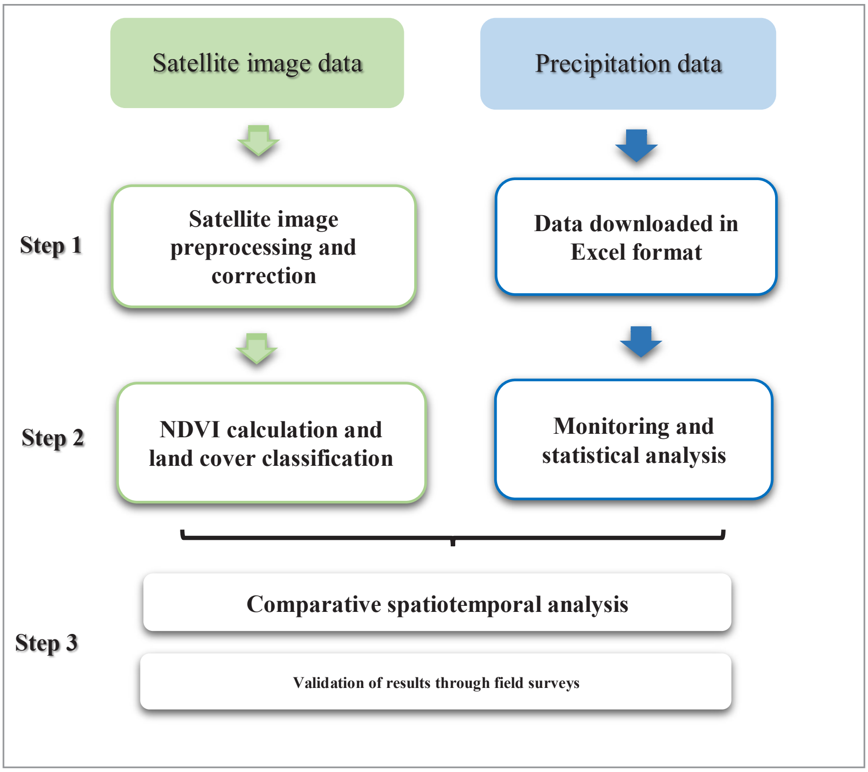


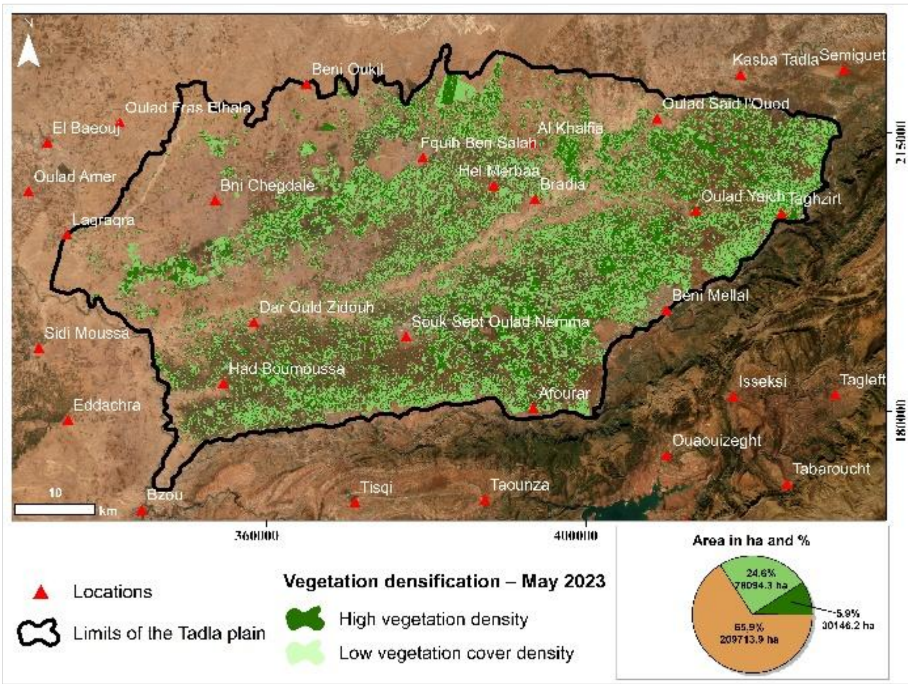
Fig. 1. Methodological diagram

4 Results and discussion

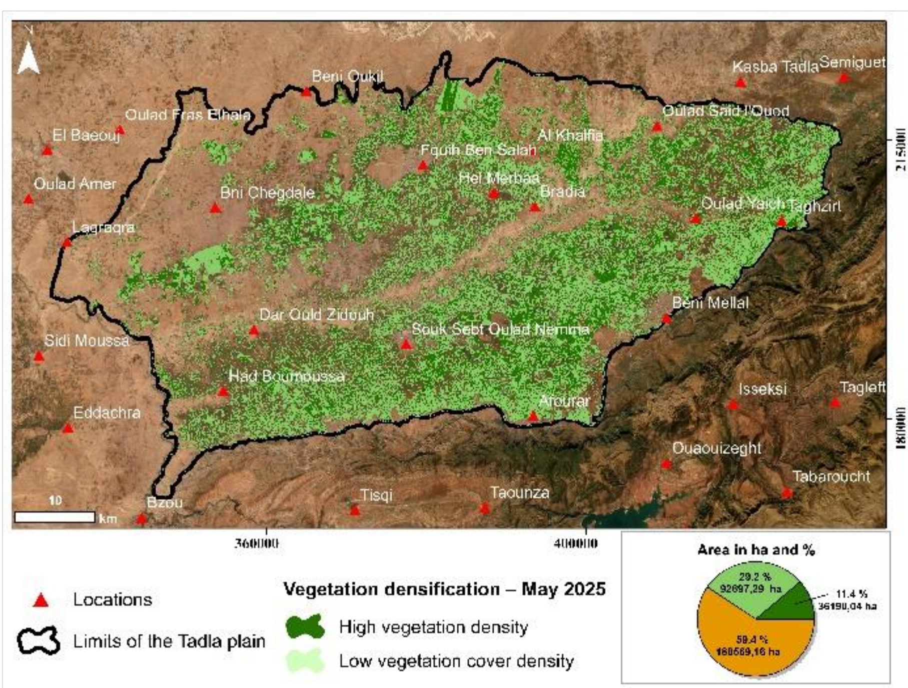
4.1 Extent of agricultural land

In May 2023 (Map 2), areas exhibiting high vegetation density were largely confined to the irrigated schemes and to the eastern sector of the Tadla Plain, representing approximately 5.9% of the total area (30,146.2 ha). Zones with limited vegetation cover occupied about 24.6% (78,094.3 ha), while the dominant land category corresponded to non-vegetated surfaces, which accounted for nearly two-thirds of the plain (65.9%, equivalent to 209,713.9 ha) (Fig. 2).

A decade later, in May 2025 (Map 3), a marked shift in vegetation patterns was observed. Densely vegetated areas expanded to 11.4% of the total surface (36,190.04 ha), with the most pronounced growth occurring within irrigated perimeters, particularly in the western part of the region. At the same time, moderately vegetated zones increased substantially, reaching approximately 29.2% of the plain. Conversely, areas devoid of vegetation declined to 59.4%, corresponding to 188,569.16 ha, indicating an overall improvement in vegetation cover distribution.



Map. 2. Spatial distribution of vegetation densification in the Tadta plain in May 2023



Map. 3. Spatial distribution of vegetation densification in the Tadta plain in May 2025

Fig. 2. Photos of different areas of the Tadla plain: A, B, and C show an increase in vegetation, while E, F, and G exhibit low or no vegetation cover

4.2 annual precipitation evolution in the Tadla plain

The bar chart highlights the changes in annual precipitation across five sites in the Tadla Plain for the agricultural years 2023 and 2025 (fig. 3). A general upward trend is observed, reflecting a notable improvement in climatic or hydric conditions across all sites.
In 2023, precipitation ranged from approximately 223.86 mm to 265.48 mm (240.38 mm comme valeur Moyenne des 5 site), indicating moderate levels. By 2025, these values had increased significantly, ranging from 378.21 mm to 438.77 mm (402.43 mm comme valeur Moyenne des 5 site), reflecting an overall enhancement in rainfall.

The most pronounced increases occurred at Sites 1 and 2, reaching 438.77 mm in 2025. This could be explained by favorable local climatic factors or indirect human interventions, such as optimized water management or improved agricultural infrastructure. Sites 3, 4, and 5 also showed increases, but to a lesser extent (around 378.21 mm), indicating a smaller improvement despite the positive trend.

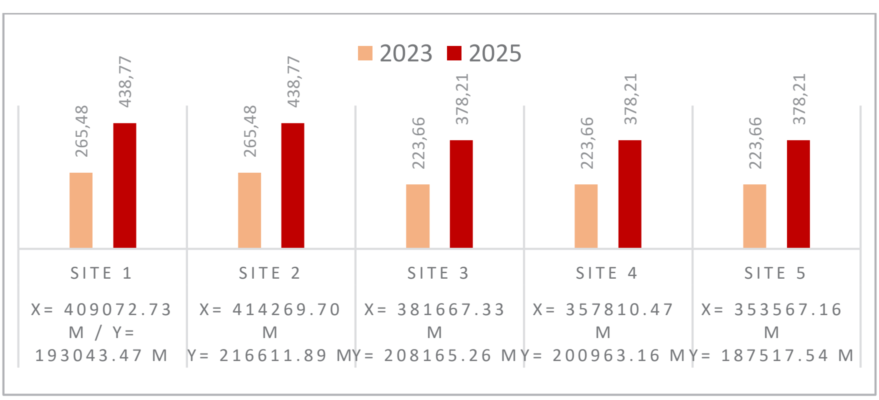


Fig. 3. Annual precipitation variation in the survey sites

5 Conclusion

The bar chart illustrates variations in annual rainfall recorded at five observation sites across the Tadla Plain for the 2023 and 2025 agricultural seasons (Fig. 3). Overall, the data reveal a clear increase in precipitation between the two periods, suggesting an improvement in regional hydrological conditions.
During the 2023 season, rainfall amounts ranged between 223.86 mm and 265.48 mm, with a mean value of approximately 240.38 mm across the five sites, reflecting moderately dry conditions. In contrast, by 2025, precipitation levels rose substantially, varying from 378.21 mm to 438.77 mm and yielding an average of 402.43 mm. This increase indicates a significant enhancement in rainfall availability at the scale of the plain.
The largest gains were observed at Sites 1 and 2, where annual totals reached 438.77 mm in 2025. These higher values may be linked to localized climatic influences or to indirect anthropogenic factors, such as improved water management practices or the development of agricultural infrastructure. Although Sites 3, 4, and 5 also experienced higher rainfall, the increase was comparatively smaller, with values around 378.21 mm, pointing to a more moderate improvement despite the overall positive trend.

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