Towards an assessment of the impact of the Green Morocco Plan on terrestrial ecosystems: the case of Bouarfa region

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Abstract. Since independence, Morocco has implemented reforms and strategies to modernise agricultural sector. Foremost among these initiatives, the Green Morocco Plan (GMP, 2008-2020) was key, transforming agriculture by increasing productivity through a dual approach, combining modern agribusiness with supporting small-scale agriculture. Despite its benefits on the economy and on farmers' incomes, GMP has negative effects on the environment and natural resources. To further measure the impact of GMP on natural ecosystems of an arid region (Bouarfa), this study first aims at mapping existing habitats of the region, combining phytosociological surveys with high-resolution satellite imagery analysis. Spectral indices (NDVI, NDWI, NDESI, ASTER_SI), and a topographical analysis based on the DEM were used to characterise the specific characteristics of each habitat. Image classification was developed using supervised (Random Forest, Support Vector Machine) and unsupervised (K-means) classification methods, followed by field validation, using a confusion matrix and calculation of the kappa coefficient. The results of this study present a habitat map with 82% accuracy, validated through field observations, providing a strong basis for analysing natural habitat degradation in the Bouarfa region.
Keywords: Terrestrial ecosystems, Houbara bustard, Green Morocco Plan, Natural habitat, GIS, Remote sensing, Bouarfa.

1 Introduction

Since Morocco gained its independence in 1956, the country has launched a series of reforms to ensure food security, modernise its agricultural sector, redistribute land, improve infrastructure, and import new technologies (Figure 1).

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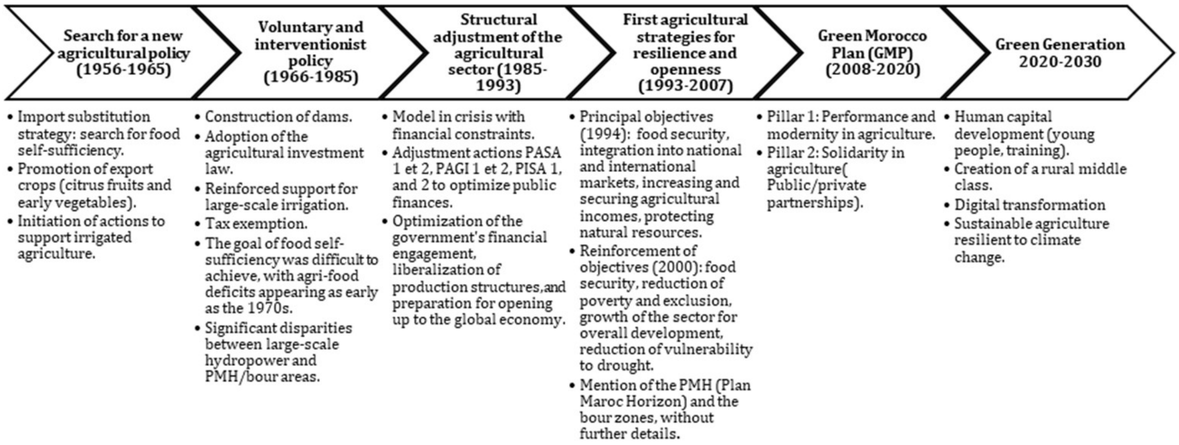

Fig. 1. Evolution of agricultural policy and strategy since independence [1].

From 1985, agricultural policy shifted from food self-sufficiency to liberalisation and opening to market forces and international trade. Despite the progress made between 1956 and 2007, unsustainable practices caused environmental degradation, particularly desertification affecting soil, biodiversity, and water resources in arid regions [2].

Confronted with global challenges of food security, climate change, and rising prices [3], Morocco launched the Green Morocco Plan (GMP, 2008-2020) to modernise agriculture, promote growth, create jobs, increase agricultural Gross Domestic Product (GDP), boost exports, and improve the living conditions of farmers [4]. The first pillar of the GMP develops modern, high value agriculture led by the private sector. The second pillar supports small-scale farmers [4].

The GMP benefited 2.7 million people with a 44 billion MAD budget, agricultural GDP rose from 65 to 125 billion dirhams (2007-2020), and by 2020, employed 40% of the workforce, compared to before 2008. Investments totalled nearly 118 billion dirhams (2008-2019). However, environmental studies reveal soil and water deterioration from overuse and agrochemical pollution [4].

Such impacts are exacerbated by climate change, with rainfall declining by 10- 20% since 1986 and predicted to decrease up to 30% in Saharan areas by 2050 [5]. This decline of rainfall directly affects “bour” crops (rainfed crops) and leads to a reduction in cereal yields of 50-75% in dry years and 10% in normal years [5]. Concomitantly, temperatures are predicted to rise by 2-5°C by 2100 which will intensify evaporation and aggravate water deficit, putting the sustainability of agricultural production at high risk [5].

Measuring effects of the GMP on arid lands of Morocco is challenging and often hindered by a lack of detailed mapping of natural habitats and human land use (agriculture).

With the aim of assessing the impact of the GMP on terrestrial ecosystems of an arid zone, this study focused on the Bouarfa region in Eastern Morocco, a region with limited water resources and high vulnerability to desertification. In recent years, the rapid increase in individually managed farms relying on groundwater pumping has intensified pressure on local ecosystems, contributing to natural habitat fragmentation and a decline in ecosystem functionality. To measure the impact of the GMP in the Bouarfa region, we first need to accurately map the natural and anthropogenic habitats of the area.

The methodology combines habitats’ inventory and description (phytosociological surveys) carried out in the field from 2015 to the present, with Sentinel-2 image analysis. Spectral indexes were calculated (NDVI, NDWI, NDESI, ASTER_SI), and a topographic analysis based on the Digital Elevation Model (DEM) was used to integrate aspect and slope characteristics. Finally, unsupervised (K-means) and supervised (Random Forest, Support Vector Machine) classification was executed, followed by field validation, confusion matrix, and calculation of the Kappa coefficient. This workflow allowed us to produce a habitat map, based on a standardized habitat classification.

2 Methods

2.1 Study area

The study area is located in eastern Morocco, to the west and southwest of the city of Bouarfa and extends over 4,811 km² (Figure 2). It is characterised by an arid or desertic climate, marked by cold winters, very hot summers, low precipitation, and a lot of wind.

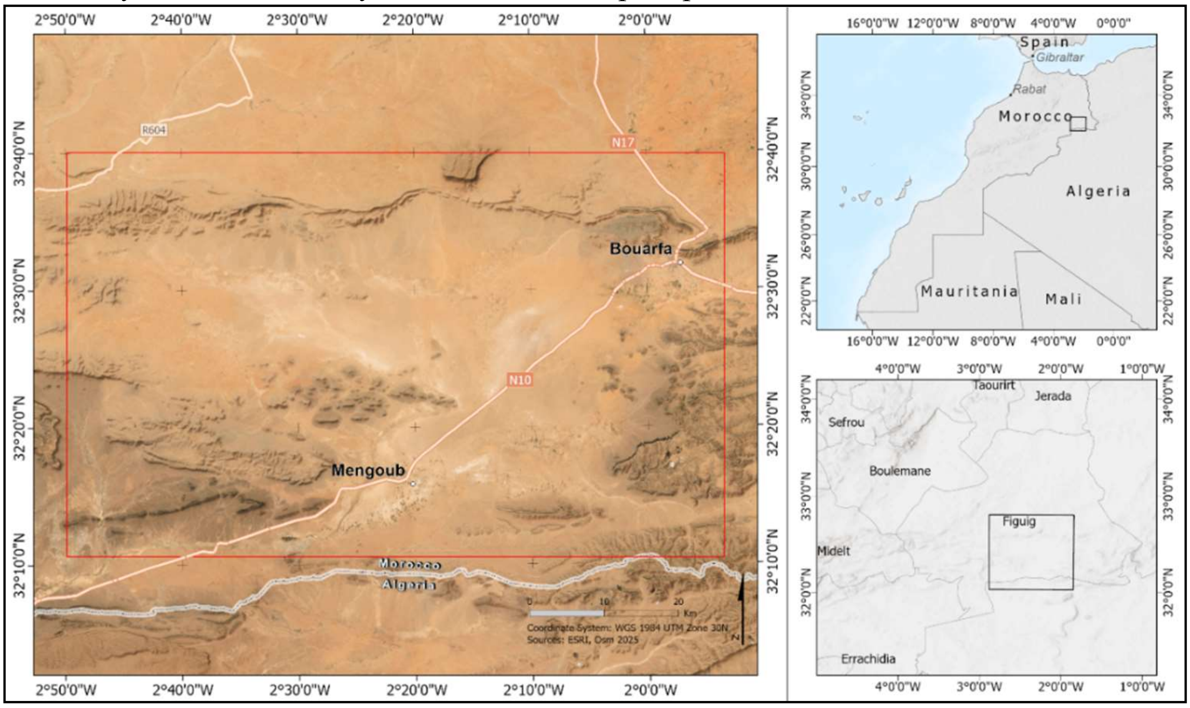

Fig. 2. Location of the Bouarfa study area, Eastern Morocco.

2.2 Habitats Inventory

Since 2015, the Emirates Center for Wildlife Propagation (ECWP) has been inventorying the habitats in the study area as part of research program on the North African Houbara Bustard (*Chlamydotis undulata*) and its ecology. A habitat is defined as a uniform vegetation community, which is named according to an eco-physiognomic concept (e.g. 'reg with *Fredolia aretioides* and *Hammada scoparia*'). The exhaustive inventory process combines visual analysis of satellite images to pre-identify potential habitat areas, followed by field surveys during the vegetation optimum period. Habitats are inventoried and described by several "phytosociological relevés " (here after phytosociological surveys) [6], each survey encompasses records on habitat ecology, pedology, hydrology, salinity, slopes, orientation, anthropisation, taxa inventories and ground cover. Depending on habitat abundance, the number of relevés varied from one (rare) to several dozen, although at least three are needed for reliable classification and comparison [7].

A total of 251 sample points were studied, including 222 phytosociological surveys and 29 complementary pointing without phytosociological surveys, have been added to improve the spectral representativeness of two insufficiently sampled habitats. The surveys are generally well distributed across the study area but are still lacking in the western portion due to unfavourable weather which did not permit performing any vegetation record until now (figure 3). In December 2024, a field mission was conducted to validate the list of habitat classes and added complementary points for each habitat type, with the objective to establish a robust habitat typology suitable for remote sensing analysis in the study area (figure 3).

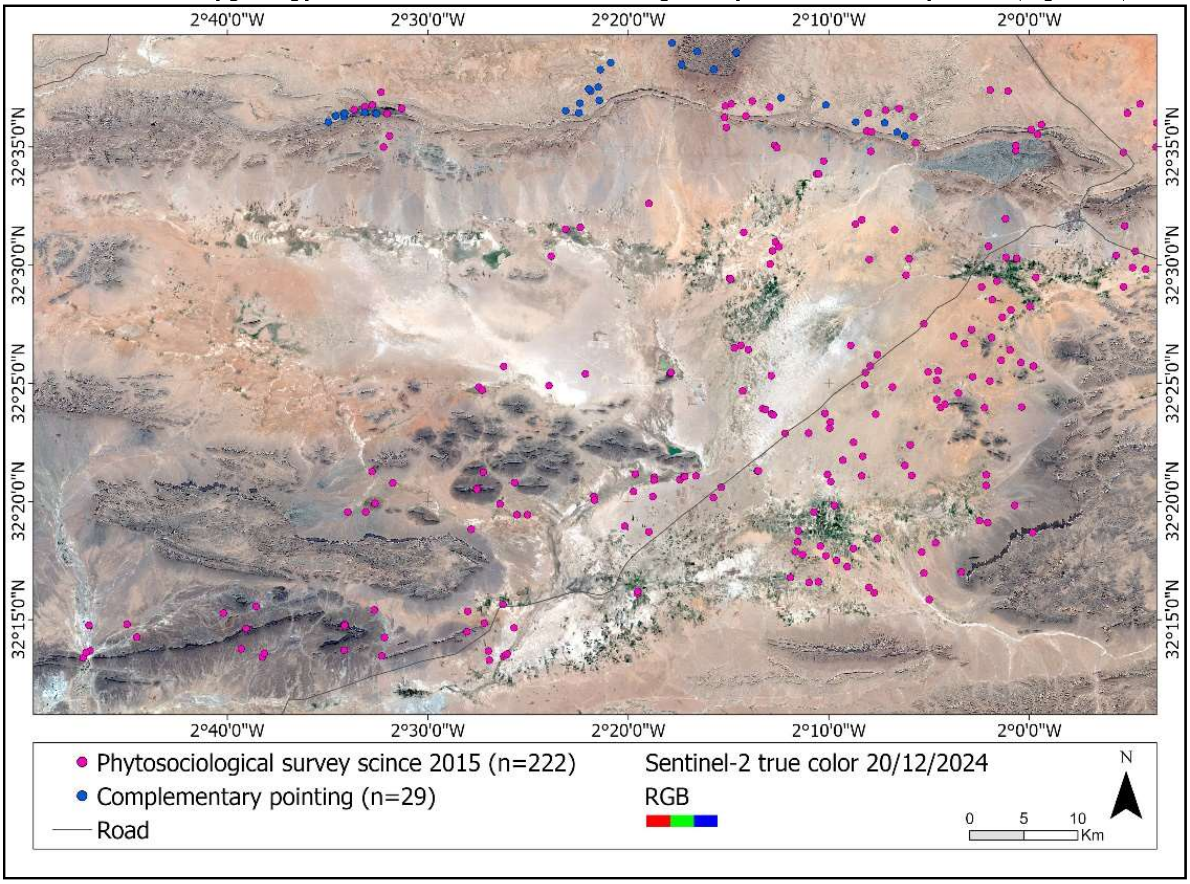

Fig. 3. Sentinel-2 imagery with habitat surveys in the Bouarfa study area, Eastern Morocco.

2.3 Remote Sensing Data Processing

2.3.1 Digital Elevation Model (DEM) Analysis

The high-resolution ALOS PALSAR DEM (12.5 m) enabled the extraction of the slope and aspect, which helped identify scree habitats. It refines understanding of hydrography, soil salinisation and the characteristics of habitats adapted to such conditions. This precise mapping provides an understanding of habitats distribution in relation to topography and hydrology, as illustrated by [8] and outlined in the methodological flowchart (Figure 4).

2.3.2 Sentinel -2 Analysis

2.3.2.1 Data acquisition

To map and classify habitat types, high resolution sentinel-2 images (10 m) were acquired from Copernicus Browser. Three dates were selected: 26 September 20 December 2024, and 17 March 2025. September captured lake boundaries at maximum water levels after rainfall. December corresponds to the field phytosociological surveys, while march was reserved for reverification and validation in the field.

2.3.2.2 Spectral indices

A spectral index is a combination of different spectral bands to detect vegetation, water, soil, sand, urban area, etc. For this study, four indices were chosen to facilitate habitat identification (Tableau 1), as shown in the methodological flowchart (Figure 4). NDVI for vegetation; NDWI for Water and moisture; NDESI for sandy areas; ASTER_SI for soil salinity, with SWIR bands are more sensitive to slight and moderate salinity in irrigated lands [9].

Table 1. Sentinel-2 derived spectral indices.

Index	Formula	Reference
Normalized Difference Vegetation Index	$NDVI = \frac{\rho NIR - \rho RED}{\rho NIR + \rho RED}$	[10]
Normalized Difference Water Index	$NDWI = \frac{\rho Green - \rho NIR}{\rho Green + \rho NIR}$	[11]
Normalized Difference Enhanced Sand Index	$NDESI = \left(\frac{\rho B07 - \rho B02}{\rho B07 + \rho B02}\right) - \left(\frac{\rho B12 - \rho B11}{\rho B12 + \rho B11}\right)$	[12]
ASTER_SI (Salinity Index)	$ASTER\_SI = \left(\frac{\rho B11 - \rho B12}{\rho B11 + \rho B12}\right)$	[9]

2.4 Habitat Classification

Using ArcGIS Pro 3.2.0, habitat areas were identified through cluster analyses of multiple parameters. An initial broad classification was done with unsupervised K-means clustering, on Sentinel-2 imagery to reveal natural grouping. Then, supervised classification methods, such as Random Forest and support Vector machine were employed, training the model with phytosociological surveys to achieve a more precise habitat delineation. The results of classification were then validated through a dedicated field surveys conducted in March 2025 to assess classification results, in collaboration with ECWP botanist. It is based on 50 sample points randomly distributed across the study area, selected based on field accessibility and optimised using slopes, elevation, and road networks. A kappa coefficient between 60% and 80% indicates good accuracy, while above 80% reflects very good accuracy of results [13]. The methodology flowchart for habitat mapping used in this study is shown in Figure 4.

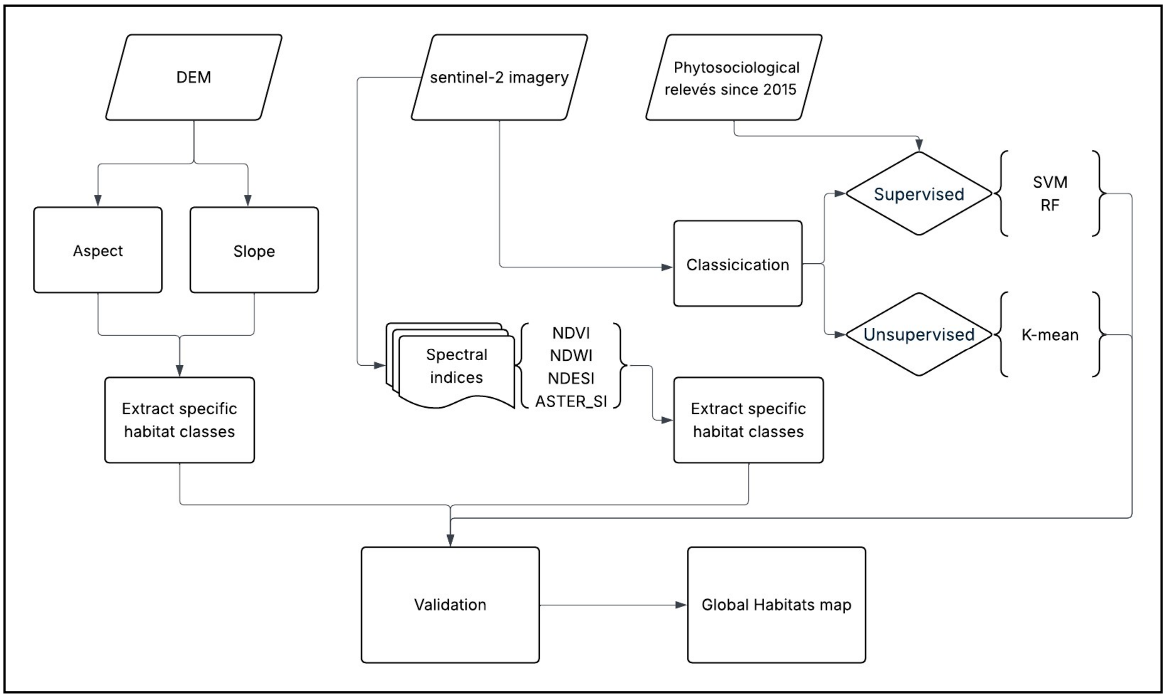

Fig. 4. Methodology flowchart for habitat mapping in the Bouarfa study area, Eastern Morocco.

3 Results and Discussion

3.1 DEM Analysis

Based on the DEM, slope and aspect (exposition) were extracted from view to identify areas characterised by Scree habitat (Figure 5), marked by high slope (>30°) and a north, northwest, and northeast orientation [14].

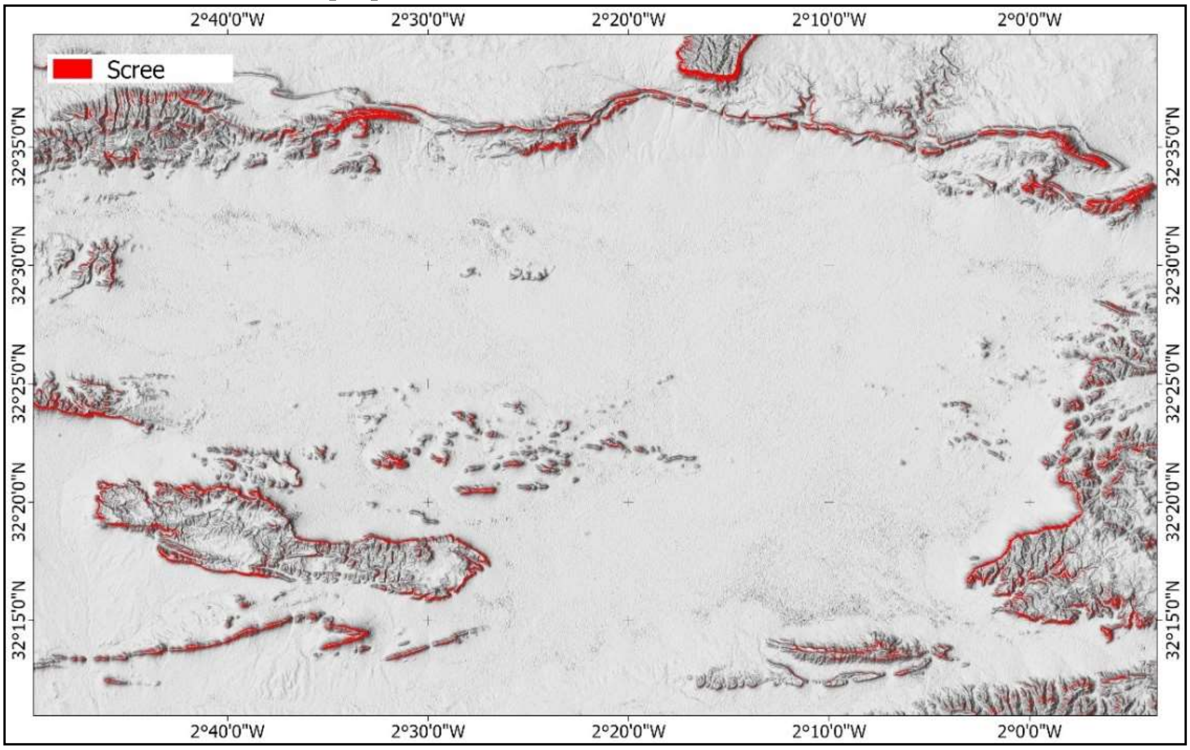

Fig. 5. Distribution of scree habitat of the Bouarfa study area, Eastern Morocco.

3.2 Sentinel -2 Analysis

The spectral indices NDVI, NDWI, NDESI, and ASTER_SI were calculated (Figure 6).
NDVI (Sentinel-2, 20 December 2024) is particularly useful for detecting vegetation and assessing its density, with values ranging from -0.3 to 0.7, values closer to 1 indicate denser vegetation. NDWI (Sentinel-2, 26 September 2024) enables the detection of water surfaces and identification of lakes, with values near 1 indicating areas with high moisture content. NDESI (Sentinel-2, 17 March 2025) highlights sand and dunes dominated areas, where high values indicate a greater presence of sandy surfaces. ASTER_SI (Sentinel-2, 17 March 2025) detects saline areas, a crucial factor in habitat distribution, with high values indicating a high salt concentration.

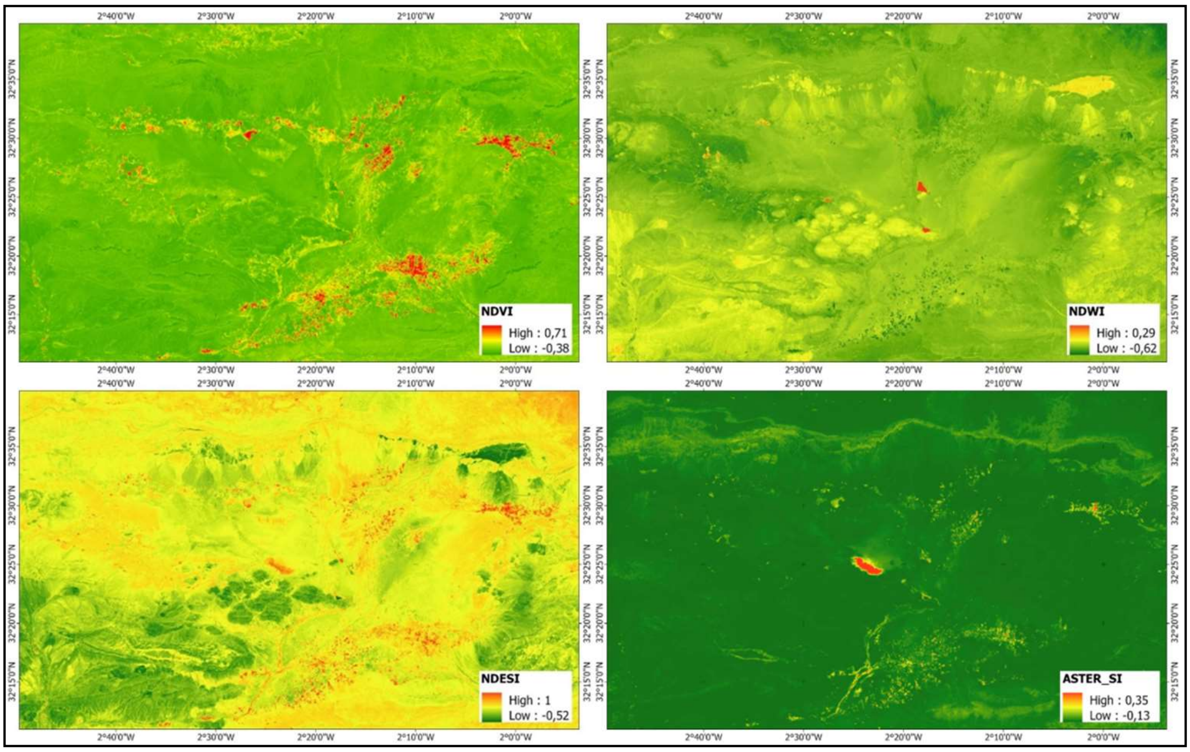

Fig. 6. Spectral indices derived from Sentinel-2 of the Bouarfa study area, Eastern Morocco.

To better understand high salinity areas, the hydrographic network derived from the DEM was overlaid on saline zones from ASTER_SI and satellite images (Figure 7). This highlights surface flows accumulation and convergence in areas most affected by salt build up. However, significant confusion has been observed regarding dunes of very white sand, which were mistakenly classified as saline areas.
According to [15] irrigation practices enhance salt deposition, leading to soil degradation, reduced fertility and intensifying ecological stress in this arid environment. This topic warrants further analysis using additional tools to assess the impact of the GMP on soil salinity.

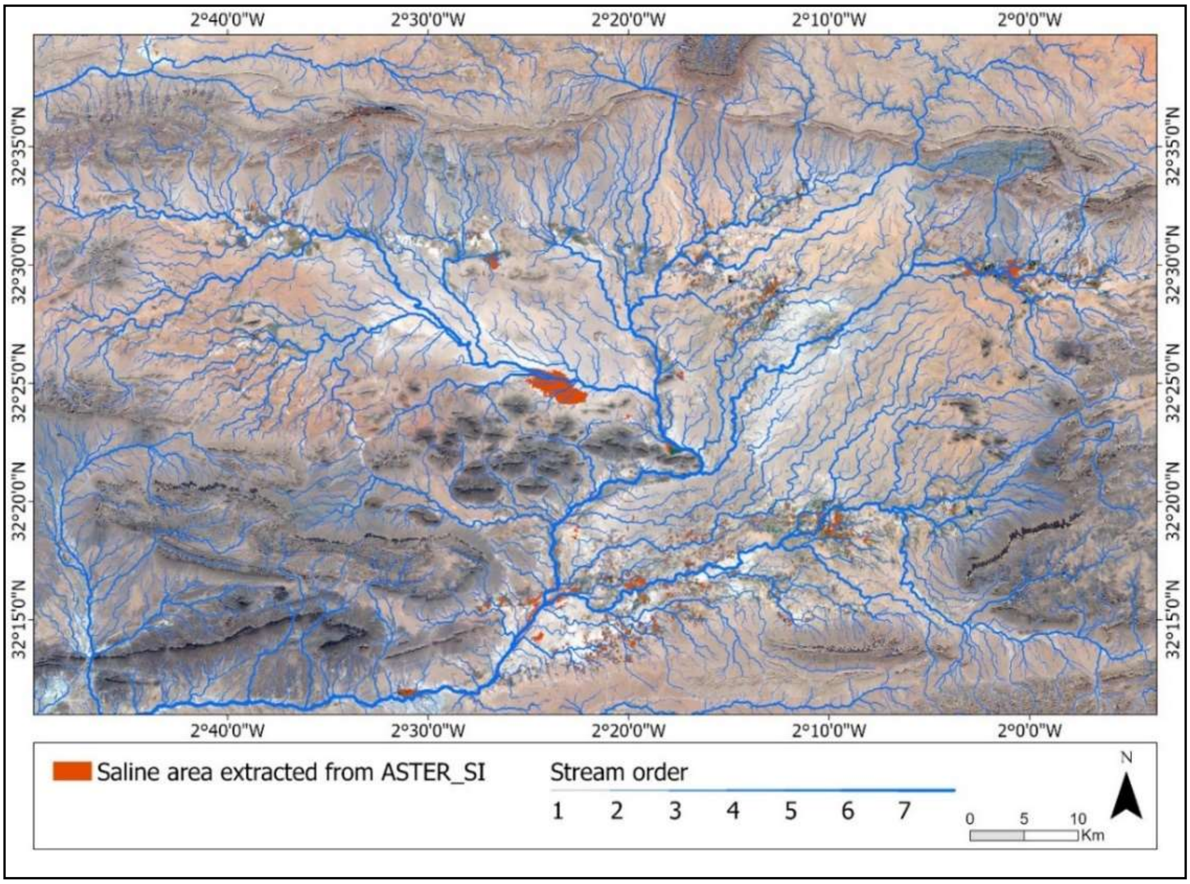

Fig. 7. Overlay of the hydrographic network extracted from the DEM on sentinel-2 imagery (26 September 2024).

3.3 Habitat classification

3.3.1 Habitat classes

The classification is structured around 11 distinct habitat classes, which reflect the main ecological units of the study area. These include *Atriplex steppe*, *Juniperus phoenicea* open woods, lakes, cultivated/fallow areas, regs, rockeries, salty steppes, sands, screes (rocky slopes with a gradient > 30°), spreading areas, and chamaephytic/grass steppes.

3.3.2 Supervised and Unsupervised Classification

The ISO Cluster classifier, using the K-means method, was set to 11 habitat clusters to remain consistent with the number of habitat classes identified in the field within the Bouarfa study area (Figure 8). This preliminary classification shows some clusters correspond to dense vegetation, sandy areas, or saline zones, providing an initial overview of habitat distribution. To achieve higher accuracy in the supervised classification, a Support Vector Machine (SVM) and a Random Forest classification were conducted (Figure 9).

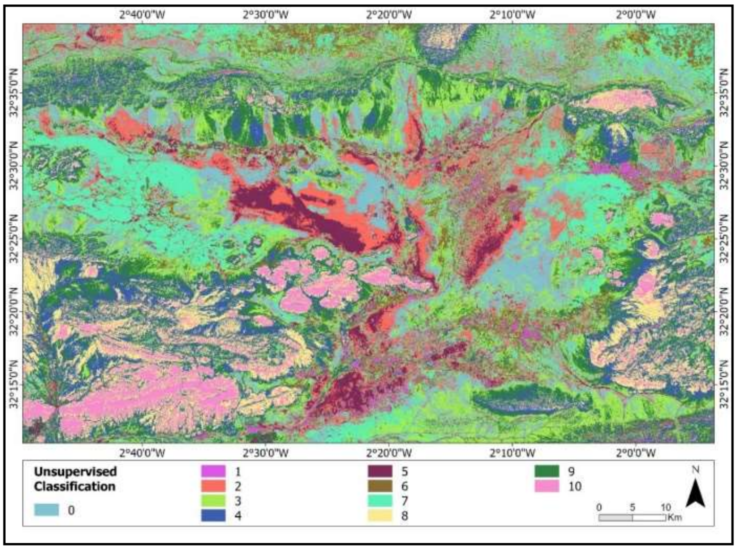

Fig. 8. Unsupervised classification of Sentinel-2 (17 March 2025) for the Bouarfa study area, Eastern Morocco.

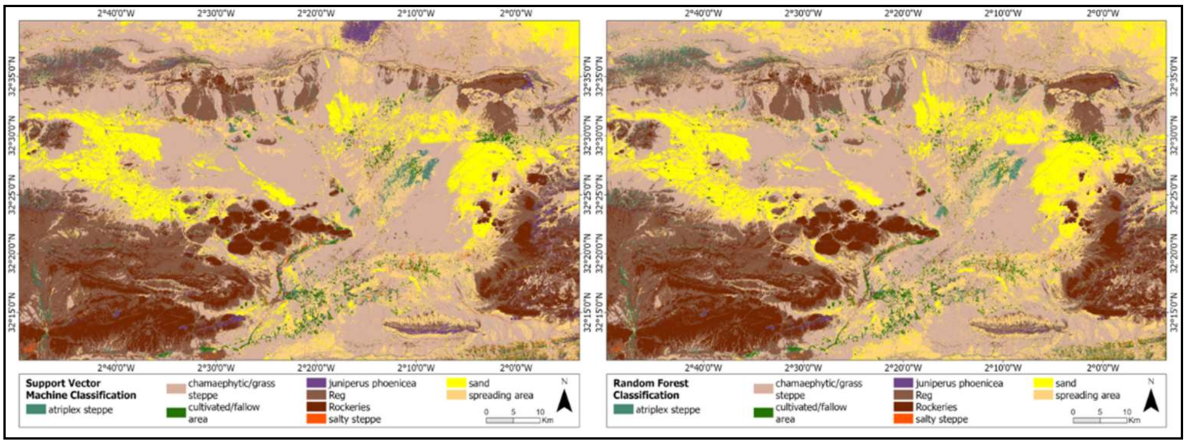

Fig. 9. Supervised classification of Sentinel-2 (17 March 2025) for the Bouarfa study area, Eastern Morocco, with Support Vector Machine Classification (left) and Random Forest Classification (right) supervision.

3.3.3 Validation

The kappa coefficient is 76% for SVM and 82% for Random Forest classification, confirming a good agreement between satellite classification and real habitats. Random Forest classification achieved a slightly higher score than the SVM, confirming its very high accuracy and ability to identify habitats in the study area. Figure 16 presents the final classified habitat map and illustrates the spatial distribution of habitats identified in the Bouarfa region.

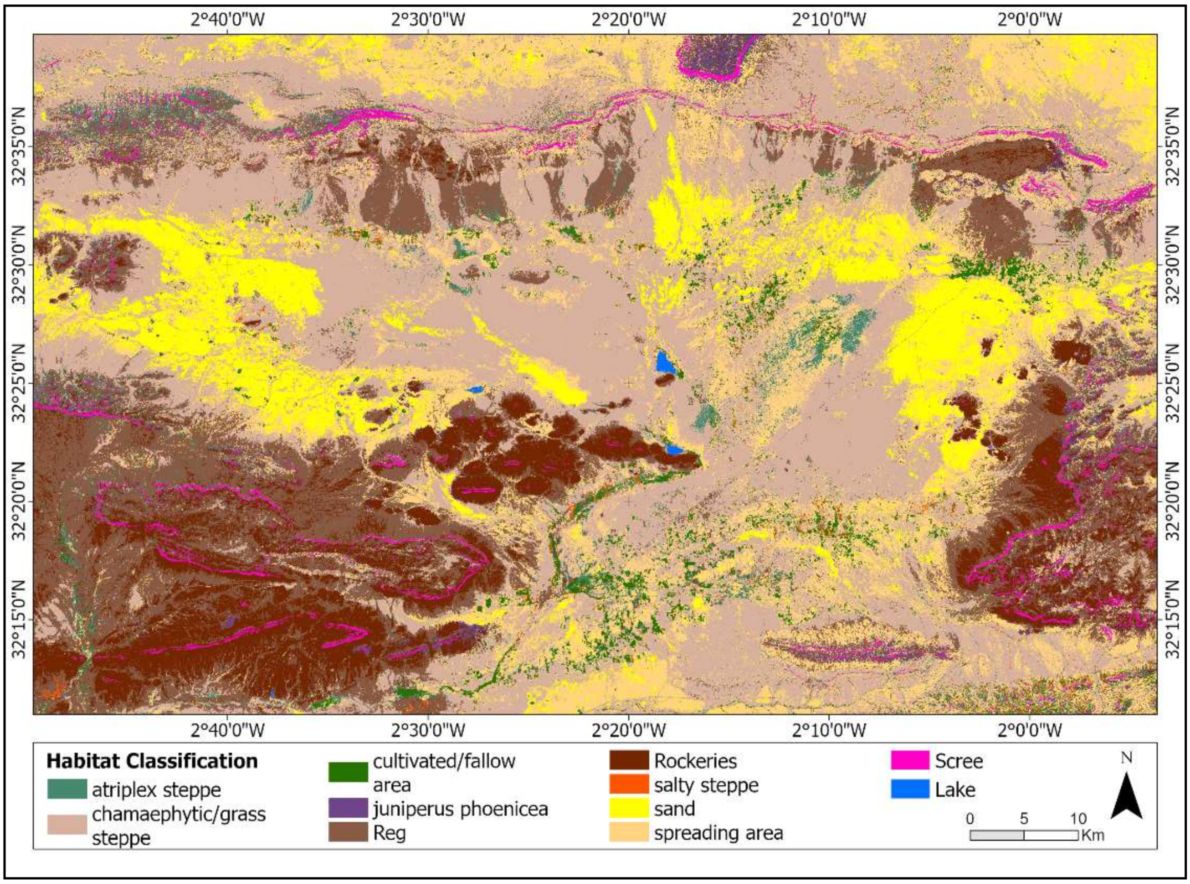

Fig. 10. Final habitat classification map of the Bouarfa study area, Eastern Morocco.

4 Conclusion

This study identified and mapped the habitats in the Bouarfa region, an arid area subjected to climate change and the impact of the GMP, by combining Digital Elevation Models (DEM), satellite image classification, and phytosociological surveys as a training dataset. Eleven (11) main habitat classes have been identified with an accuracy of 82% using Random Forest classifier.

Preliminary descriptive analysis indicates that natural habitat distribution is strongly influenced by topography, hydrography, and salinity, all associated with water resource availability, subjected to overexploitation through agricultural practices under the GMP. The Bouarfa habitat map provides a solid foundation for further investigations into the ecological impact of the GMP combined with climate change in the region. Our ongoing research aims at analysing the evolution of habitats (presence, size and distribution) over time using chronological sequences of satellite imagery, combined with measurements of groundwater conditions, evapotranspiration and agricultural pressure.

While our study confirmed the effectiveness of using remote sensing for mapping natural habitats in arid environments, with Random Forest outperforming SVM in classification accuracy, some limitations remain, notably image resolution and spectral confusion. Future research could integrate more habitats surveys, higher-resolution datasets like PlanetScope (3m) or drone imagery (centimeter scale) and deep learning methods to enhance accuracy. Overall, this study provides both a detailed map of habitats in the Bouarfa region and a methodological reference for similar studies elsewhere, emphasizing the importance of remote sensing in biodiversity conservation and in evaluating the impacts of agricultural strategies.

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