Spectral Angle Mapper Approach (SAM) for Land Degradation Mapping: A Case Study of the Oued Lahdar Watershed in the Pre-Rif Region (Morocco)

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Abstract Land degradation is a complex and widespread environmental issue with significant implications for global sustainability. It encompasses various processes that negatively impact soil health and support productive ecosystems and human livelihoods. This chapter focused on mapping land use/land cover (LULC) and

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identifying land degradation features using Sentinel-2 imagery and the Spectral Angle Mapper (SAM) approach. The primary objective was to gain insight into the spatial distribution of land degradation within the study area. The step-by-step supervised classification process involved data preparation, training data collection, feature selection, SAM classification, and post-classification processing. An accuracy assessment was conducted to validate the results and ensure the reliability of the land cover map. As a result of the different LULC classifications in the research area, the arboriculture class represented 18% of the study area. In contrast, the agriculture class showed coverage of 27%, followed by the forest class occupying 22% of the catchment area, and the bare soil class representing 33% of the total study area. The combination of substantial proportions of bare soil (33%) and agriculture (27%) suggested that a large portion of the landscape may be susceptible to land degradation if appropriate measures are not implemented. The derived LULC map is a valuable resource for environmental monitoring, ecosystem conservation, and land use planning. Policymakers, researchers, and stakeholders can use this information to make informed decisions for sustainable land management, protect natural resources, and mitigate the impact of land degradation.

Keywords Land degradation · Spectral angle mapper · Pre-Rif Morocco · LULC · Lahdar Watershed

1 Introduction

The earth's land is a necessary resource for humans because it enables more than 7.5 billion people living there to eat every day, but it is also a limited resource because there are currently only 33 million km^2 (or 6.4% of the earth's surface) that can be used for agriculture (Farah et al. 2021; Bammou et al. 2023). Land degradation is one of the most important and persistent environmental issues the Earth has long faced (Fadhil 2009; Ganasri and Ramesh 2016; Rawat et al. 2016; Benzougagh and Fellah 2023). Land degradation is a complex and widespread environmental issue with significant implications for global sustainability. It encompasses various processes that negatively impact soil health and its ability to support productive ecosystems and human livelihoods (Hossain et al. 2020; Benzougagh et al. 2022). Land degradation affects the vast expanses of the Earth's land surface, resulting in reduced crop yields, increased vulnerability to erosion, loss of biodiversity, and diminished ecosystem services (Eswaran et al. 2001; UNCCD 2017; Hossini et al. 2022). The Food and Agriculture Organization (FAO) has estimated that approximately 24% of the global land area is already somewhat degraded, and an additional 8% is at risk of degradation (FAO 2015). Moreover, it is estimated that land degradation costs the global economy by approximately 10% of the annual gross product (GDP) through the loss of ecosystem services and reduced agricultural productivity (Costanza et al. 2014; Sestras et al. 2023).

Both natural and anthropogenic variables affect the complicated processes of land degradation. Land deterioration can be accelerated by natural factors such as geological processes, extreme weather, and climate variability (Cavicchioli et al. 2019; Wong et al. 2021). For example, protracted droughts and strong rains can worsen agricultural areas by causing soil erosion, vegetation loss, and other environmental problems. Geological aspects, such as delicate soils, can further accelerate land degradation in some areas (Al-Quraishi and Negm 2020; Benzougagh et al. 2020a, b; Meshram et al. 2022). Conversely, human activity is a major contributor to land degradation (Al-Quraishi 2004; Gong et al. 2022; Kader et al. 2023a). Deforestation, excessive grazing, and poor irrigation are examples of unsustainable land use practices that can deplete soil nutrients and lower land production.

In addition to causing habitat loss and fragmentation, the expansion of agriculture and urbanization can transform natural ecosystems into degraded land (Zheng et al. 2021; Kader et al. 2023b). Additionally, socioeconomic factors, such as population increase, poverty, and lack of access to resources and technology, can exacerbate the pressures associated with land degradation (Seifollahi-Aghmiuni et al. 2022). Poor land management methods and ineffective land tenure structures may deter investments in sustainable land use strategies and hasten further deterioration (Searchinger et al. 2014; Asaaga et al. 2020). Overall, the interaction between natural and human-induced factors creates a complex web of drivers that influence the rate and extent of land degradation. Understanding these factors is crucial for developing effective land management strategies and policies to combat land degradation and promote sustainable land use practices for the well-being of the environment and society (Benzougagh et al. 2016, 2017).

The consequences of land degradation extend beyond ecological degradation and pose serious socio-economic challenges, particularly for communities reliant on agriculture and natural resources (Montanarella and Panagos 2021; Karimi et al. 2022a, b; Brandolini et al. 2023). As land degradation continues to accelerate owing to human activities and climate change, there is an urgent need for effective monitoring and mapping techniques to inform conservation efforts and promote sustainable land management practices.

Land use and land cover (LULC) information is paramount, supporting various environmental assessments and effective soil and water resource management. Land cover mapping serves as a valuable tool for landscape management, offering valuable insights into the patterns of environmental monitoring, natural resources, and human activities that influence the diverse surface areas of Earth. By accurately identifying and categorizing different types of LULC, we understand how human actions and natural processes interact with the environment. This knowledge is vital for making informed decisions and implementing sustainable practices to preserve and protect precious natural resources (Shi and Yang 2017; Kathwas and Saur 2022; Benzougagh and Fellah 2023).

The Oued Lahdar catchment is part of the Oued Inaouene watershed located in northeast Morocco and is also a Sebou sub-basin. The Lahdar watershed is also exposed to heavy soil erosion owing to its favorable geographical, climatic, geological, and geomorphological characteristics. Examining the relative significance of climate, LULC, and conservation strategies helps to better understand how soil erosion changes over time due to land degradation, endangering agricultural fertility, and the ecosystem. Watershed management entails monitoring spatial and temporal changes in basins, with LULC mapping being a crucial method for territorial management, planning, and studying the environment over time. This mapping technique plays a vital role in understanding and interpreting the evolving landscape, enabling effective decision-making to preserve and sustainably utilize natural resources within the watershed.

The outcomes of LULC mapping hold significant value for planners, engineers, and decision-makers when implementing conservation measures and managing natural resource development. Remote sensing is a convenient and effective data source for generating thematic maps of LULC. This data-driven approach aids in understanding the spatial distribution of land-use types and land-cover classes, enabling informed and well-targeted decisions to promote sustainable land management practices and protect the environment (Benzougagh and Fellah 2023). Many techniques have been developed to achieve this goal, with image classification being the most popular (Mathur and Foody 2008; Perez and Wang 2017; Gulzar 2023). Accurate and timely information on spatial distribution and severity is crucial. Remote sensing technologies have become indispensable tools for assessing and mapping land degradation over large areas (Zhang et al. 2022; Shahfahad et al. 2023). Remote sensing platforms, including satellites and airborne sensors, provide multispectral and hyperspectral imagery capable of capturing detailed information about the Earth's surface (Adão et al. 2017). These data enable monitoring changes in vegetation cover, soil moisture, and land use patterns, which are essential for identifying areas susceptible to degradation.

The Spectral Angle Mapper (SAM) approach is a prominent remote sensing technique for land degradation mapping. SAM is a spectral classification algorithm that quantifies the similarity between the spectral signatures of reference and target areas by calculating their spectral angle (Kruse et al. 1993). Two n-dimensional vectors form the spectral angle, each representing a pixel's spectral values in a multiband image. The smaller the angle between the two spectra, the more similar are their spectral characteristics, and vice versa. SAM has been widely used in various remote sensing applications, including land cover classification, mineral mapping, and vegetation analysis (Christovam et al. 2019; Chakravarty et al. 2021; Benzougagh and Fellah 2023).

This chapter explores the potential of the SAM approach for mapping land degradation and improving the understanding of the relative importance of dynamic parameters, particularly LULC, on land degradation in the Lahdar watershed in Northeast Morocco. In addition, erosion risk zones are monitored using cutting-edge supervised machine-learning algorithms, such as SAM, with data from Sentinel-2 images to identify areas susceptible to soil degradation. Integrating SAM-derived data with ground truth observations and soil samples will facilitate a comprehensive assessment of land degradation patterns and their implications for regional land management. These findings will aid managers and decision-makers in formulating appropriate conservation plans for natural resources in the research area.

2 Materials and Methods

2.1 Study Area

The Oued Lahdar catchment is part of the Oued Inaouene watershed, which covers 3680 km^2 and is also a Sebou subbasin (Fig. 1). After the Oued Ouergha, the Oued Inaouene is Sebou's second most important tributary; it travels east–west via the southern Rif corridor, eventually reaching the Idriss I dam. It encompasses a portion of the External Rif on the left, a portion of the Middle Atlas on the right, and southern Rif Corridor Fez-Taza. The Lahdar Basin, with a total area of 610 km^2, is located northwest of Taza in Taza Province, in the Fez-Meknes region (Morocco). The study area is located in the Eastern Pre-Rif in the northeast of Morocco between Cartesian coordinates X = 604.000 m W and 63.0000 m E) and Y = 446.000 m N and 404.000 S, respectively (Fig. 1).

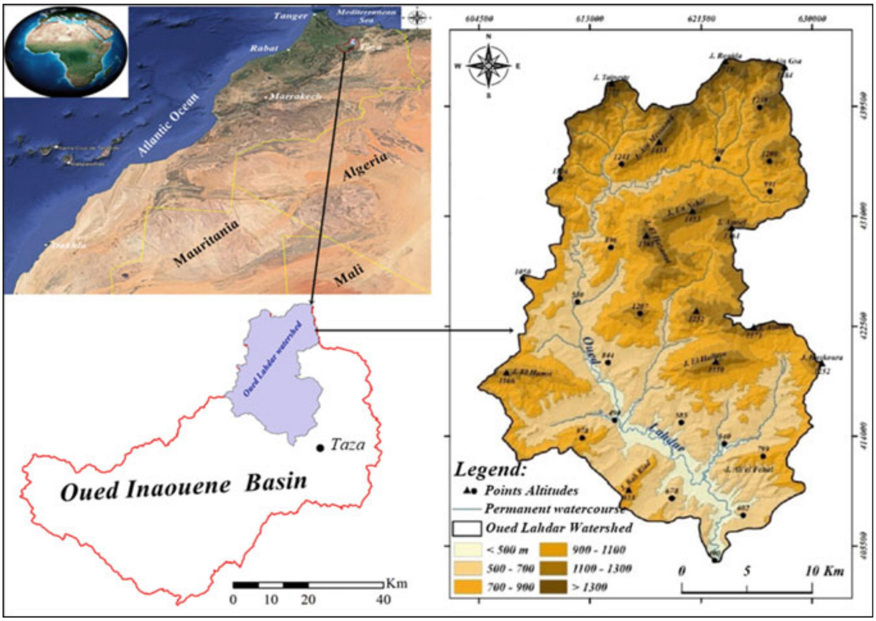


Fig. 1 Location map of the study area in Morocco

2.2 *Erosion Susceptibility Assessment of the Lahdar Watershed*

The Lahdar watershed is shaped in the Eastern Pre-Rif region in northeastern Morocco, covering an area of approximately 610 km^2. Geomorphologically, the reliefs are strong and uneven, with varied geological terrains. It is characterized by the dominance of soft rocks (marl, marly limestone, sandstone marl, schists, etc.). Morphologically, the upstream parts of the study area showed mountainous ridges at an altitude of 1700 m, and the slopes were strong and exceeded 25% (Fig. 2). Towards the south, low mountains and hills dominate mountains and hills, offering aerated relief and less pronounced slopes (Amhani and Tribak 2021).

Geologically, the Rifan domain is the only Moroccan massif that has formed as a result of alpine orogeny, and most of its facies are more similar to those of Andalusia than to those of the rest of Morocco (Khalis et al. 2021). The basin of Lahdar, which is a geological component of the Rifan chain, is unique in that it shares two structural domains with a wide variety of units (Fig. 3). The watershed of the Oued Lahdar ranges over the Outer Rif, which is characterized by fragile terrain and high altitudes. In the North, the internal domain of the Rif is constituted in the majority by allochthonous grounds with resistant material with some autochthonous grounds marly or schisto-sandstone (Fig. 3). To the south, the autochthonous marly terrain of the Perifaine nappe dominates, and is partly covered by allochthonous terrain belonging to the Ouezzane system (Leblanc 1977). A lithological mosaic seen as the outcrop of several units dominated by soft materials, mainly marl-limestone and marl-sandstone tertiary, within a tormented structure, is an important factor that conditions a rapid and disorderly evolution of the slopes (Tribak et al. 2017; Benzougagh et al. 2020a, b).

Tribak et al. (2017) state that this region is characterized by superficial and skeletal mineral soils. Of the soil classes, little evolution of erosion occurred on the strong slopes, vertisols, and calcimagnesic soils in the less hilly and less hilly areas, and soils of alluvial contribution developed on the terraces bordering the rivers. Consequently, the different types of soils in the study area show, globally, favorable behaviors to erosive processes, although the latter vary in nature, intensity, and degree of activity from one soil to another. They are characterized by low organic matter content and the predominance of silty or silty-clay textures, making them more unstable and highly sensitive to rainfall-aggressive rainfall phenomena.

The Mediterranean climate dominated the region with continental oceanic influence. Seasonal solid contrasts and clear irregularities in rainfall mark it. The research area is part of a semi-arid Mediterranean environment characterized by erratic annual rainfall and violent thunderstorms that cause serious water erosion. The necessary rainfall was measured between September and May (wet season). In contrast, the least amount was measured between June and August (dry season) (Fig. 4). A common method for investigating the hydrological interactions of rainwater with soils and simulating rainfall that causes runoff and soil erosion is the use of rainstorm simulators (Isa et al. 2018; Benzougagh et al. 2020a, b).

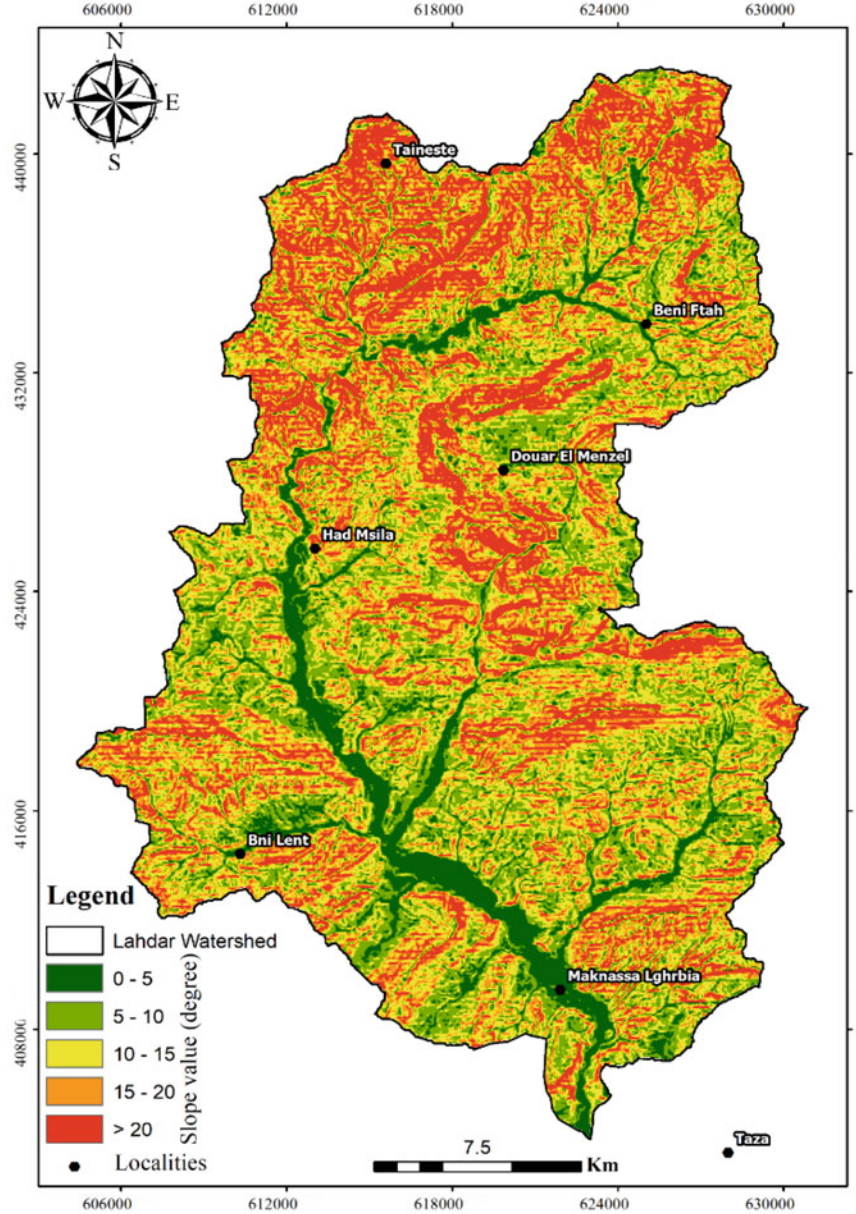


Fig. 2 Slope map of the Lahdar watershed

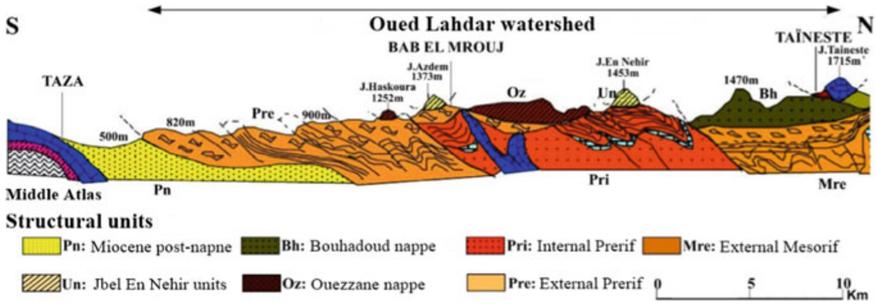


Fig. 3 Geological section of structural units in the Eastern Prerif (study area)

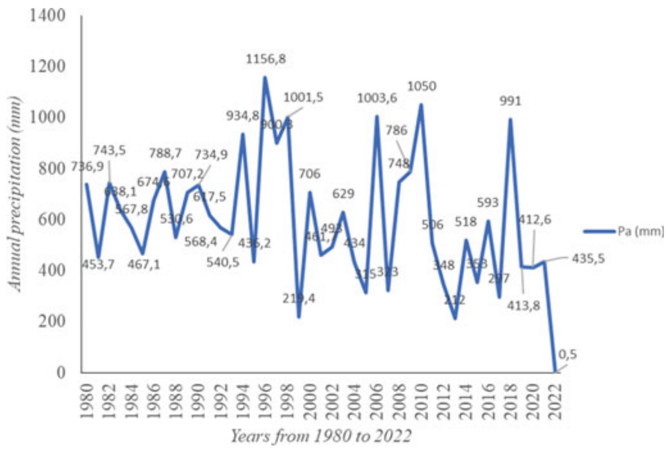


Fig. 4 Precipitation in the study area for the period 1980–2022

3 Methods

Using the SAM approach as a supervised classification technique, the current research demonstrated the capacity to use hyperspectral data to distinguish between areas prone to soil deterioration and those shielded from it. We employed several materials for this purpose, as shown in the workflow depicted in Fig. 5.

3.1 Image Datasets

The first step in developing a land-use map was to collect Sentinel-2 satellite imagery from the Copernicus Earth Observation Program distributed by the US Geological

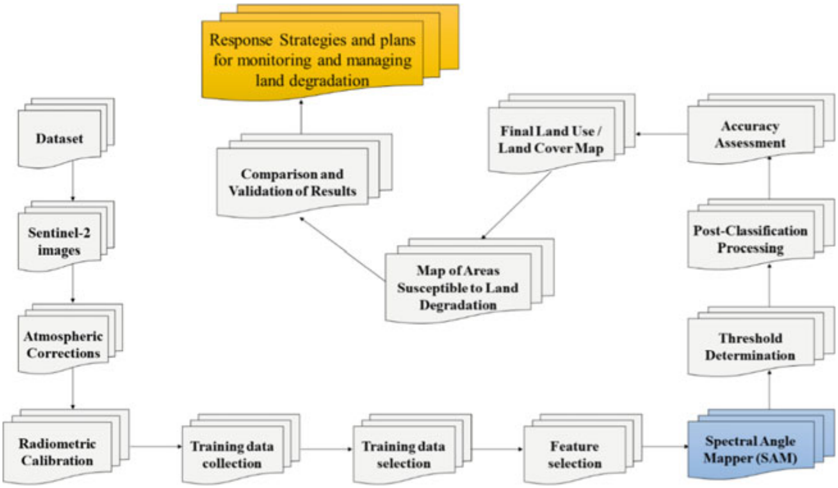


Fig. 5 Flowchart of the work methodology for the spectral angle mapper

Survey (https://earthexplorer.usgs.gov/). The Sentinel-2 satellite, which the European Space Agency (ESA) launched on June 23, 2015, has 13 bands that can record multispectral images (Table 1). Sentinel-2 data are used in the Global Monitoring for Environment and Security (GMES) program, which the European Commission and the European Space Agency jointly run. Services provided by this program include monitoring natural disasters, humanitarian efforts, and services related to land management, agricultural production, and forestry. Sentinel-2 imagery was acquired for the study area, ensuring that it covered the region of interest and was cloud-free or with minimal cloud cover. Ensure that the imagery is preprocessed, including atmospheric correction and radiometric calibration, to normalize reflectance values. All data were projected onto the UTM (zone 30) and WGS 84 data. The study area lies within 127 paths and 57 rows of the WRS2 reference system. The acquired data were used for the LULC mode classification.

3.2 *Images Classifications*

The European Space Agency's (ESA) Sentinel Application Platform (SNAP) software from the European Space Agency was used to classify Sentinel-2 images. We also used ENVI software, and for the cartography of the study results, this study employed QGIS software. We performed a detection analysis using a supervised classification approach based on the definition of training sites. No automatic classification processes exist. By manually entering the training polygons, the detector establishes the classes seen on the image using an in-depth understanding of the field. These polygons are then classified in accordance with the corresponding class

Table 1 Sentinel-2 image characteristics

Band name	Sensor	Band number	Sentinel-2A		Sentinel-2B		Resolution (m)
			W (nm)	B (nm)	W (nm)	B (nm)	
Coastal aerosol	MSI	B1	443.9	20	442.3	20	60
Blue	MSI	B2	496.6	65	492.1	65	10
Green	MSI	B3	560.0	35	559	35	10
Red	MSI	B4	664.5	30	665	30	10
Vegetation red edge	MSI	B5	703.9	15	703.8	15	20
	MSI	B6	740.2	15	739.1	15	20
	MSI	B7	782.5	20	779.7	20	20
NIR	MSI	B8	835.1	115	833	115	10
Narrow NIR	MSI	B9	864.8	20	864	20	20
Water vapour	MSI	B10	945.0	20	943.2	20	60
SWIR-cirrus	MSI	B11	1373.5	30	1376.9	30	60
SWIR	MSI	B12	1613.7	90	1610.4	90	20
SWIR	MSI	B13	2202.4	180	2185.7	180	20

NB: MSI: Multispectral Instrument; W: Central wavelength; B: Bandwidth

after the classification algorithm has finished analyzing the spectral signatures of each pixel contained in each class (Benzougagh and Fellah 2023). Representative samples of different land cover classes were chosen for training data collection, and ground-truth data were gathered through field surveys or existing references. Subsequently, we separated the ground truth data into training and validation datasets, ensuring that the training set adequately represented each land cover class.

Feature selection involves identifying the relevant spectral bands and indices from Sentinel-2 imagery, emphasizing the Red, Green, Blue, Near-Infrared, and Shortwave Infrared bands used in the SAM approach. We applied the SAM classifier with the training data and selected features, which calculates the spectral angle between each pixel's spectral signature and those of land cover classes in the training dataset. Threshold determination is important when assigning each pixel to a class. Pixels with spectral angles below the threshold were assigned to the nearest spectral signature, whereas the others were either unclassified or formed a separate class. Post-classification processing refines the results and removes misclassifications through spatial filtering or object-based refinement for coherent land cover polygons. We used the validation dataset to assess the accuracy and compare the classified map with the ground truth data, calculating classification metrics such as the overall accuracy and kappa coefficient. Finally, we incorporated post-classification refinements and accuracy assessment results into the final land-cover map. Visualization and interpretation ensured well-defined classes that were representative of the actual land cover distribution. Following these steps, the SAM approach with Sentinel-2 imagery yielded a reliable LULC map, effectively distinguishing land cover classes with subtle spectral differences.

3.3 SAM

The primary objective of this study is to identify and map the spatial distribution of land degradation features using hyperspectral image classification. We used the SAM classification algorithm to achieve this goal. SAM is a powerful technique employed for hyperspectral image classification, which allows us to accurately categorize different land cover and land degradation classes based on their spectral signatures. The SAM technique is based on the definition of the spectral similarities in the domain of (n-dimensional) structure. The angle (α) determines the difference in the spectra. By measuring the angle between the pixel and the reference spectrum (Fig. 6), an image can be separated into any number of classes (Kruse et al. 1993). Smaller angles correspond closely to the reference spectrum (Kruse et al. 1993; Abdolmaleki et al. 2022; Benzougagh and Fellah 2023).

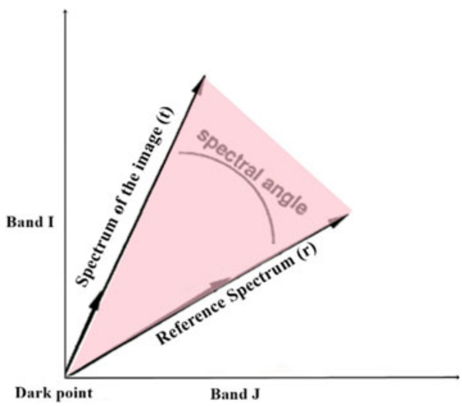
Based on the trigonometric function of the cosine arc, all angles between the total of all target pixels (t) and all reference pixels (r) were calculated for all the band numbers (nb). The formula for Eq. (1) is as follows:

$$\boldsymbol{\alpha} = \mathbf{Cos}^{-1}\left(\frac{\left(\sum_{i=1}^{nb} \boldsymbol{tiri}\right)}{\left(\sum_{I=1}^{nb} \boldsymbol{ti}^2\right)1/2\left(\sum_{i=1}^{nb} \boldsymbol{ri}^2\right)1/2}\right) \quad (1)$$

where:

- α: spectral angle between vectors; nb: number of spectral bands; t: target pixel; r: reference pixel.

Fig. 6 Spectral angle in two-dimensional space between the reference and image spectra



The group with the lowest pixel angle received a pixel on its own. Instead of measuring the vector size, the angle size of the radiant and angle is used.

4 Results and Discussion

4.1 Accuracy Assessment

The classification LULC map produced by supervised classification algorithms must first undergo an accuracy assessment to determine its dependability and quality. Comparing the categorized results with reference data, which are typically derived from field research or independently validated data sources, is what this process entails.

4.2 Final LULC Map

During the application of supervised classification using the SAM algorithm and Sentinel-2 imagery in the watershed of Oued Lahdar, four classes were defined as areas of interest to produce an LULC map: Arboriculture, Agriculture, Forests, and Bare Soil (Fig. 7). The table below shows the percentages and areas covered in the study area for each class (Table 2).

The distribution of the different LULC classifications in the research area is shown in Table 2, and we examine how this relates to the risk of land degradation. Land degradation refers to a number of factors, some of which are natural and others that are frequently brought on by human activity or natural processes. We analyze the table by concentrating on its implications for the risk of soil degradation.

- Arboriculture: This area accounts for 109.8 km^2, or 18% of the entire area. Growing trees, such as fruit or ornamental trees, are known as arboricultures. The risk of soil degradation in these areas may change depending on the management techniques and soil conservation measures used. Effective management and soil conservation practices in arboriculture settings can reduce the risks of erosion and deterioration.
- Agriculture: The area used for agriculture totals 164.7 km^2, or 27% of the total area. Soil deterioration, including erosion, nutrient depletion, and loss of soil structure, can be caused by intensive agricultural methods, such as monoculture, excessive use of fertilizers and pesticides, and inadequate soil management. Sustainable agricultural methods and measures for soil conservation are crucial for reducing the risk of soil degradation in these locations.
- Forests: 134.2 km^2, or 22% of the total area, is covered by forests. Forests are essential for the preservation and protection of soil. Tree roots contribute to soil stabilization and erosion reduction. These forests can lessen the danger of soil

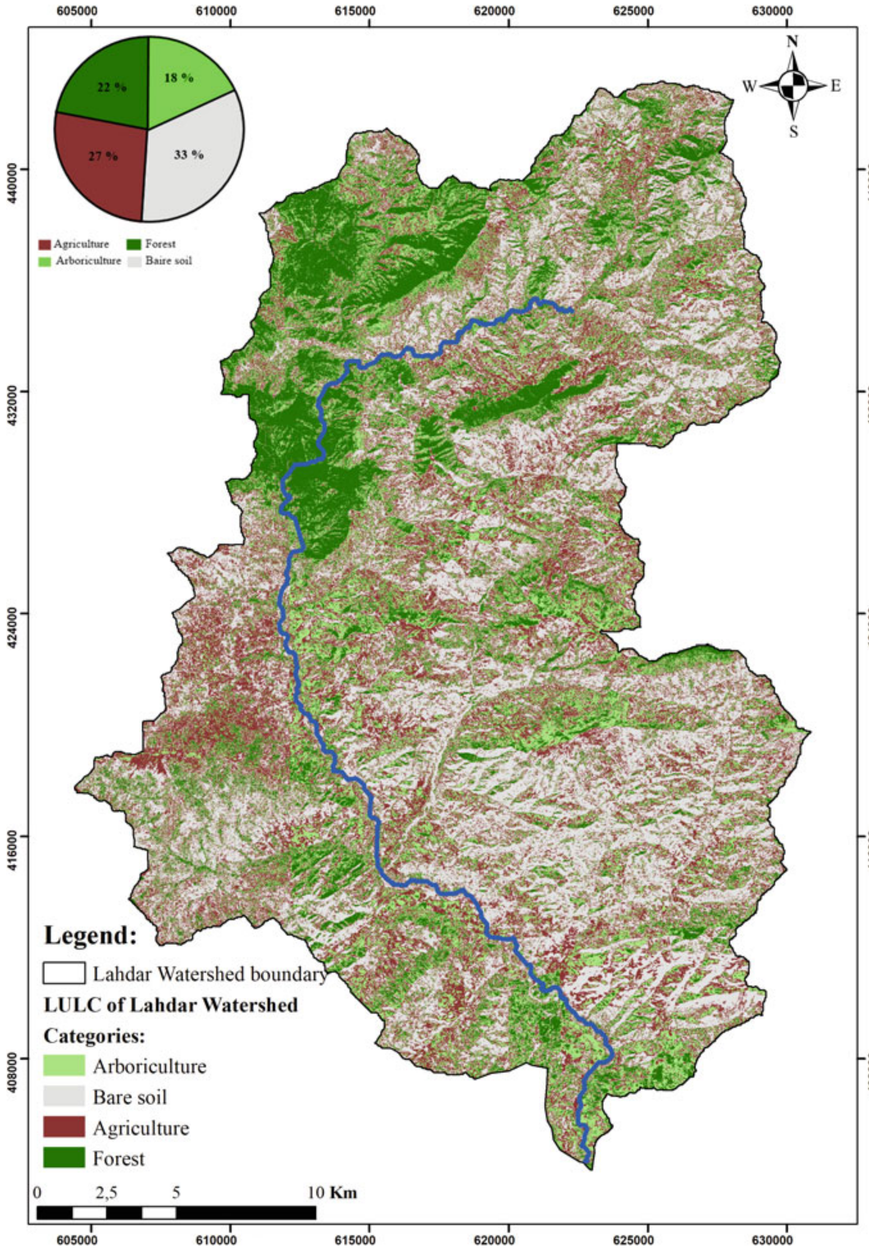


Fig. 7 The Lahdar watershed map of LULC

Table 2 Areas and percentages of each LULC class according to the SAM approach

Class	SAM (km^2)	SAM (%)
Arboriculture	109.8	18
Agriculture	164.7	27
Forests	134.2	22
Bare soil	201.3	33
Total	610	100

degradation if properly managed and not subjected to deforestation or destructive logging.

– Bare soil: A total of 201.3 km^2, approximately 33% of the total area, falls under the bare soil category. In particular, bare soil regions are more susceptible to land degradation if exposed to erosive influences such as water and wind. Without vegetation, there is a large increase in the risk of soil erosion and loss of fertile topsoil. Implementing soil conservation activities such as reforestation or ground cover planting is crucial for lowering the risk of soil degradation in bare soil areas.

The data presented in Table 2 and Fig. 7 indicate a significant concern for the overall land degradation risk in the Lahdar Watershed. The combination of substantial proportions of bare soil (33%) and agriculture (27%) suggested that a large portion of the landscape may be susceptible to land degradation if appropriate measures are not implemented (Fig. 8). Bare Soil areas are particularly vulnerable to erosion and loss of fertile topsoil, especially when exposed to erosive forces, such as water runoff and wind (Chamizo et al. 2017; Weeraratna 2022). The absence of vegetation cover leaves soil unprotected, making it more susceptible to degradation (Wassie 2020; Benzougagh and Fellah 2023). To mitigate the risk of soil degradation in these areas, urgent intervention is necessary, such as implementing soil conservation practices such as afforestation, reforestation, or ground cover planting. Agricultural lands covering a significant portion of the study area are also at considerable risk of soil degradation. Intensive agricultural practices, including monoculture, excessive use of fertilizers and pesticides, and improper soil management, can lead to soil erosion, nutrient depletion, and a decline in soil quality (Singh 2000; Nair and Nair 2019).

Sustainable agricultural practices such as crop rotation, cover cropping, reduced tillage, and organic farming techniques are vital for preserving soil health and mitigating degradation risks (Peigné et al. 2007; Crystal-Ornelas et al. 2021; Kader et al. 2022). Although Forested areas provide valuable protection against soil erosion owing to their stabilizing effect on the soil through tree root systems (Zuazo and Pleguezuelo 2009; Karimi et al. 2022a, b), it is essential to ensure that these forests are well managed and protected from deforestation or destructive logging practices. Sustaining healthy forests can significantly reduce the risk of soil degradation and maintain the integrity of the ecosystem.

Addressing the overall land degradation risk requires comprehensive LULC planning and targeted soil conservation strategies. To devise effective and sustainable management approaches tailored to each land cover class, it is crucial to consider

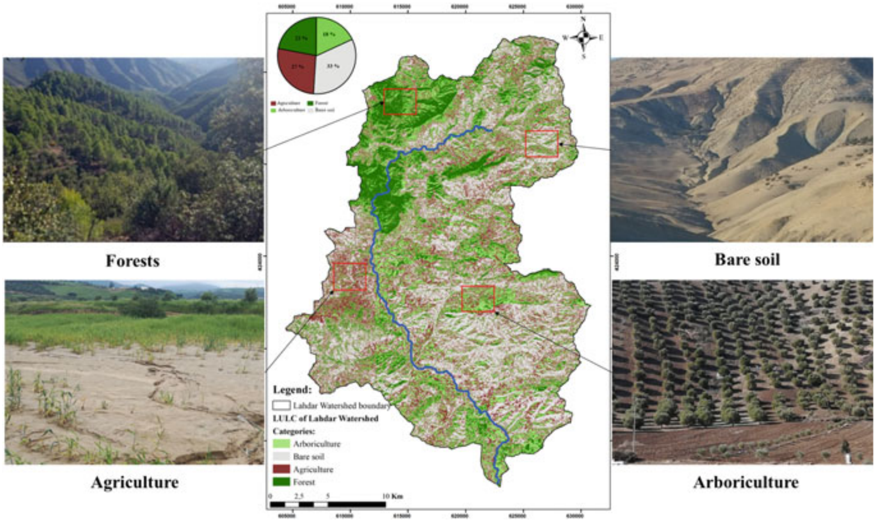


Fig. 8 Different classes of LULC and forms of soil degradation in the Lahdar watershed

site-specific factors such as soil properties, climatic context, topography, geomorphology, geology, and LULC history. Additional evaluations, including soil property analysis, erosion studies, and monitoring of land use practices, are essential for acquiring more precise knowledge of the risk of soil degradation. The findings will inform policymakers, land managers, and other stakeholders of such evaluations to take necessary precautions to protect the study area's soil health and overall environmental sustainability.

5 Conclusions

Remote sensing is vital in studying various earth science applications, particularly in addressing environmental issues such as land degradation and soil erosion mapping. Its significance lies in its ability to reduce expenses associated with field mapping, overcome challenges in accessing remote regions, and identify areas prone to land degradation. This study utilized Sentinel-2 imagery and the SAM approach to perform supervised classification for land cover mapping and identification of land degradation features. The application of SAM allowed us to accurately categorize different land-cover classes based on their spectral signatures, providing valuable insights into the spatial distribution of land degradation within the study area. We systematically acquired and preprocessed Sentinel-2 imagery, collected ground-truth data, selected relevant features, and applied the SAM classifier. Post-classification processing and accuracy assessment were conducted to refine the results and evaluate the reliability of the land cover map.

As a result of the different LULC classifications in the research area, the arboriculture class represented 18% of the study area, while the agriculture class showed coverage of 27%, followed by the forest class occupying 22% of the catchment area, and finally, the bare soil class representing 33% of the total study area. The combination of substantial proportions of bare soil (33%) and agriculture (27%) suggested that a large portion of the landscape may be susceptible to land degradation if appropriate measures are not implemented.

The accuracy assessment revealed promising results, demonstrating the effectiveness of the SAM approach in accurately classifying land cover classes and identifying areas prone to land degradation. This information is vital for informed land management and conservation strategies as it aids in identifying vulnerable areas and guiding targeted conservation measures for sustainable development. It is worth noting that the study's success is attributed to the comprehensive validation of results, ensuring the accuracy and credibility of land cover mapping through field missions and the use of Google Earth. The validation process allowed us to understand the strengths and limitations of the classification and enabled iterative improvements to enhance the classification methodology. The derived LULC map is valuable for environmental monitoring, ecosystem conservation, and land use planning. Policymakers, researchers, and stakeholders can use this information to make informed decisions for sustainable land management, protect natural resources, and mitigate the impact of land degradation.

6 Recommendations

At the end of this chapter, a number of recommendations have been made:

- Promote the use of remote sensing, specifically Sentinel-2 imagery, in addressing environmental issues such as land degradation and soil erosion mapping. Highlight the cost-effectiveness and efficiency of remote sensing compared to traditional field mapping methods.
- Encourage the application of the Spectral Angle Mapper (SAM) approach for supervised classification of land cover mapping and identification of land degradation features. Emphasize the accuracy and reliability of SAM in categorizing different land cover classes based on their spectral signatures.
- Advocate for the implementation of appropriate measures to prevent land degradation in areas with substantial proportions of bare soil and agriculture. Raise awareness of the vulnerability of these areas and the potential consequences if preventive actions are not taken.
- Highlight the importance of accuracy assessment and validation in remote sensing studies. Emphasize the need for ground-truth data collection, field missions, and the use of tools like Google Earth to validate and refine classification results.

- Stress the value of the derived land cover map for environmental monitoring, ecosystem conservation, and land use planning. Encourage policymakers, researchers, and stakeholders to utilize this information for informed decision-making in sustainable land management and resource protection.
- Promote collaboration between researchers, policymakers, and stakeholders to develop targeted conservation measures based on the identified vulnerable areas. Emphasize the role of collective efforts in mitigating the impact of land degradation and ensuring sustainable development.
- Encourage further research and studies in the field of remote sensing and its applications in addressing environmental issues. This can include exploring advanced classification algorithms, integrating multi-sensor data, and investigating other remote sensing platforms for improved accuracy and coverage.
- Promote capacity building and training programs for professionals and stakeholders involved in land management and conservation. Provide education and resources on remote sensing techniques, data analysis, and interpretation to enhance their understanding and utilization of these tools in decision-making processes.
- Foster collaboration between academia, government agencies, non-governmental organizations, and local communities to develop integrated land management strategies. Encourage the sharing of data, knowledge, and best practices to facilitate evidence-based decision-making and promote sustainable land use practices.

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