Romanian Journal of Petroleum & Gas Technology
Vol. VI (LXXVII) • No. 1/2025

APPLICATION OF PHOTO-INTERPRETATION AND REMOTE SENSING TECHNICS FOR GEOLOGICAL MAPPING – CASE OF THE REGION OF ZAGORA, MOROCCO

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DOI: 10.51865/JPGT.2025.01.05

ABSTRACT

The current era of digital technology has opened up endless possibilities for exploring and understanding our world. Among these advances, Geographic Information Systems (GIS) and remote sensing have revolutionized our ability to study and interpret geological phenomena without being physically present on the ground. The objective of this study therefore aims to use these tools to develop a more in-depth understanding of the geology of the Zagora province, a region of Morocco, using Landsat 9 images to produce a detailed geological map of the region characterized by a diversity of geological formations thus coupling the photo-interpretation approach and the Random Forest supervised classification algorithm. The results highlighted lithostratigraphic units, hydrographic networks and faults with great precision. The integration of these two methods provided complementary information, improving the accuracy and detail of the geological mapping of the area and highlights the importance of remote sensing tools and GIS for geological analysis and resource management.

Key words: geological mapping, Landsat 9, Zagora, Morocco, supervised classification, photo-interpretation, random forest, GIS, remote sensing

INTRODUCTION

Morocco is a North African country located both on the Mid-Atlantic continental margin and on the western area of the Mediterranean basin (Tethyan margin). The current geomorphology of Morocco is mainly linked to the convergence between the African and

Eurasian plates, resulting in the inversion of the High and Middle Atlas rifts as well as the formation of the Anti-Atlas and Rif mountains [1],[5],[6]. In this sense, the geological map becomes a tool for analysing and understanding the phases of formation of the different types of rocks (sedimentary, magmatic, metamorphic rocks, etc.) as well as their chronologies. These maps provide important information about geology in a very understandable form. They are very useful in making geotechnical or environmental decisions [2],[4].

The geological map is therefore a representation of the rocks and geological structures present at the outcrop or subsurface of a region. The objective of the latter is to present the spatial distribution of the lithological facies, their successions, as well as various tectonic structures. On a topographical background, geological formations are generally plotted using various graphic elements (symbols, figures and colours). Hence the existence today of printed and digitized geological maps in the form of raster or vector datasets.

The advancement of the tools and techniques of Earth Observation sciences, the characterization of the nature, age, structure and history of outcropping rocks on the Earth's surface have become much more efficient and more varied. Recent technical developments in this field have made it possible to significantly improve spatial, spectral and temporal resolution [3]. The characteristics offered by these tools make it possible to highlight certain major structures, in particular linearity accidents that are barely visible in the field, but well expressed on the images. The various Earth observation tools also make it possible to reconstruct the geometrical characteristics of formations (geological structure, geographical extent) more accurately and save considerable time than conventional methods. It is in this sense that our work aims to map geological formations from Earth Observation data. As part of this work, the following were produced:

- Geological maps by photo-interpretation and image classification and to compare them;
- Geological lineament maps (fracturing rosette, density map, etc.);
- Permeability and erodability maps from the geological map

The current era of digital technology has opened up endless possibilities for exploring and understanding our world. Among these advances, Geographic Information Systems (GIS) and remote sensing have revolutionized our ability to study and interpret geological phenomena without being physically present in the field [4]. This project aims to use these tools to develop a deeper understanding of the geology of the province of Zagora, a region of Morocco with fascinating geological diversity. Using Landsat 9 imagery and supervised classification, we aspire to create a detailed geological map that illustrates the geological history of Zagora [10],[11],[13].

PRESENTATION OF THE STUDY AREA

Localization

The province of Zagora, located in the Drâa-Tafilalet region of Morocco, is a region of great geographical and ecological diversity. It consists of the municipalities of Zagora and Agdz, with Zagora as its capital. Positioned at 30°19′ north latitude and 5°50′ west longitude, the province covers an area of 23,000 km², making it one of the largest subdivisions in the Souss-Massa-Draâ region [2],[7],[19]. Zagora is a land of contrasts. On one side, it is home to sand dunes to the east, typical of the desert landscapes of this part of Morocco [8],[9]. On the other hand, it is home to the largest palm groves in Africa, centered around the Wadi Draa, which bring a touch of greenery to this arid landscape. These palm groves are a source of life for local communities and an attraction for visitors. In addition to these features, the province of Zagora is also rich in mountains and valleys, offering varied terrain that contributes to its unique natural beauty [20],[24],[25]. It is also blessed with forests, including *Acacia raddiana* and *Tamarix aphylla*, which add to the diversity of the flora of the region [19],[20].

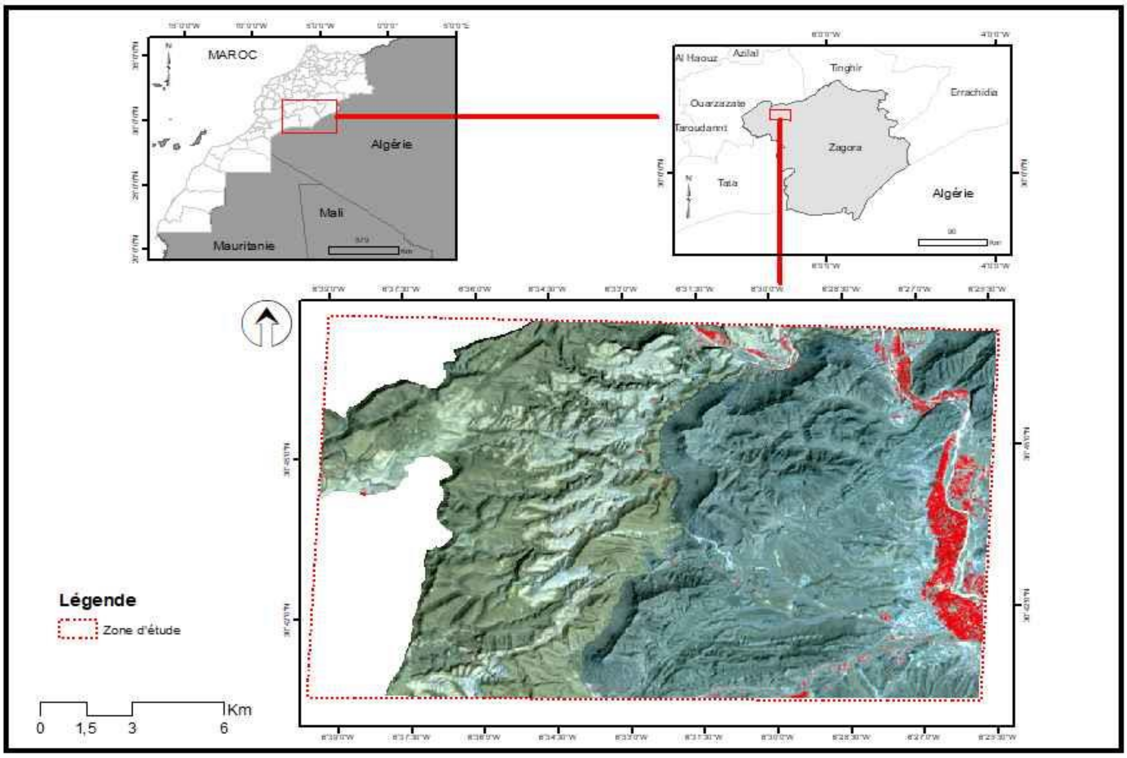

Figure 1. *Presentation of the study area*

GEOLOGICAL SETTING

The province of Zagora, located in the south-east of Morocco, is characterised by a great geological diversity, inherited from the Anti-Atlas range. This diversity of formations includes sedimentary, igneous and metamorphic rocks [13],[15].

The geology of Zagora records part of the geological history of Morocco. The Ordovician and Quaternary deposits are the most dominant outcrops in the province [16],[17].

The Ordovician, a period of the Paleozoic era dating from about 485 to 443 million years ago, is known for a great biological diversification, including the appearance of many groups of marine invertebrates. The Quaternary deposits, dating from the last 2.6 million years, include sediments deposited during the last glacial and interglacial periods.

In addition to its geodiversity, the province of Zagora is also rich in geological heritage, highlighting the long geological history of the region. For example, the Bani Geopark project, the first UNESCO Global Geopark in Africa and the Arab world, was launched in the province of Zagora. This Geopark is characterized by great geodiversity and a rich geo-cultural heritage, reflecting the interaction between geological processes and human activities over time [12],[13]. The geological map we plan to create will help highlight these different formations and provide a better understanding of the geology of Zagora, precisely in our part of the study.

MATERIALS AND METHODS

Tools and Data used

To carry out this project, we used several tools namely geographic information system software (QGis, Geomatica, etc.) for data processing, analysis as well as the design of maps and data sources. The data comes from an April 2024 Landsat 9 image, which provides land cover information, including geological formations. The selected bands have a resolution of 30 m and are 7 in number. We also used the geological map of the province of Zagora in the 200th century to help interpret the Landsat image. The image properties are summarized in the table 1 below :

Table 1. *Image Landsat 9 properties*

N°	***Designations***	***Values***
1	*Numbers of Bands*	*7 (Band 1, Band 2, Band 3, Band 4, Band 5, Band 6, Band 7)*
2	*Source type*	*Generic*
3	*Datum*	*WGS_1984*
4	*Columns and Rows*	*384, 735*
5	*Cell Size (X, Y)*	*30, 30*
6	*XY Coordinate System*	*WGS_1984_UTM_Zone_29N*
7	*Pixel Depth*	*32 Bit*

METHODOLOGY

Our methodology illustrated in Figure 2 is to combine these different data sources to create a detailed geological map of Zagora. We started with the acquisition and pre-processing of the Landsat 9 image.

Then, we used photo-interpretation to identify the geological features visible in the image. We then used supervised classification to classify the different geological formations present in the image. In parallel, we used geological and topographic maps to validate and refine our interpretation of the Landsat image. Finally, we compiled all this information to create a detailed geological map of Zagora.

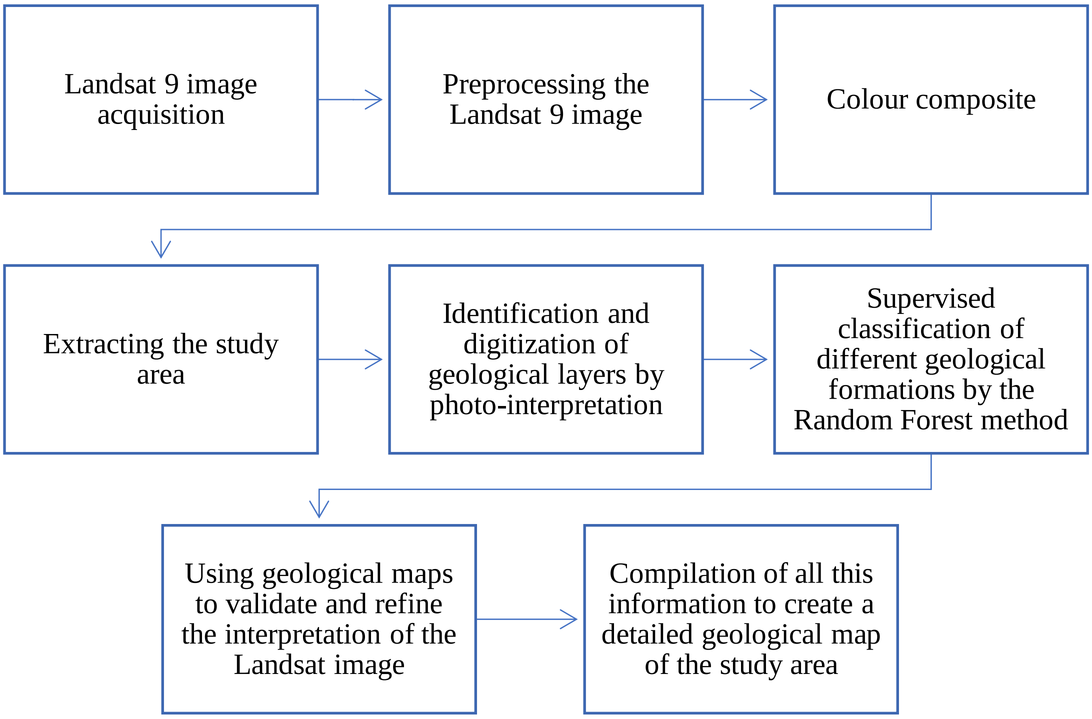

***Figure 2**. Work methodology flowchart*

RESULTS AND INTERPRETATIONS

Geological map drawn up by photo-interpretation from the Landsat 9 Image

Figure 3 shows a detailed view of the geological formations in the province of Zagora, located in southeastern Morocco. It highlights various lithostratigraphic units as well as the hydrographic network and faults of the region.

The map shows the following:

- Low terrace (qA, Quaternaire) : this Quaternary formation corresponds to recent deposits located in the region, often associated with alluvial plains [11].
- Tabanit Sandstone Group (Ks2b, middle Cambrian): this Cambrian formation includes sandstones, typically Tabanit, indicating an early fluvial or coastal depositional environment [12],[20].
- Terminal sandstone formations (Ki, Georgien terminal): these Georgian terminal sandstones are sediments deposited at the end of the Georgian period, suggesting a depositional environment that may be associated with deltas or floodplains [13].
- Schisto-limestone formation (Ad3, Adoudounien supérieur): this formation includes schists and limestones, indicating a shallow marine environment during the Upper Adoudounian [14].
- Wine Lees Formation (Ad2, Adoudounien moyen): This formation is characterized by fine detrital deposits, such as siltstones and argillites. These

deposits formed in shallow marine environments, subject to low-energy conditions,

- Hydrographic network and faults.

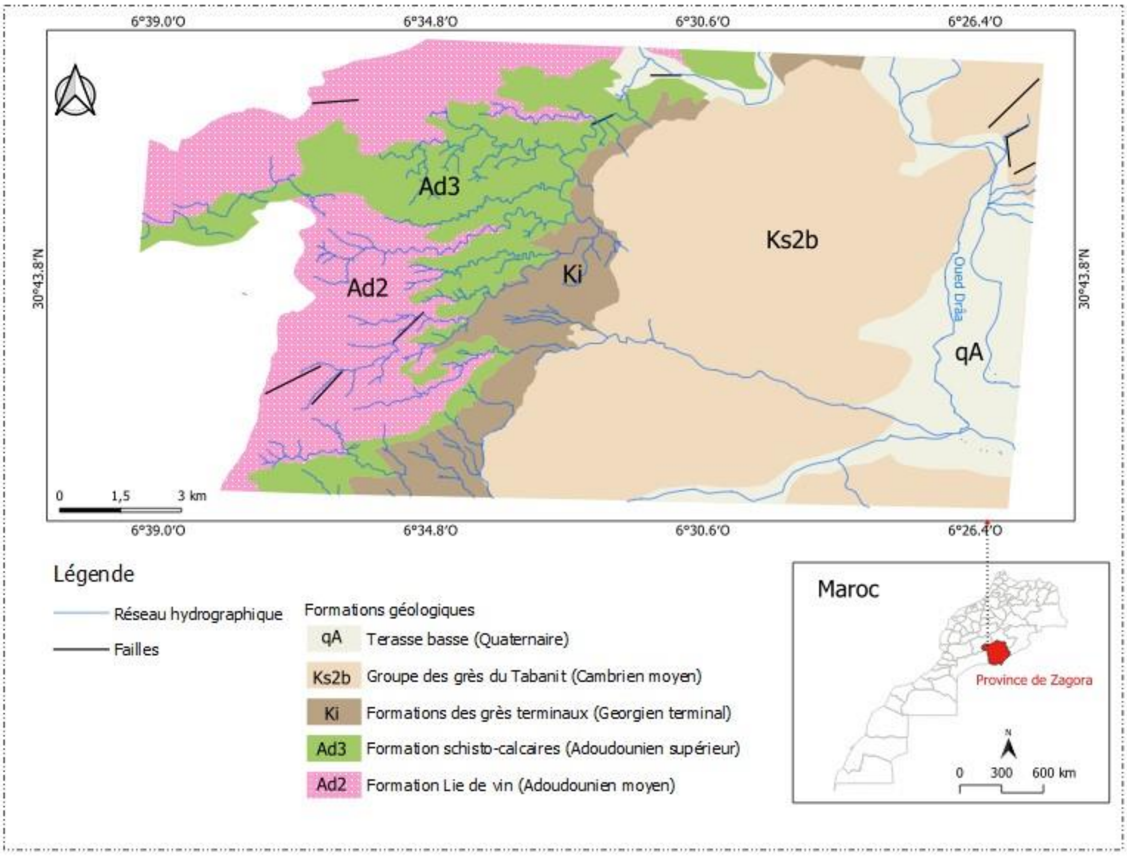

Figure 3*. Map of lithological formations drawn up by photo-interpretation*

The map also shows the main hydrographic network of the region, in particular the Oued Drâa marked in blue, as well as the geological faults, indicated by black lines. Rivers play an important role in landscape shaping and sediment redistribution, while faults are indicators of past and present tectonic activity. These faults can influence the distribution of natural resources and the stability of land for human construction.

Geological map drawn up by supervised classification from the Landsat 9 Image

The map in Figure 4 above shows the lithological layers as well as the map in Figure 4. They were obtained by a method called supervised classification. A Machine Learning model was chosen for this method, in particular the Random Forest model, for better accuracy given the reality on the ground. The tool that allowed us to run this model is Dzetsaka: classification tool integrated into the Qgis software.

In this thematic map, we observe the same format of the layers with minimal difference from the one drawn up by photo-interpretation. The lithostratigraphic descriptions are the same as those in Figure 3.

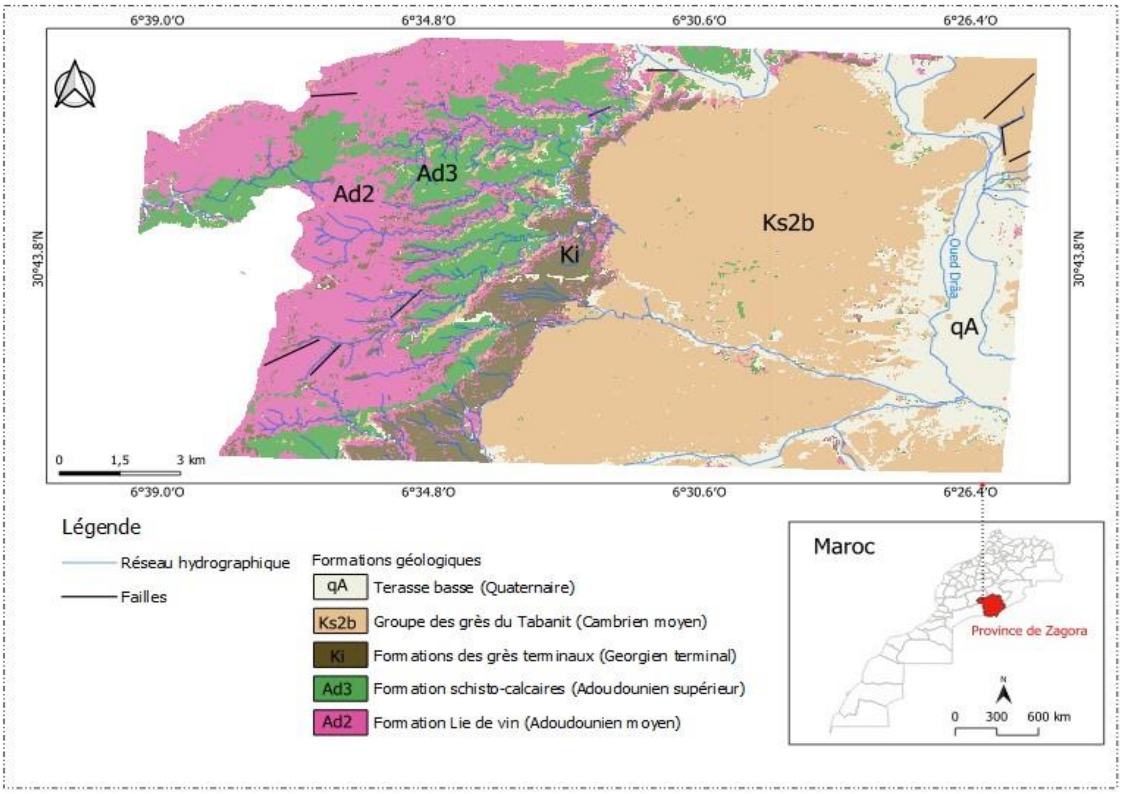

Figure 4*. Map of lithological formations drawn up by supervised classification*

Comparison of the lithological map obtained by photo-interpretation and supervised classification

Figure 5 allows you to make a visualization in order to compare the two maps obtained previously. It appears that the two maps present the same lithostratigraphic units of our study area, although obtained differently. The first was digitized and the second was generated through the samples of each previously defined layer. The digitized one does not bring out the details because of the resolution of our image and what we perceive. The second shows us the details because of its pixel-based approach, which means that the map drawn up by classification shows us more or less a spatial distribution of the formations close to that of the image used.

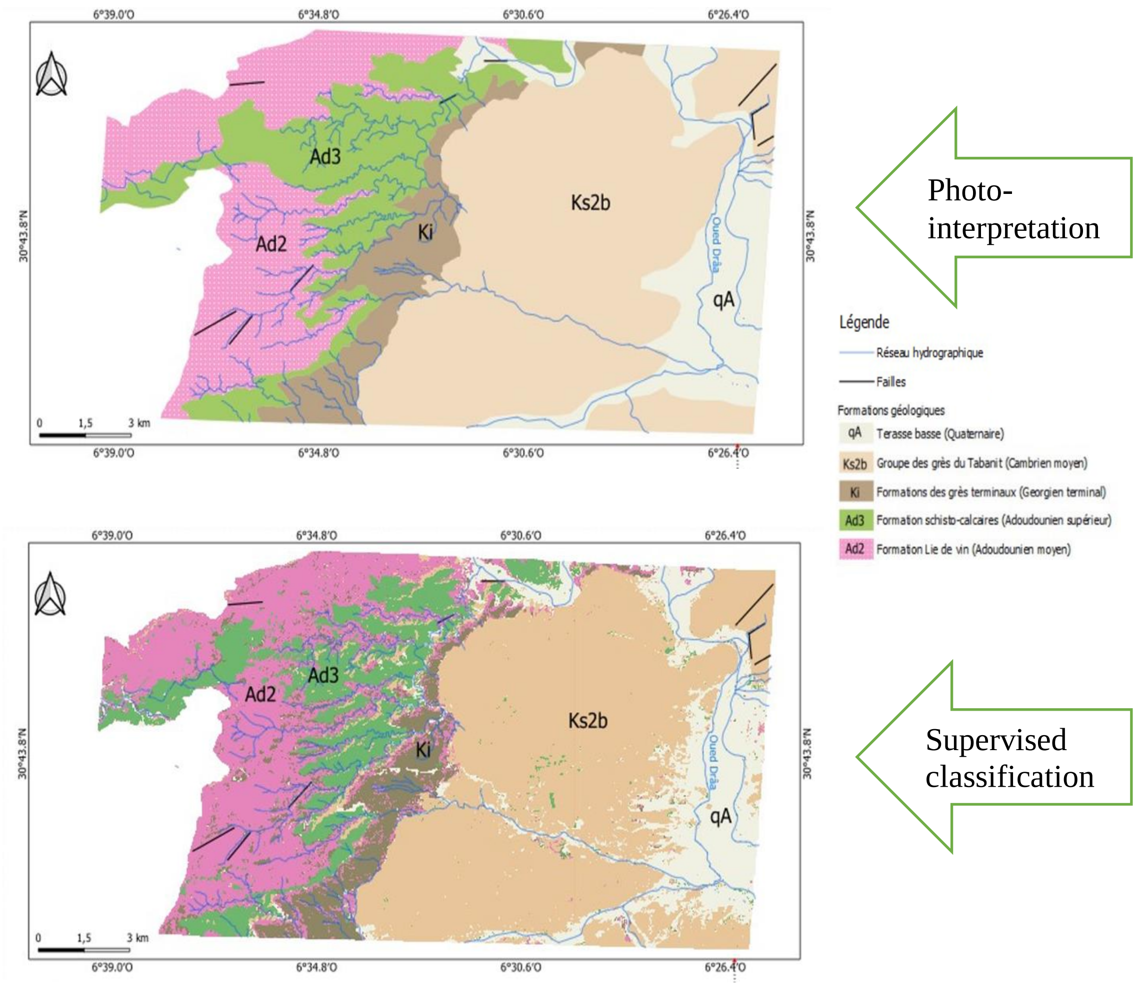

Figure 5*. Comparison map of lithological formations drawn up by photo-interpretation and supervised classification*

Map of lineaments and its density established from the image

The map shown in Figure 6 shows the distribution of lineament densities in our study area. Lineaments are linear features visible on satellite images or geological maps, such as faults, expansion joints, and streams. Lineament density analysis can provide valuable information about the geological structure of a region and the geological processes that have affected it [17],[18].

The map shows that the density of lineaments varies considerably in this part. Areas of high density of dark red lineaments are usually found in tectonic deformation zones, such as mountain ranges and sedimentary basins [14],[19]]. The low density areas of lineaments in light red are generally found in areas of flat and undeformed rock, this allows us to generate the fracture dew diagram as shown in Figure 7.

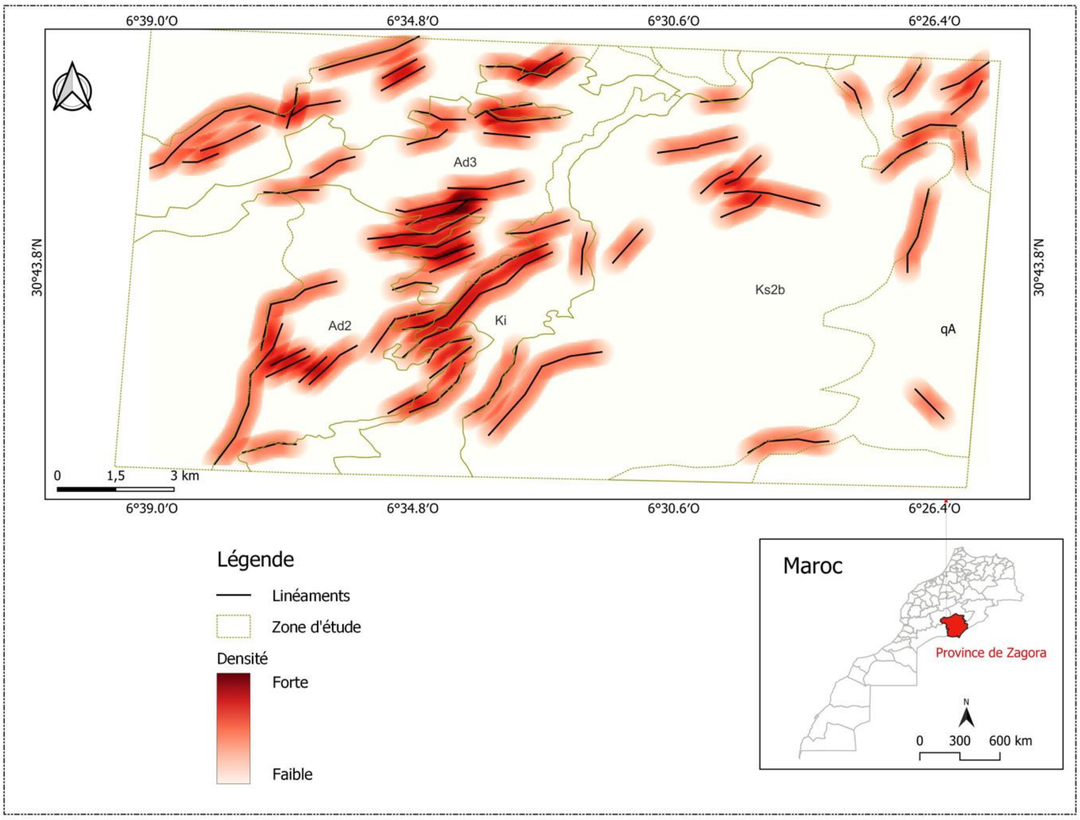

***Figure 6**. Lineament map and their densities*

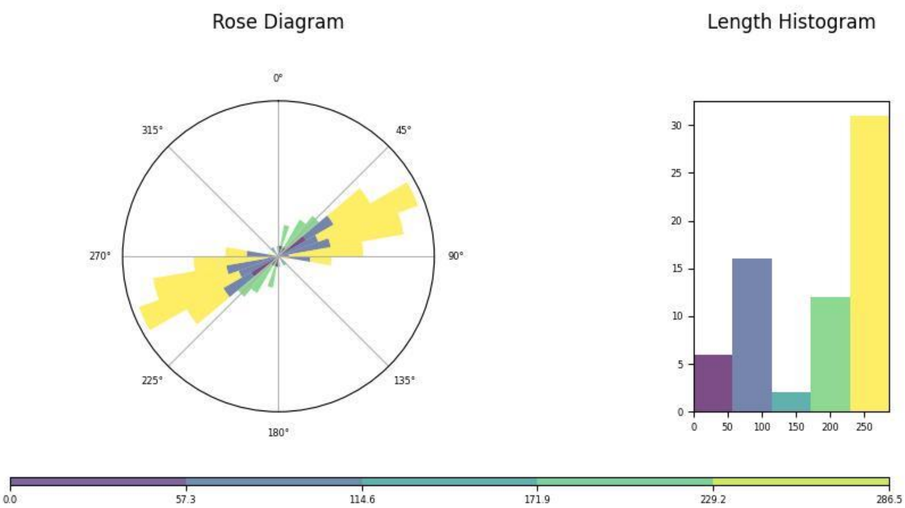

***Figure 7**. Rose window diagram and histogram of lineament lengths*

The rosette diagram shows us the orientation of the lineaments of our study, with two predominant directions between 45° and 90° from NE to SW. The histogram of the lengths shows a wide range of lineament lengths, with a peak around the range 100 to 150 meters. This implies that lineaments include a variety of geological structures. The presence of longer lineaments suggests the possibility of deeper faults or structures that may have played an important role in the geological evolution of the region.

Extraction of the permeability map

Figure 8 shows the permeability map of geological formations. Permeability is the ability of a material to allow fluids, such as water or air, to pass through. It is measured by the speed at which a fluid can flow through the material. Permeability is an important property of many materials, including soils, rocks, etc.

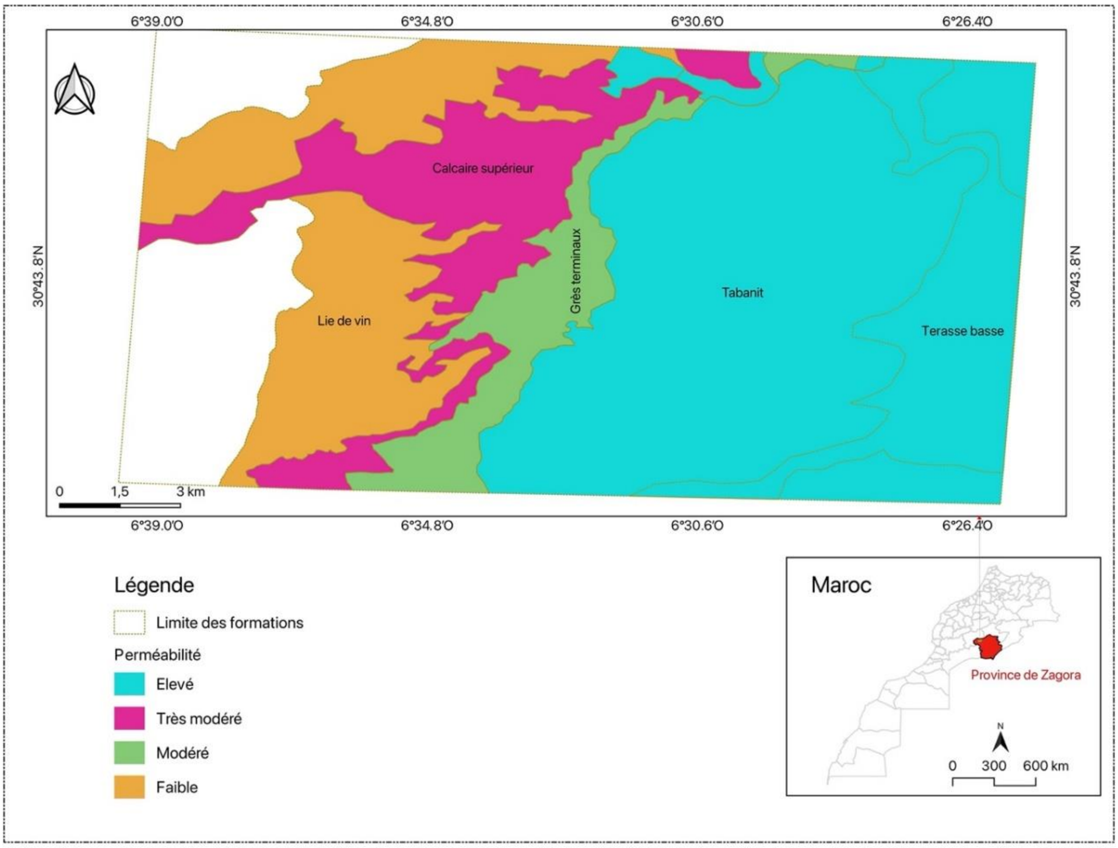

***Figure 8**. Permeability map*

The permeability map was obtained by processing remote sensing data in QGIS, using spectral indices and hydrogeological models. These data were interpolated and converted into a raster layer to represent the spatial distribution of permeability. In this map, the rock formations of our area have a permeability that ranges from low to high, in particular the Lie de vin formations in beige, the formations of the terminal sandstone and upper limestone which are respectively moderate and very moderate. Finally, the Tabanit group and the low terraces which have a high permeability.

Extraction of the erodability map of the rocks standards of the parent materials

Erodibility is the ability of a soil or rock to be eroded by natural agents such as water, wind, or ice and can be influenced by several factors, as illustrated in Figure 9 [26].

This erodability map shows the formations in our study area that are coherent, namely the Tabanit group and the formations of the upper limestone, the latter represented in red. In Yellow we have the formation of terminal sandstones which have a moderately coherent erodability. The formations with a soft erodability are, as shown on the map, the Lie de vin formations and the low terraces in blue.

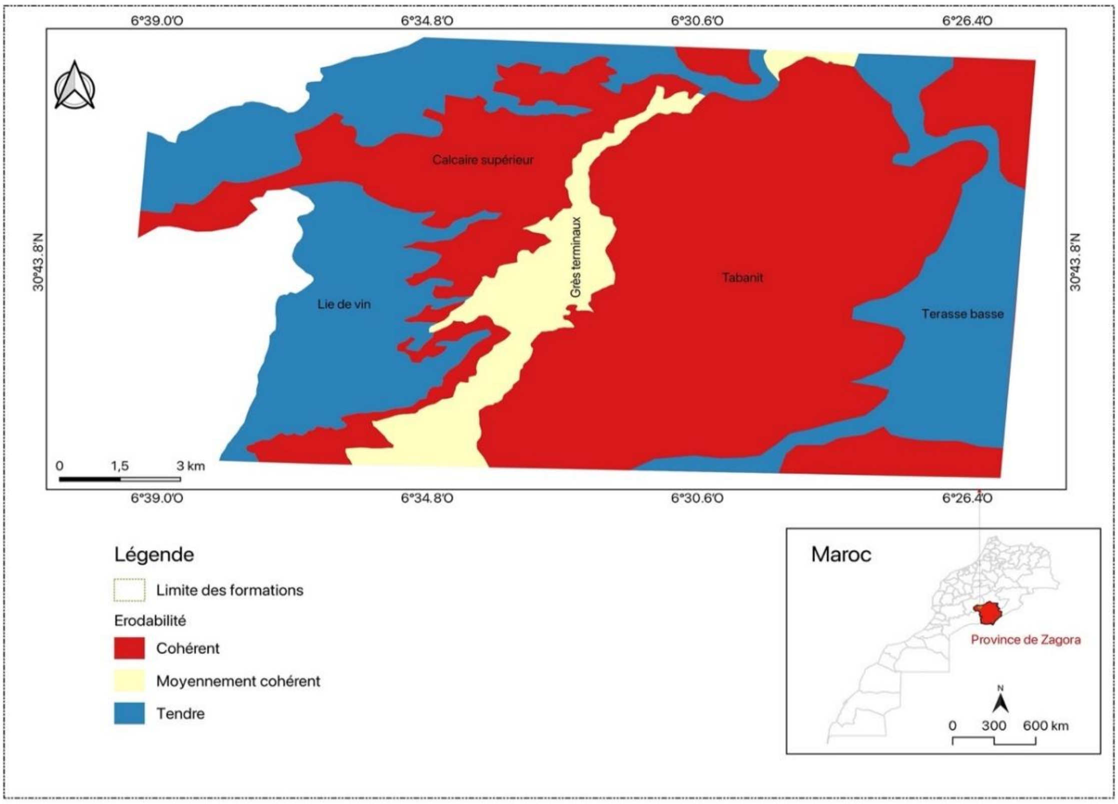

***Figure 9**. Erodability map*

CONCLUSIONS

This work made it possible to explore the geology of the Drâa-Tafilalet region, Zagora province, using remote sensing techniques and geographic information systems (GIS). The Landsat 9 satellite image was acquired for the study area and processed using QGIS software [2],[10].

Analysis of this satellite image resulted in the creation of several geological maps representing the lithological formations, lineaments, permeability and erodibility of the region. Pixel Random Forest classification was used to identify the geological formations accurately, confirming the presence of the Wine Lees, Upper Limestone, Terminal Sandstones, Tabanit and Low Terraces Formations.

These formations range from the Late Quaternary to the Middle Cambian deposits, each with its own lithological characteristics and implications for land use, water resource management, and mining research. The river network and faults add additional dimensions to the geological analysis, highlighting the importance of this map for various scientific and practical applications.

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Received: September 2024; Revised: February 2025; Accepted: February 2025; Published: February 2025