لجمهورية الجزائرية الديمقراطية الشعبية

PEOPLE'S DEMOCRATIC REPIBLIC OF ALGERIA
وزارة التعليم العالي والبحث العلمي

MINISTRY OF HIGHER EDUCTATION AND SCIENTIFIC RESEARCH
المدرسة الوطنية العليا للتكنولوجيا والهندسة. عنابة
NATIONAL HIGHER SCHOOL OF TECHNOLOGY AND ENGINEERING. ANNABA
(Ex ENSMM)

Department of Mining Engineering

Final Year Thesis
To obtain the diploma of Master degree

DOMAIN : SCIENCE AND TECHNOLOGY
FIELD : MINING ENGINEERING
SPECIALTY : ADVANCED FIELD CONTROL

Entitled

Geological mapping using Hyperspectral images in Djanet ,Algeria

Presented by

KHOUMS IKRAM

Supervisor	Grade	Affiliation Institution
CHENITI Hamza	**MCA**	**ENSTI-Annaba-**
President	Grade	Affiliation Institution
BOUSTILA Amir	**MAB**	**ENSTI-Annaba-**
Examiner(s)	Grade	Affiliation Institution
AICHOURI Imen	**MCA**	**ENSTI-Annaba-**

year / 2023

Ministère de l'Enseignement Supérieur et de la Recherche Scientifique

Ecole Nationale Supérieure de Technologie et d'Ingénierie – Annaba

Département Génie Minier

AUTORISATION DE DEPOT FINAL DU MEMOIRE DE MASTER

Je soussigné (e) Mr......BOUSTILA AMIR......

Président(e) du jury de soutenance de mémoire de Master, déclare avoir autorisé Mr ....Khouns Ikram....

à déposer son mémoire de Master après avoir apporté les corrections signalées par les membres du jury.

Avis de l'encadrant : A.F

Dr. CHENITI

Avis de l'Examinateur :

A.F

Dr Aichaoui Imen

Président du Jury A.F

BOUSTILA AMIR

Acknowledgments

First and foremost, I want to offer this endeavor to our God Almighty for the wisdom and knowledge He bestowed upon us, the strength, the endurance, and good health to finish this research.

I would like to express my profound gratitude to my supervisor, Dr. Cheniti Hamza, for his guidance and constant supervision, as well as for providing necessary information regarding this study.

My thanks also go to the jury members who agreed to evaluate our work. I look forward to their further valuable advice.

My heartfelt gratitude knows no bounds to the professors I have met in my engineering career at ENSTI over the past five years, who have welcomed my passion for learning and deepened my knowledge. Because of their sacrifices, I fearlessly took the first step towards the future.

Last but not least, our sincere gratefulness would be incomplete without attributing a part of it to my family and supportive friends. Special thanks to my loving and generous parents who have always been there for me with their emotional support and spiritual guidance throughout our lives.

Dedication

This study is wholeheartedly dedicated

To my respective parents, whose love and belief in me have been the foundation
of my strength, thank you for always standing by me and for instilling
in me the values of perseverance and determination.
Your unwavering support and sacrifices
have made this achievement possible.

To my dearest sisters Imane, Ilhem and Nadia who have stand by my side
and gave me strength when I thought of giving up, who have
cheered me on, provided a listening ear, and celebrated
both the successes and the setbacks.

To my best friends and My beloved ones, who have emotionally
encouraged me and held my hand to reach
the goal I set five years ago.

ملخص
تركز أطروحة الماجستير هذه على تطبيق الصور الفائقة الطيفية كوسيلة بديلة لرسم الخرائط الجيولوجية في الجزائر. تعد الخرائط الجيولوجية مهمة لفهم موارد الأرض وخصائصها الجيولوجية، خاصة في الجزائر بتكويناتها الجيولوجية المتنوعة ومواردها المعدنية القيمة. تم تحديد قيود في نظام القمر الصناعي Alsat-1 لرسم الخرائط الجيولوجية في الجزائري، مما دفع إلى استكشاف الصور الفائقة الطيفية كحل محتمل.
تهدف الدراسة إلى تقييم فاعلية البيانات الفائقة الطيفية في التحديد الدقيق للخصائص الجيولوجية ورسم خرائط لها. يتضمن التنفيذ العملي معالجة وتحليل البيانات الفائقة الطيفية باستخدام أدوات برمجية مثل ENVI وArcGIS، تساهم نتائج هذا البحث في فهم التكوينات الجيولوجية للجزائر وإبراز مزايا الصور الفائقة الطيفية لرسم خرائط جيولوجية دقيقة.

الكلمات المفتاحية: صور فائقة الطيفية، الخرائط الجيولوجية، ENVI، الجزائر، التكوينات الجيولوجية

Abstract
This master's thesis is for the application of hyperspectral imaging as an alternative method for geological mapping in Algeria. Geological mapping is importantin understanding the Earth's resources and geological features, particularly in Algeria with its diverse geological formations and valuable mineral resources. The limitations of the Alsat-1 satellite system for geological mapping in Algeria are identified, prompting the exploration of hyperspectral imaging as a potential solution.
The study aim to evaluate the effectiveness of hyperspectral data in accurately identifying and mapping geological features. Practical implementation involves processing and analyzing hyperspectral data using software tools such as ENVI and ArcGIS. The findings of this research contribute to the understanding of Algeria's geological formations and highlight the benefits of hyperspectral imaging for precise geological mapping.

Key words: hyperspectral image, geological mapping, ENVI, Algeria, geological formations

Résumé
Ce mémoire de master porte sur l'application de l'imagerie hyperspectrale en tant que méthode alternative pour la cartographie géologique en Algérie. La cartographie géologique est importante pour comprendre les ressources de la Terre et les caractéristiques géologiques, en particulier en Algérie avec ses diverses formations géologiques et ses précieuses ressources minérales. Les limitations du système satellitaire Alsat-1 pour la cartographie géologique en Algérie sont identifiées, ce qui incite à explorer l'imagerie hyperspectrale comme une solution potentielle.
L'étude vise à évaluer l'efficacité des données hyperspectrales dans l'identification précise et la cartographie des caractéristiques géologiques. La mise en œuvre pratique implique le traitement et l'analyse des données hyperspectrales à l'aide d'outils logiciels tels que ENVI et ArcGIS. Les résultats de cette recherche contribuent à la compréhension des formations géologiques de l'Algérie et mettent en évidence les avantages de l'imagerie hyperspectrale pour une cartographie géologique précise.

Les mots clés : image hyperspectral , cartographie geologique, ENVI , l'Algérie , les formation geologique

Table of Contents

List of Figures

List of Abbreviations

- **ACORN** : Atmospheric Correction Now
- **ALSAT** : Algerian Satellite
- **ANGCM** : National Agency for Geology and Mining Control,
- **ASAL** : Algerian Space Agency
- **ASGA** : Geological Survey Agency of Algeria,
- **BIL**: Band Interleaved by Line.
- **DEM** : Digital Elevation Model
- **DN** : digital numbers
- **ENVI** : Environment for Visualizing Images
- **EO-1** : Earth Observing-1
- **ESRI** : Environmental Systems Research Institute
- **FLAASH** : Fast Line-of-Sight Atmospheric Analysis of Spectral Hypercube
- **GIS** : Geographic Information System
- **HIS** : Hyper spectral imaging
- **NIR** : near infrared
- **QUAC** : Quick Atmospheric Correction
- **SVM** : Support Vector Machines
- **SWIR** : shortwave infrared
- **USGS** : United States Geological Survey
- **VNIR** : Visible and Near-Infrared

General Introduction

The field of mapping is so important in understanding and managing the Earth's resources and geological features. In Algeria, geological mapping is of particular importance due to the country's diverse geological formations and rich mineral resources.

One of the satellite systems used for mapping purposes in Algeria is Alsat-1, which has been employed for geological mapping projects. However, Alsat-1 has certain limitations that can hinder its effectiveness in this context. This master's thesis aims to explore the use of hyperspectral imaging as a potential alternative for geological mapping in Algeria, for that we choose a study area, which is djanet in the eastern HOGGAR to detect a geological formations using a hyperspectral image of this area.

The first chapter provides an overview of geological mapping in general, highlighting its significance in understanding the Earth's structure. Furthermore, it focuses specifically on geological mapping in Algeria, discussing the country's geological formations,

Chapter two delves into hyperspectral imaging, a remote sensing technique that captures detailed spectral information across a wide range of wavelengths. It explores the principles of hyperspectral imaging, its advantages over multispectral imaging, and the potential applications in geological mapping. A comparison between hyperspectral and multispectral imaging is provided to highlight the unique capabilities and benefits of hyperspectral data.

The final chapter presents the practical aspect of the thesis, focusing on the implementation of hyperspectral imaging for geological mapping in Algeria. It discusses the use of software tools such as ENVI and ArcGIS for processing and analyzing hyperspectral data. The chapter describes the methodology adopted for generating geological maps from hyperspectral images, including image classification techniques and feature extraction algorithms. It displays the benefits of hyperspectral data in accurately identifying and mapping geological feature.

Chapter I: Geological Mapping

CHAPTER I Geological mapping

Part 01: Geological mapping in General

I.1 Introduction

Geological mapping is so important in the overall process of mining exploitation. It involves the systematic study and mapping of the Earth's geology to understand the distribution, structure, and characteristics of mineral resources. Geological mapping provides valuable information about the geological formations, rock types, mineral occurrences, and potential deposit locations.

Moreover, by conducting detailed geological maps, mining companies can identify prospective areas for exploration and determine the most efficient methods for extraction. This information guides decision-making throughout the mining process, from exploration and resource estimation to mine planning and production

I.2 Geological Mapping

Geological mapping entails the physical presence of a geologist in the field, where they document pertinent geological data derived from exposed rock formations. The geologist's observations typically encompass the identification of rock type boundaries, the identification of structural elements like fault lines, and indications of rock deformation. It is worth noting that mapping is not limited to mineral exploration alone; it serves as a fundamental step in numerous investigations, as comprehending the nature of underlying rock formations lays the groundwork for all geologically related studies. During the initial stages of mineral exploration, geologists performing mapping activities remain vigilant for valuable ore minerals, signs of metal-rich fluids permeating through rocks, and the documentation of mineralized veins and their distribution. Depending on the scale and scope of the mapping endeavor, completion can range from several days to several months, often necessitating the collaboration of a team of geologists. **[1]**

Geological mapping forms the foundation of mineral prospection by providing valuable insights into the geology of an area. It helps identify areas with geological features favorable for hosting mineral deposits. Prospection, on the other hand, builds upon geological mapping by implementing further exploration methods to locate and evaluate potential mineral resources.

1. The process of geological mapping

The process of geological mapping involves systematic data collection, analysis, and interpretation to understand the geology of an area.

- **Research and data compilation**: the process begins with gathering existing geological information, including maps, reports, and scientific literature, about the target area. This helps in understanding the regional geology and existing knowledge about the area.
- **Field reconnaissance**: Geologists conduct a preliminary field visit to familiarize themselves with the area's topography, rock exposures, and geological features. They make general observations, note significant rock types, structures, and other relevant geological characteristics.

IKRAM, KHOUMS
National Higher School Of Technology And Engineering. Annaba (Ex ENSMM) 2023

- **Base mapping**: creating a base map of the area using aerial photographs, satellite imagery, or topographic maps. This map serves as a reference for locating and documenting geological features during fieldwork.
- **Field mapping**: by conduct detailed fieldwork, systematically traversing the area and recording geological observations. They identify and map various rock types, geological structures, mineral occurrences, and other relevant features. Measurements and sampling may be carried out to support the mapping process.
- **Sampling and analysis**: Geologists collect rock, soil, and mineral samples during fieldwork. These samples are analyzed in laboratories to determine their composition, mineralogy, and geochemical characteristics. This data helps in understanding the nature and potential of mineral resources in the area.
- **Geophysical and remote sensing surveys**: Geophysical techniques, such as seismic surveys, magnetic surveys, and ground-penetrating radar, may be employed to gather additional subsurface information. Remote sensing methods, including satellite imagery and aerial photography, provide valuable data on surface features and geological structures.
- **Data integration and interpretation**: Geologists analyze and integrate all collected data, including field observations, laboratory analysis results, and geophysical/remote sensing data. They interpret the data to create a comprehensive geological map, depicting the distribution and relationships of different rock units, structures, and other geological features.
- **Map production**: Using specialized software, geologists create detailed geological maps that accurately represent the geology of the area. These maps may include different layers, such as rock types, structures, and mineral occurrences, and are typically accompanied by explanatory notes and cross-sections.
- **Reporting and sharing findings**: The final step involves documenting the findings, interpretations, and conclusions of the geological mapping process in a comprehensive report. The report may include detailed descriptions, diagrams, and supporting data to communicate the geology of the area effectively.**[2]**

2. The importance of geological mapping in mining field

Geological mapping holds immense importance in the field of mining, the subsequent diagram show some key reasons why geological mapping is important in mining:

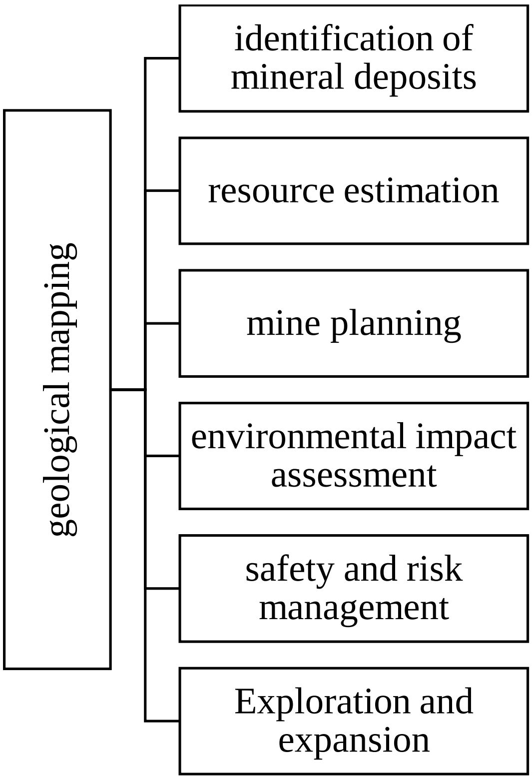


Figure I.01: diagram of geological mapping importance in mining field **[3]**

3. Challenges and concerns

Geological mapping presents challenges and concerns and some of them are:

- Conducting geological mapping can be challenging in remote or inaccessible areas with rugged terrain. Geologists may encounter difficulties in reaching certain locations or accessing specific rock formations, which can hinder the accuracy and completeness of the mapping process.
- Despite advancements in technology, certain geological features may still pose challenges for mapping. For instance, dense vegetation cover, deep soil layers, or complex geological structures can hinder direct observation and mapping accuracy. Geologists must leverage available technologies, such as remote sensing, geophysical surveys, or 3D modeling, to overcome these limitations and enhance mapping outcomes.
- Geological mapping relies heavily on accurate data collection and interpretation. Geologists must ensure the reliability and representativeness of the data gathered from field observations, measurements, and sampling. Inaccurate or incomplete data can lead to erroneous interpretations and affect subsequent decision-making in mineral exploration or resource estimation
- Effective geological mapping requires well-trained and experienced geologists who possess a deep understanding of geological processes and rock formations. The availability of skilled personnel can be a challenge, particularly in remote or less-explored regions. Investing in training programs and professional development is essential to maintain a skilled workforce for geological mapping activities.

I.3 Conclusion

Geological mapping provides critical insights into the geological characteristics of a mining area, allowing mining companies to make informed decisions and optimize their operations. It assists in target selection, resource estimation, mine planning, geotechnical assessments, and environmental management, ultimately contributing to the sustainable and responsible exploitation of mineral resources.

Part 02: Geological mapping in Algeria

I.1 Introduction

With a population of 44 million and an extensive landmass encompassing around 2.38 million square kilometers, Algeria stands as the largest and most prosperous country in Africa and has a diverse and significant geological history. It is a subject of extensive scientific research due to the country's diverse geological features and abundant mineral resources.

I.2 Geological mapping in Algeria

As part of the collaboration between ASAL (Algerian Space Agency) and the Geological Survey Agency of Algeria, ASGA (formerly known as the National Agency for Geology and Mining Control, ANGCM), a study was conducted on geological mapping using remote sensing from the Algerian satellite Alsat-1. This approach harnesses the capabilities of remote sensing to obtain accurate and detailed geological information, contributing to a better understanding of the country's geology.**[4]**

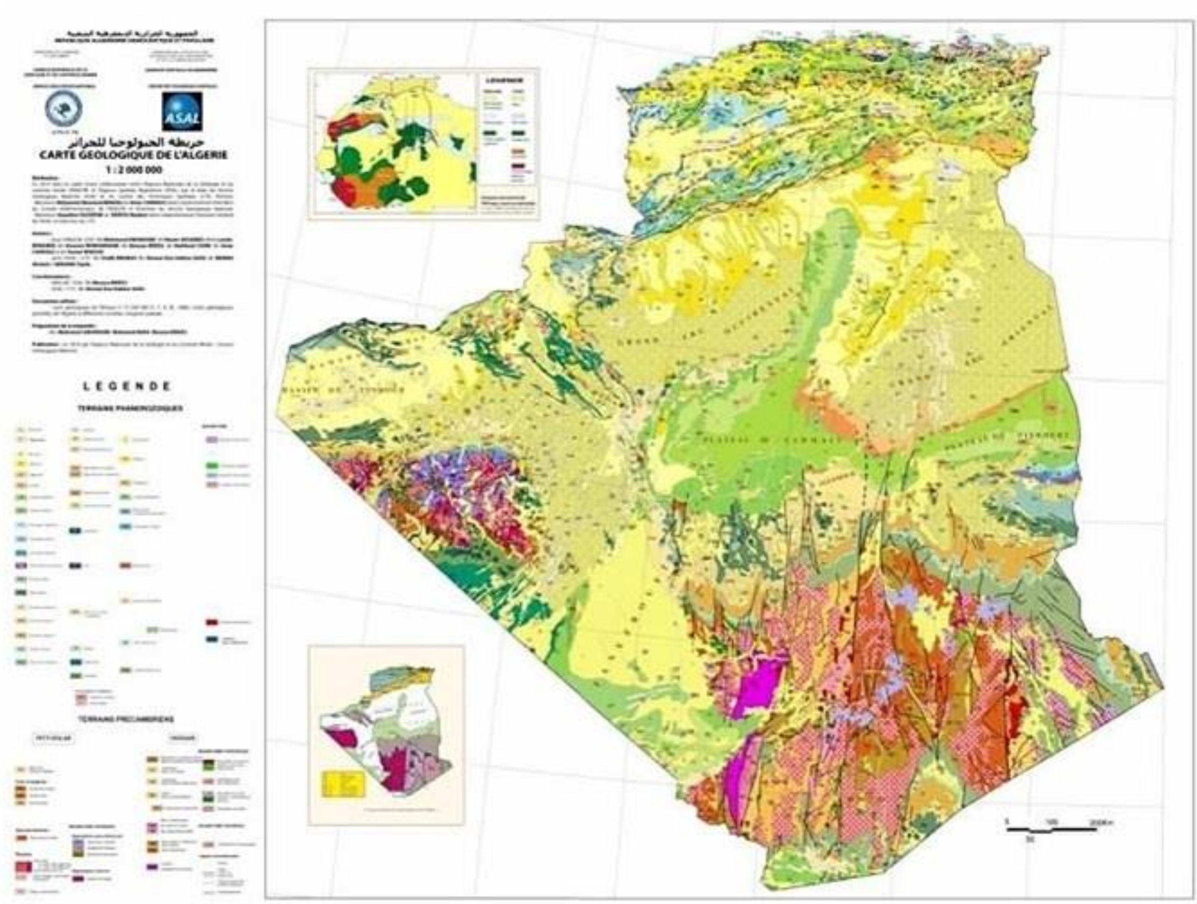


Figure I.02. Vue générale de la nouvelle carte géologique de l’Algérie au 1/2.000.000ème,**[4]**

I.2.1 Data Format of Alsat-1

Scope

- Management and inventory of natural resources.
- Land use mapping.
- Forestry.
- Agricultural statistics.

• Desertification.
• Infrastructure localization (airport, urban areas, etc.).
• Monitoring of evolving phenomena.

I.2.2 Preprocessing Level and Format

The receiving station located at the National Center for Space Techniques in Arzew downloads Alsat-1 data in BIL format (Band Interleaved by Line).

The header of the image file contains:
• Image capture parameters.
• Telemetry and orbitography information.**[4]**

I.2.3 Alsat-1 Format

Level L0R: The three components (Near Infrared, Red, and Green) of the image are vertically flipped to match the image acquisition direction (satellite's ascending node). They undergo radiometric processing to correct, on one hand, the vertical lineament effects between even and odd columns, and on the other hand, the vignetting effects caused by the camera optics.

Level L1R: The three Alsat-1 channels from L0R level are corrected for geometric distortions caused by the optics of each camera and the orbital inclination of the microsatellite.

Alsat-1 covers only three bands of the electromagnetic spectrum:

• Band 1 (Green: 0.523 – 0.605 µm)
• Band 2 (Red: 0.629 – 0.690 µm)
• Band 3 (Near-Infrared: 0.774 – 0.900 µm

I.3 Geological considerations

The geological setting of Algeria is complex. Geologically, the country can be subdivided into several distinct regions with different characteristics.

In the southeastern part, the Hoggar (Touareg shield) is prominent, representing a portion of the Transsaharan Pan-African belt. It comprises three main domains with varying lithological and structural features, separated by two megashear zones that extend in a north-south direction. To the southwest of these shears, the geology is dominated by the Eglab (Reguibat shield), primarily consisting of Archean terrains and forming part of the West African Craton, along with the Ougarta folding system range.

In northern Algeria, specifically the Tellian chain, a broad zone parallel to the coast belongs to the Alpine system. This region encompasses multiple domains with distinct lithology. The main formations consist of folded metamorphic and sedimentary rocks spanning from the Paleozoic to the Cenozoic era. The southern boundary of this region is defined by the South Atlasic Fault (Flexure). These southern and northern geological regions are separated by the Saharan platform, predominantly composed of sedimentary terrains. The platform comprises numerous basins with sedimentary thicknesses reaching up to 8 km, showcasing significant hydrocarbon potential **[5]**

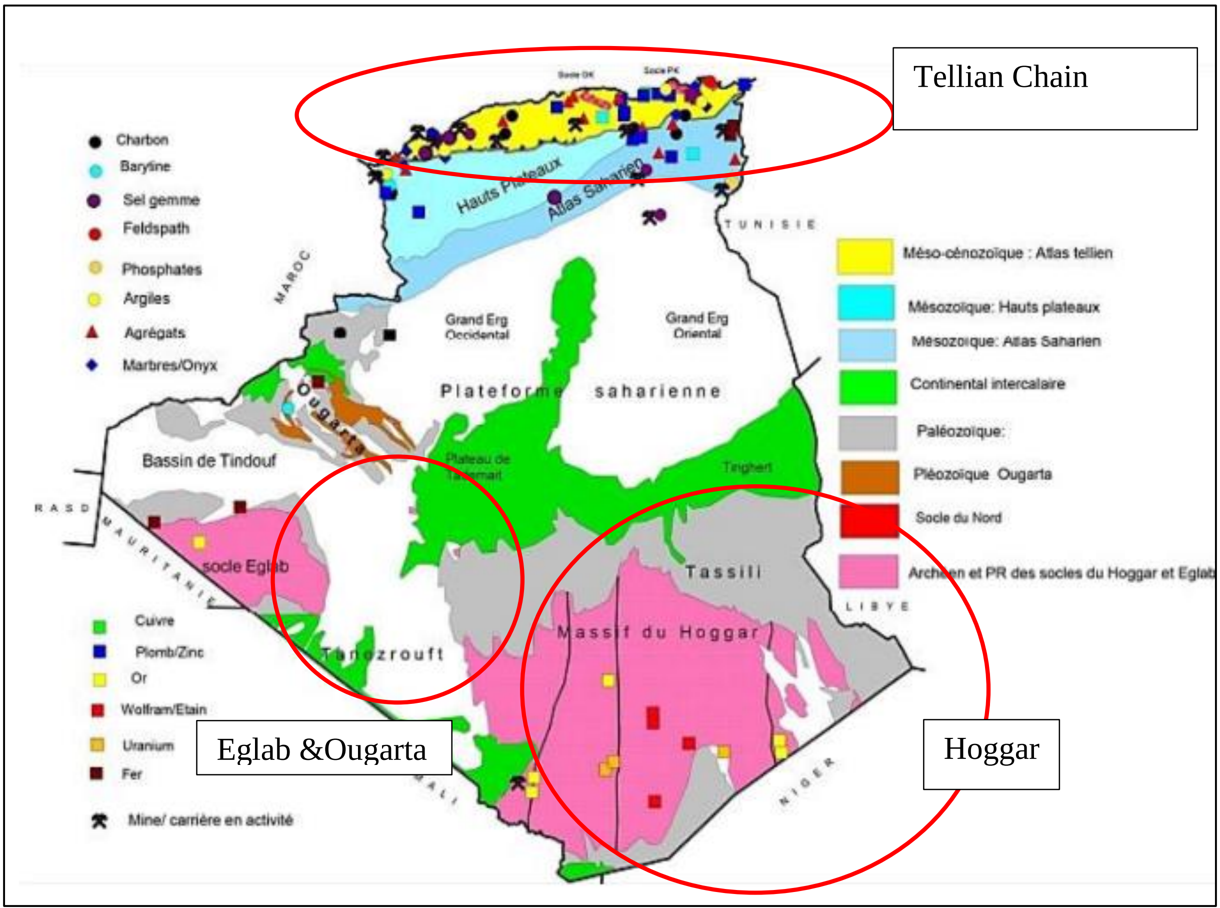


Figure I.03. Map of geological regions in Algeria**[6]**

I.4 The challenges of Geological mapping in Algeria

Geological mapping in Algeria faces specific challenges due to the country's diverse geology, vast size, and unique geological features.

- **Desert Environment and Sand Cover**: Algeria is known for its extensive desert regions, such as the Sahara Desert. Mapping in desert environments poses challenges due to sand cover, which can obscure underlying geological features. It requires specialized techniques, such as satellite remote sensing and aerial photography, to overcome these challenges and map accurately.**[7]**
- **Complex Tectonic History and Structural Geology**: Algeria is characterized by a complex tectonic history, with multiple geological structures and fault systems. Understanding and mapping these structures is crucial for various applications, including natural resource exploration and hazard assessment. However, deciphering the complex structural geology poses challenges in terms of data interpretation, integration, and mapping accuracy.**[8]**
- **Limited Geological Data and Infrastructure**: Algeria's geological mapping efforts may face challenges due to limited data availability and infrastructure. This includes insufficient geological surveys, incomplete geological databases, and limited access to historical records. Addressing these limitations requires investment in data collection, storage, and infrastructure development to ensure comprehensive and accurate geological mapping.**[9]**
- **Multilingualism and Knowledge Transfer**: Algeria has a diverse linguistic and cultural landscape, which can present challenges in knowledge transfer and communication among geologists and researchers. Multilingualism in geological mapping projects may require

effective translation and interpretation processes to ensure accurate data sharing, collaboration, and understanding.**[10]**

1.5 Conclusion

Geological mapping in Algeria is of significant importance due to its diverse geology and expansive size. The collaboration between ASAL and ASGA, utilizing remote sensing through Alsat-1 using a multispectral imaging, plays a vital role in acquiring accurate geological information.

The country's complex geological setting, with distinct regions like the Hoggar and Eglab shields, Tellian chain, and Saharan platform, presents specific challenges.

The next chapter will show the difference between the hyperspectral imaging and the multispectral imagin.

Chapter II: Hyperspectral Imaging

CHAPTER II Hyperspectral imaging

II.1 Introduction

Remote sensing is one of the methods used in both mineral prospecting and geological mapping, providing valuable information about the Earth's surface from a distance. It involves the use of various technologies and techniques to collect and analyze data, allowing geologists and mining professionals to identify potential mineral deposits and assess their economic viability. By utilizing remote sensing, valuable insights can be gained into the geological structures, alteration patterns, and spectral signatures associated with mineralization. This enables efficient and targeted exploration efforts, ultimately leading to the discovery and extraction of mineral resources. Remote sensing complements traditional field-based exploration methods, offering a cost-effective and non-invasive approach to identify and evaluate mineral prospects.

There are several types of remote sensing techniques used for mineral exploration and prospection. Some of the commonly employed methods are mentioned in the coming figure:

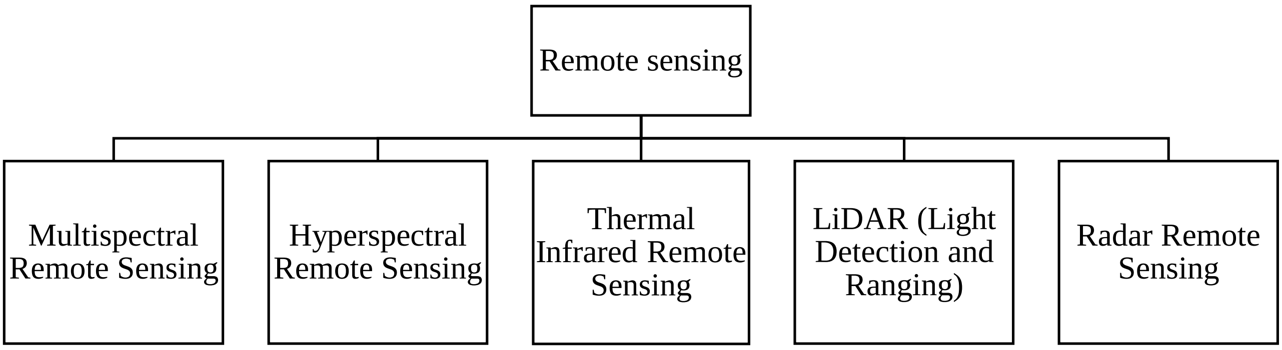


Figure II.01.Remote sensing techniques that used for mineral exploration.

II.2 Hyperspectral imaging (Remote sensing)

Hyperspectral remote sensing is an advanced technology that allows for detailed and comprehensive data collection of Earth's surface using sensors capable of capturing a wide range of spectral information. This field of study combines principles of optics, spectroscopy, and image processing to analyze the unique spectral signatures of materials and objects on the Earth's surface. By capturing and analyzing data across numerous narrow and contiguous spectral bands, hyperspectral remote sensing enables scientists and researchers to gain valuable insights into various environmental phenomena, including mineral exploration, vegetation analysis, land cover classification, and pollution monitoring, among others.**[11]**

The principles of hyperspectral remote sensing involve the collection of data using airborne or satellite-based sensors that capture high-resolution imagery across hundreds of narrow spectral bands. Each band corresponds to a specific range of wavelengths, allowing for the identification and characterization of different materials based on their unique spectral signatures. These spectral signatures are influenced by the absorption, reflection, and emission of light by various substances, enabling the discrimination of different minerals, vegetation types, water bodies, and man-made structures.

II.3 Mineral Spectrometry

Reflectance spectroscopy can be defined as a technique that utilizes the energy in the visible, near-infrared, and short-wave infrared wavelength regions of the electromagnetic spectrum to analyze minerals. The science and techniques of reflectance spectroscopy are based on the spectral properties of materials. Certain atoms and molecules absorb energy based on their atomic structures. The various absorption processes and their dependence on wavelength enable us to derive information about the chemistry of a mineral from the light it reflects or emits.**[12]**

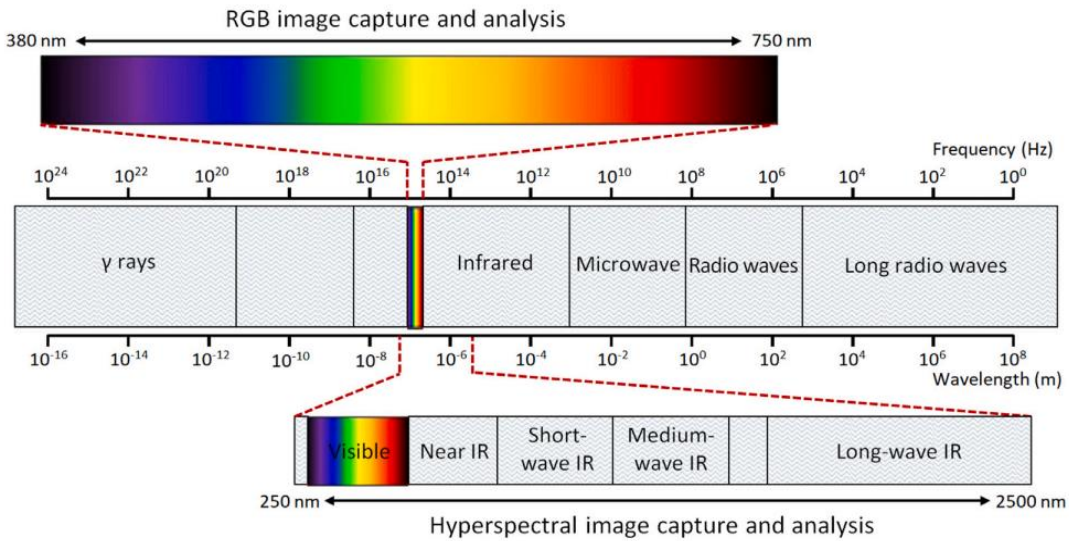


Figure II.02. Electromagnetic spectrum range of RGB and hyperspectral images**[13]**

II.4 Hyperspectral sensors

Hyperspectral sensors collect information as a set of images. Each image represents a narrow wavelength range of the electromagnetic spectrum, also known as a spectral band. These images are combined to form a three-dimensional (x, y, λ) hyperspectral data cube for processing and analysis, where x and y represent two spatial dimensions of the scene, and λ represents the spectral dimension (comprising a range of wavelengths)**[14]**

Technically speaking, there are four ways for sensors to sample the hyperspectral cube: Spatial scanning, spectral scanning, snapshot imaging, and spatio-spectral scanning:

- **Spatial scanning :** acquisition techniques for hyperspectral imaging, visualized as sections of the hyperspectral datacube with its two spatial dimensions (x,y) and one spectral dimension (λ).

  In spatial scanning, each two-dimensional (2-D) sensor output represents a full slit spectrum (x, λ). Hyperspectral imaging (HSI) devices for spatial scanning obtain slit spectra by projecting a strip of the scene onto a slit and dispersing the slit image with a prism or a grating. These systems have the drawback of having the image analyzed per lines (with a push broom scanner) and also having some mechanical parts integrated into the optical train. With these line-scan cameras, the spatial dimension is collected through platform movement or scanning. This requires stabilized mounts or accurate pointing information to 'reconstruct' the image. Nonetheless, line-scan systems are particularly common in remote sensing, where it is sensible to use mobile platforms. Line-scan systems are also used to scan materials moving by on a conveyor belt. A special case of line scanning is point scanning (with a whiskbroom scanner), where a point-like aperture is used instead of a slit, and the sensor is essentially one-dimensional instead of 2-D.**[15]**

- **Spectral scanning:** in spectral scanning, each 2-D sensor output represents a monochromatic ('single-colored'), spatial (*x*, *y*) map of the scene. HSI devices for spectral scanning are typically based on optical band-pass filters (either tunable or fixed). The scene is spectrally scanned by exchanging one filter after another while the platform remains stationary. In such 'staring', wavelength-scanning systems, spectral smearing can occur if there is movement within the scene, invalidating spectral correlation/detection. Nonetheless, there is the advantage of being able to choose spectral bands, and having a direct representation of the two spatial dimensions of the scene**[16]**
- **Non scanning:** in non-scanning, a single 2-D sensor output contains all spatial (x, y) and spectral (λ) data. HIS devices for non-scanning yield the full datacube at once, without any scanning. Figuratively speaking, a single snapshot represents a perspective projection of the datacube, from which its three-dimensional structure can be reconstructed.[**16]**
- **Spatiospectral scanning:** in spatiospectral scanning, each 2-D sensor output represents a wavelength-coded ('rainbow-colored', λ = λ(y)), spatial (x, y) map of the scene. A prototype for this technique, introduced in 2014, consists of a camera at some non-zero distance behind a basic slit spectroscope (slit + dispersive element). Advanced spatiospectral scanning systems can be obtained by placing a dispersive element before a spatial scanning system. Scanning can be achieved by moving the whole system relative to the scene, by moving the camera alone, or by moving the slit alone. Spatiospectral scanning unites some advantages of spatial and spectral scanning, thereby alleviating some of their disadvantages.

II.5 Structure of hyperspectral images

Hyperspectral images are characterized by their spatial as well as spectral resolution. The spatial resolution measures the geometric relationship of the image pixels to each other while the spectral resolution determines the variations within image pixels as a function of wavelength. A hyperspectral image has two spatial dimensions (Sx and Sy) and one spectral dimension (Sλ). The hyperspectral data is represented in the form of a 3D hyperspectral data cube in Figure bellow using pseudo-colors in center. A point spectrum on the data cube at the spatial location (x, y), an RGB image, and a grayscale image rendered from the hyperspectral cube are also shown. Each slice of the cube along spectral dimension is called a band or channel. **[17]**

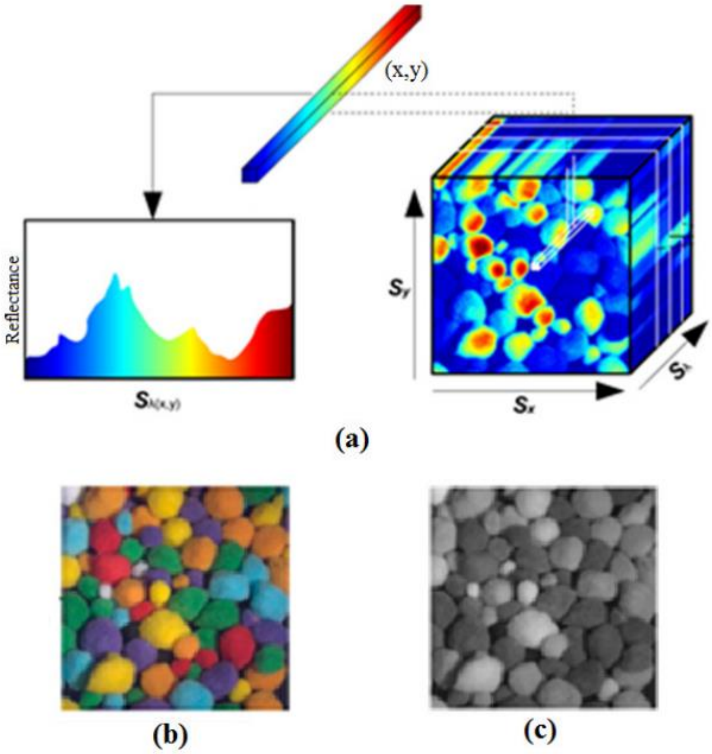


Figure II.03.hyperspectral image represented as a 3D cube.**[17]**

II.6 Application of Hyperspectral Image Analysis

Hyperspectral imagery has been used to detect and map a wide variety of materials having characteristic reflectance spectra. For example, hyperspectral images have been used by:

- geologists for mineral mapping (Clark et al., 1992, 1995)
- Detection of soil properties including moisture, organic content, and salinity (Ben-Dor, 2000). Vegetation scientists have successfully used hyperspectral imagery to identify vegetation species (Clark et al., 1995),
- Study plant canopy chemistry (Aber and Martin, 1995), and detect vegetation stress (Merton, 1999).
- Military personnel have used hyperspectral imagery to detect military vehicles under partial vegetation canopy, and many other military target detection objectives.
- Waste management: Separating a broad range of materials reliably and with high purity. This information can be used to automate recycling processes and to increase the value of recycled material.
- Environmental monitoring: Monitoring changes in land use, vegetation health, and water quality over time. This allows for detecting early signs of ecological degradation and tracking the effectiveness of conservation efforts.**[17]**

II.7 Advantages and disadvantages

The primary advantage to hyperspectral imaging is that, because an entire spectrum is acquired at each point, the operator needs no prior knowledge of the sample, and post processing allows all available information from the dataset to be mined. Hyperspectral imaging can also take advantage of the spatial relationships among the different spectra in a neighborhood, allowing more elaborate spectral-spatial models for a more accurate segmentation and classification of the image

The primary disadvantages are cost and complexity. Fast computers, sensitive detectors, and large data storage capacities are needed for analyzing hyperspectral data. Significant data storage capacity is necessary since uncompressed hyperspectral cubes are large, multidimensional datasets, potentially exceeding hundreds of megabytes. All of these factors greatly increase the cost of acquiring and processing hyperspectral data. In addition, one of the hurdles researchers have had to face is finding ways to program hyperspectral satellites to sort through data on their own and transmit only the most important images, as both transmission and storage of that much data could prove difficult and costly**.[18]**

II.8 Multispectral imaging

Multispectral imaging captures image data within specific wavelength ranges across the electromagnetic spectrum. The wavelengths may be separated by filters or detected with the use of instruments that are sensitive to particular wavelengths, including light from frequencies beyond the visible light range. Infrared and ultra-violet. It can allow extraction of additional information the human eye fails to capture with its visible receptors for red, green and blue. It was originally developed for military target identification and reconnaissance. Early space-based imaging platforms incorporated multispectral imaging technology**.[19]**

A multispectral image is a collection of a few image layers of the same scene, each of them acquired at a particular wavelength band. The well-known high-resolution visible sensor operates in the 3-band multispectral detects radiations in the following wavelengths bands:

- Blue, 450–515. 520 nm and near infrared (NIR), 750–900 nm,
- Green, 515. 520–590. 600 nm,
- Red, 600–630–680. 690 nm.

II.9 Difference between Hyperspectral and Multispectral imaging

There are many differences between Hyperspectral and Multispectral images, are as follows:

1. Number of wavebands: Multispectral imaging follows a Low Earth Orbit and sun-synchronous. The multispectral satellites capture data along 5 to 10 bands of the spectrum. Most often, it also captures all three primary colors and a few blocks in the infrared portion.
On the other hand, hyperspectral imaging can detect thousands of different bands within the light spectrum. Such imagery is extremely helpful to detect certain objects and minerals if an analyst is familiar with their spectral properties. Just like multispectral, their satellites also follow the sun-synchronization, Low Earth Orbit.
2. Spectral resolution detail: spectral resolution refers to the number and width of the electromagnetic spectrum portions measured by a sensor. Multispectral remote sensing has a poor spectral resolution. Thus, it makes it harder to discern the Earth's features as easily as hyperspectral sensors. The reason is that multispectral sensors are captured in small numbers due to the wide bands.
On the other hand, hyperspectral remote sensing has a high spectral resolution that makes it possible to detect the spectral properties of objects and minerals. It gives the better capability to see the unseen.

3. The narrowness of the band: multispectral remote sensing systems use parallel sensor arrays that detect radiation in a small number of broader wavebands.

Meanwhile, in hyperspectral remote sensing, the bands are much narrower. These numerous narrow bands in hyperspectral sensors provide a continuous spectral measurement across the entire electromagnetic spectrum. Therefore, this makes them more sensitive to subtle variations in reflected energy.

4. Ability to use artificial intelligence and machine learning: multispectral remote sensing images have lower informational content hence continued use of the same technology over time. Due to the lack of information richness in this imaging technology, it faces a disability of continual development.

On the other hand, hyperspectral-imaging technology is facilitated by the high informational content hence continuous development. It is therefore positioned to become a primary remote sensing technology used on a global scale.

5. Complexity level: due to the limited number of bands in multispectral remote sensing, data analysis and interpretation are straightforward. It is also easier to understand.

Meanwhile, one of the downfalls of hyperspectral remote sensing is its complexity. It has many bands one has to work with; hence, it may be difficult to reduce redundancies or hard work.

6. Image features: in multispectral data, reflected energy in the spectrum spans a wider range. It makes it difficult to get a lot of detail on an object or surface area captured. It is because the wavelength bands are much broader.

While when it comes to hyperspectral data, images present hundreds of points of each band hence much more detail to observe. The wavelength is split into numerous narrow bands that capture a unique spectral fingerprint or signature of an object. Therefore, the images captured contain much more data, thus preventing any analyst from the potential to detect differences among land and water features.

7. Camera differences: multispectral images are captured with special cameras that separate wavelengths using filters or with instruments that are sensitive to particular wavelengths. These can include light from frequencies that are invisible to the human eye.

Hyperspectral cameras as on the other hand, can detect many different wavelengths separately. They can also see across a wider spectrum than a human can by covering parts of the infrared and ultraviolet regions. Therefore, in this imaging technique, analysts will acquire a 2-dimensional image whereby every pixel in the image contains a continuous spectrum.

8. Costs: multispectral sensors commonly collect data from three to six spectral bands in a single observation. Such features make them cost-effective. They are cheap to buy and maintain, as the image captures are not complex.

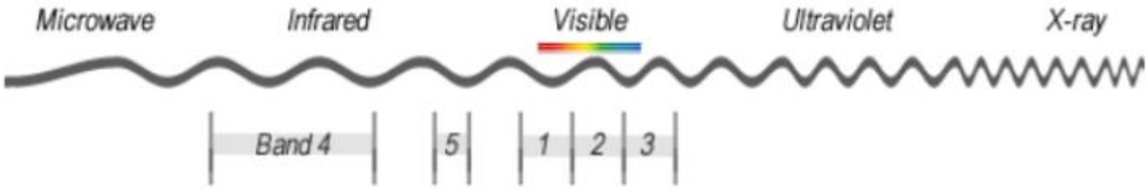
Meanwhile, hyperspectral imaging makes it possible to collect several hundred spectral bands in a single acquisition. Such a feature has made it expensive, as it demands more technological advancement to produce more detailed spectral data. With this comes issues related to increased sensor and image costs, data volumes and data-processing costs, and high demand to maintain operations.

9. Pixel composition: in multispectral remote sensing, each pixel has a discrete sample spectrum. For example, some wavebands may have 4 to 20 data points per pixel.

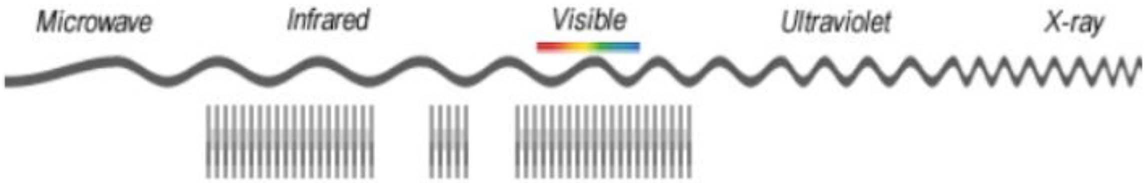
While, in hyperspectral remote sensing, each pixel has a continuous or complete spectrum

10. Processing methods: the multispectral remote sensors process limited images.**[20]**

On the other hand, the hyperspectral remote sensors processing methods include both spectral and images.



Multispectral imagery



Hyperspectral imagery

Figure II.04.Difference between hypersepctral and multispectral imagery **[21]**

Conclusion

The use of hyperspectral imaging in geological mapping has proven to be a valuable tool for obtaining detailed and precise geological information. By capturing a wide range of spectral data across the electromagnetic spectrum, hyperspectral imaging enables the identification and characterization of various minerals and rock types with enhanced accuracy. This technology improves our understanding of geological formations, facilitates mineral exploration, and aids in assessing the potential of natural resources

CHAPTER III:

Geological mapping using Hyperspectral images in Djanet, Algeria

CHAPTER III Geological mapping using Hyperspectal image in Djanet, Algeria

III.1 Introduction

The field of remote sensing has revolutionized the way we study and understand the Earth's surface. With the advent of hyperspectral imaging technology, researchers now have access to an unparalleled level of spectral information that can be utilized to unravel intricate geological processes and accurately map the distribution of various materials. In this chapter, we delve into the practical application of hyperspectral image analysis using ENVI (Environment for Visualizing Images) and ArcGIS, two robust software tools extensively employed in the field of remote sensing.

By employing software tools, we aim to extract valuable insights from the immense spectral dataset, revealing the hidden signatures of geological features and materials present on the Earth's surface.

III.2 The study area

The study area is located in the southeastern part of Algeria, Djanet is situated in a region known for its geological complexity. The area encompasses a range of geological features, including alluvial deposits, pre-tectonic granite, conglomerates and sandstone as it is shown in the figure bellow

Region coordinate: 24.479007 N, 9.460424 E

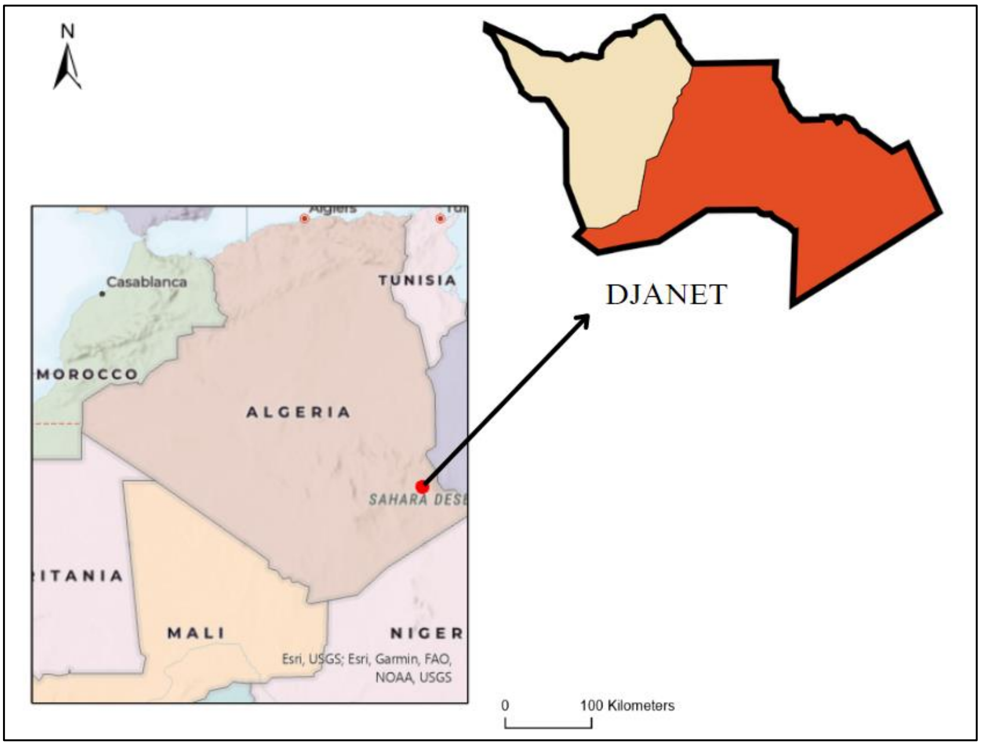


Figure III.01.map of study area "DJANET"

By focusing on this region, we aim to gain insights into the geological composition and structure of Djanet, which can contribute to the understanding of its geological history and resource potential.

To obtain the necessary data for our analysis, we accessed the United States Geological Survey (USGS) database, which provides a vast collection of hyperspectral imagery from satellite sensors. We specifically selected a hyperspectral image of the Djanet region from the USGS archive, as it covers the desired study area and offers a high level of spectral detail.

By downloading the hyperspectral image from the USGS, we gained access to valuable data that will serve as the foundation for our analysis using ENVI and ArcGIS. This dataset will enable us to explore the spectral signatures of various geological materials in Djanet, facilitating the generation of an accurate and detailed geological map of the region.

III.2.1 The data that was used for the study are

In the thesis we used :

- **Hyperion data level 1R and level 1Gst images:**

Level 1R (L1R) - radiometrically corrected only, no geometric correction are applied

Level 1Gst (L1Gst) – radiometrically corrected, resampled for geometric correction and registration to a geographic map projection. The data map is ortho-corrected using DEM.

- **Geological map of the study area**

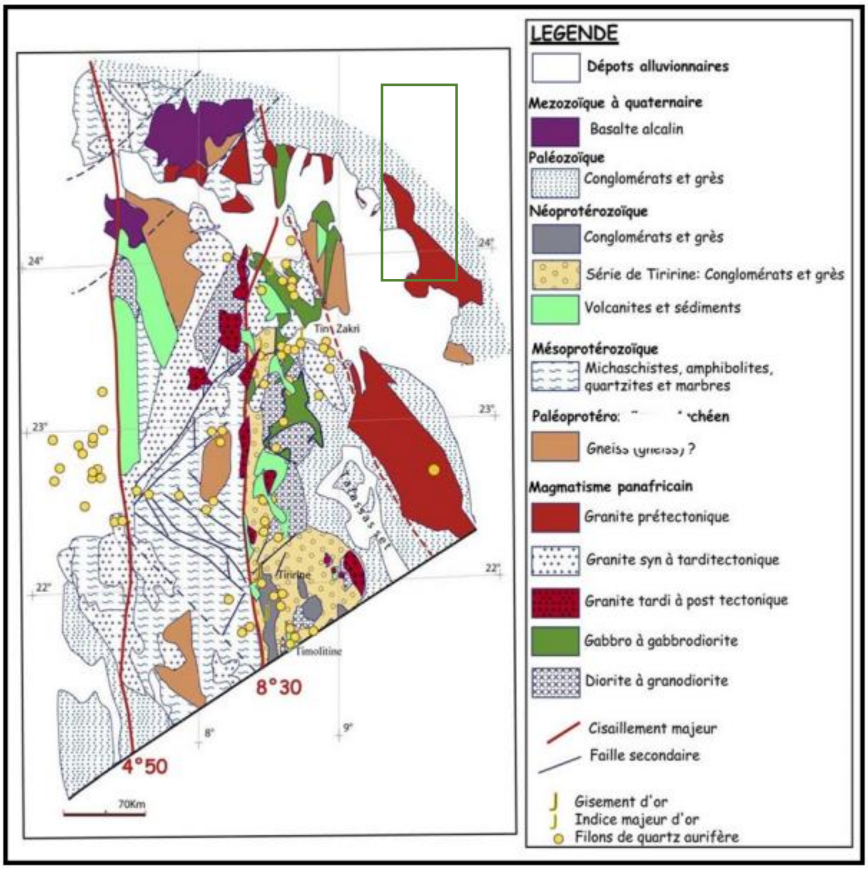


Figure III.02. Geological map of eastern Hoggar.**[22]**

III.3 Download Hyperion imagery

Hyperion is a hyperspectral-imaging sensor that was part of the Earth Observing-1 (EO-1) satellite mission operated by NASA. Launched in November 2000, Hyperion was designed to provide detailed and highly accurate information about the Earth's surface by capturing data across a wide range of wavelengths.

To download Hyperion imagery:

- After log in to the earth explorer USGS website, we pick the place or the study area, by writing it name in the GEOCODER and select the area of interest by drawing a polygon.
- Choosing from data sets the type of sensor EO-1 HYPERION.**[21]**

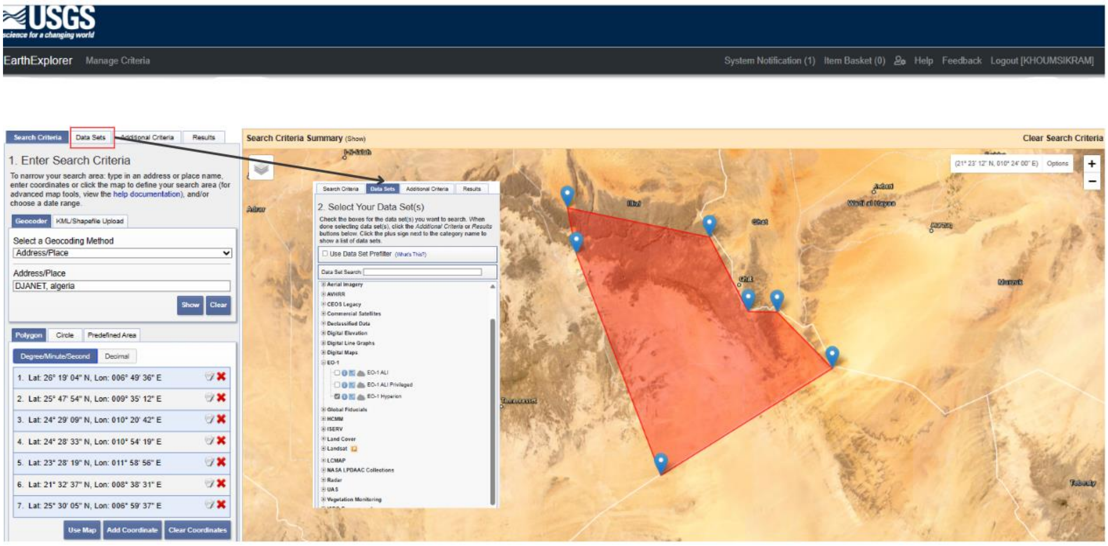


Figure III.03.Screenshot of main steps to download Hyperion imagery from USGS website.

- The next step is to download the data by clicking on results , as its shown in the screenshot below :

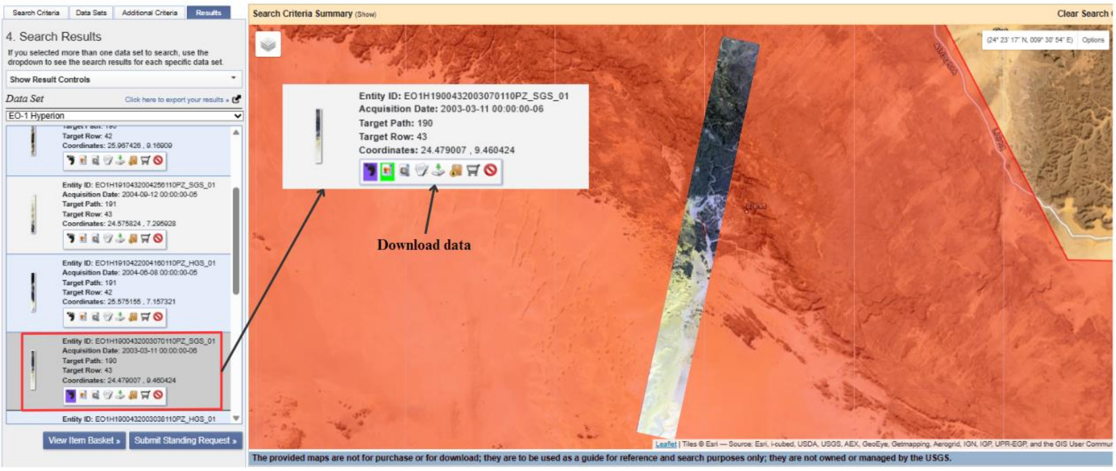


Figure III.04.Screenshot of how to download the chosen Hyperion image from USGS website.

III.4 Hyperspectral data processing using ArcGIS

ArcGIS is a geographic information system (GIS) software developed by Esri (Environmental Systems Research Institute). It provides a comprehensive suite of tools and functionalities for managing, analyzing, and visualizing geospatial data. ArcGIS is widely used in various fields, including environmental science, urban planning, natural resource management, emergency response, and many others.

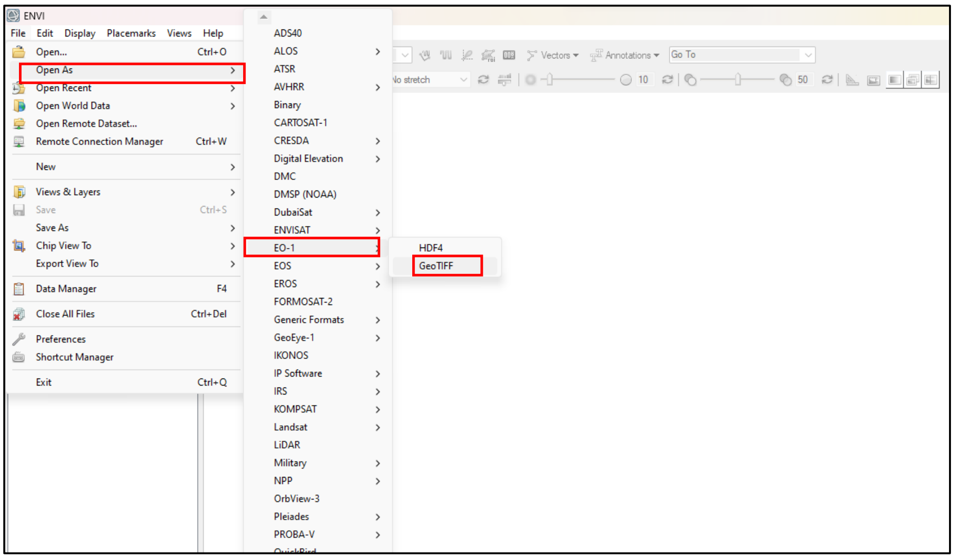
One of the key strengths of ArcGIS lies in its ability to integrate different types of geospatial data, such as raster imagery, vector datasets, and tabular data. This integration enables users to leverage diverse data sources and extract meaningful insights by performing spatial analysis and modeling.
To obtain reliable results the hyperseptral image must have a pre-processing, otherwise used by the ENVI software program (removing bad bands, atmospheric and geometric correction..) or it can simply used with ArcGIS program itself.

III.5 Hyperspectral data pre-processing using ENVI

ENVI is a powerful software program widely used in the field of remote sensing and image analysis. It provides a comprehensive set of tools and functionalities specifically designed for working with hyperspectral data, satellite imagery, and other geospatial data.
It use image-processing package includes advanced spectral tools, geometric correction, terrain analysis, radar analysis, raster and vector GIS capabilities, extensive support for images from a wide variety of sources.
Hyperspectral imagery requires significant preprocessing to remove noise and erroneous data before extracting meaningful information. This involves removing bad bands that may contain undesirable artifacts, masking out unwanted features, and correcting for atmospheric effects (particularly for spaceborne and airborne sensors).

III.5.1 Removing Bad Bands

Certain bands in imaging spectrometers can introduce significant noise, especially in wavelengths associated with atmospheric absorption and water vapor. Consequently, it becomes necessary to eliminate these problematic bands before proceeding with further processing steps.



FigureIII.05.screenshot of the ENVI window and how to download the HSI

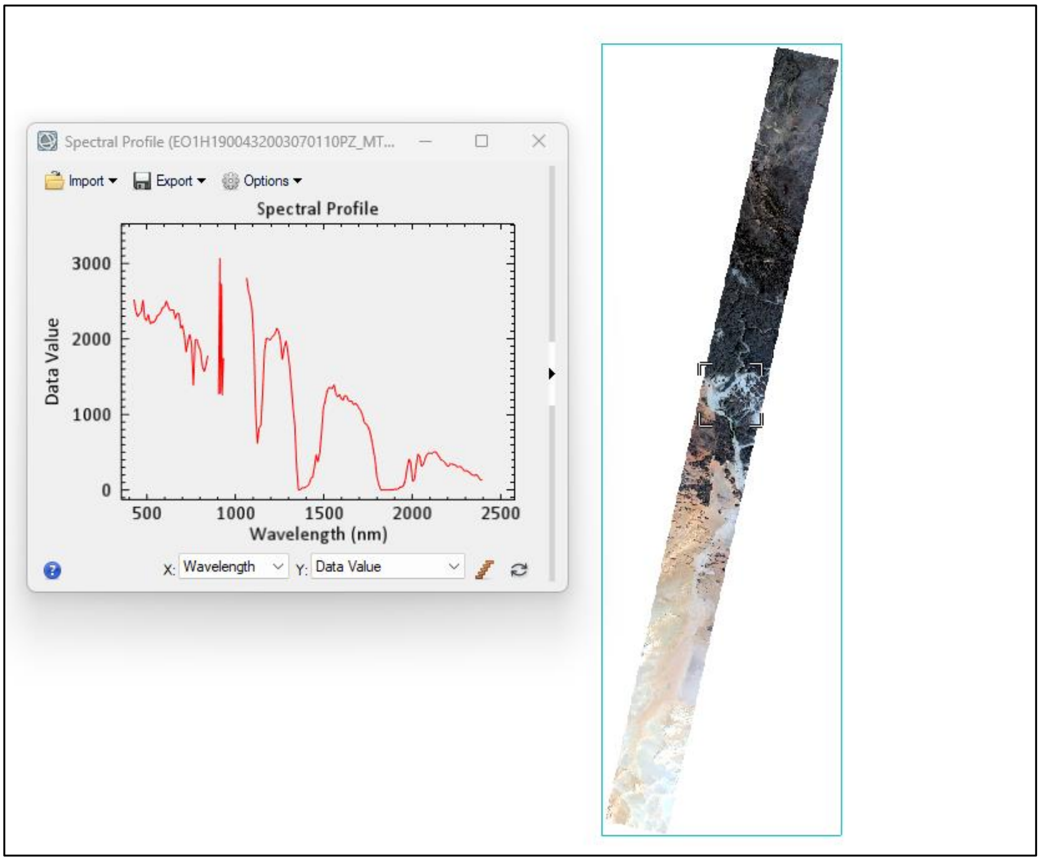


Figure III.06.screenshot of Spectral profile curve before removing any bad bands

This profile curve is showing spikes and gaps before removing the bad bands.these spikes and gaps can occur due to various factors such as sensor artifacts, atmospheric disturbances, or data acquisition issues.

With EO-1 Hyperion data bands 1-7, 58-76, and 221-242 are automatically set to values of zero (0) by the data provider (Barry 2001). In addition, bands 121-126 and 167-180 have severe noise that correspond to strong water vapor absorption and should be removed from processing (Datt et al. 2003).

- 1-7 not illuminated
- 58-78 overlap regions
- 120 -132 water vapor absorption band
- 165-182 water vapor absorption band
- 185-187 identified by Hyperion bad bands list
- 221-224 water absorption
- 225-242 not illuminated

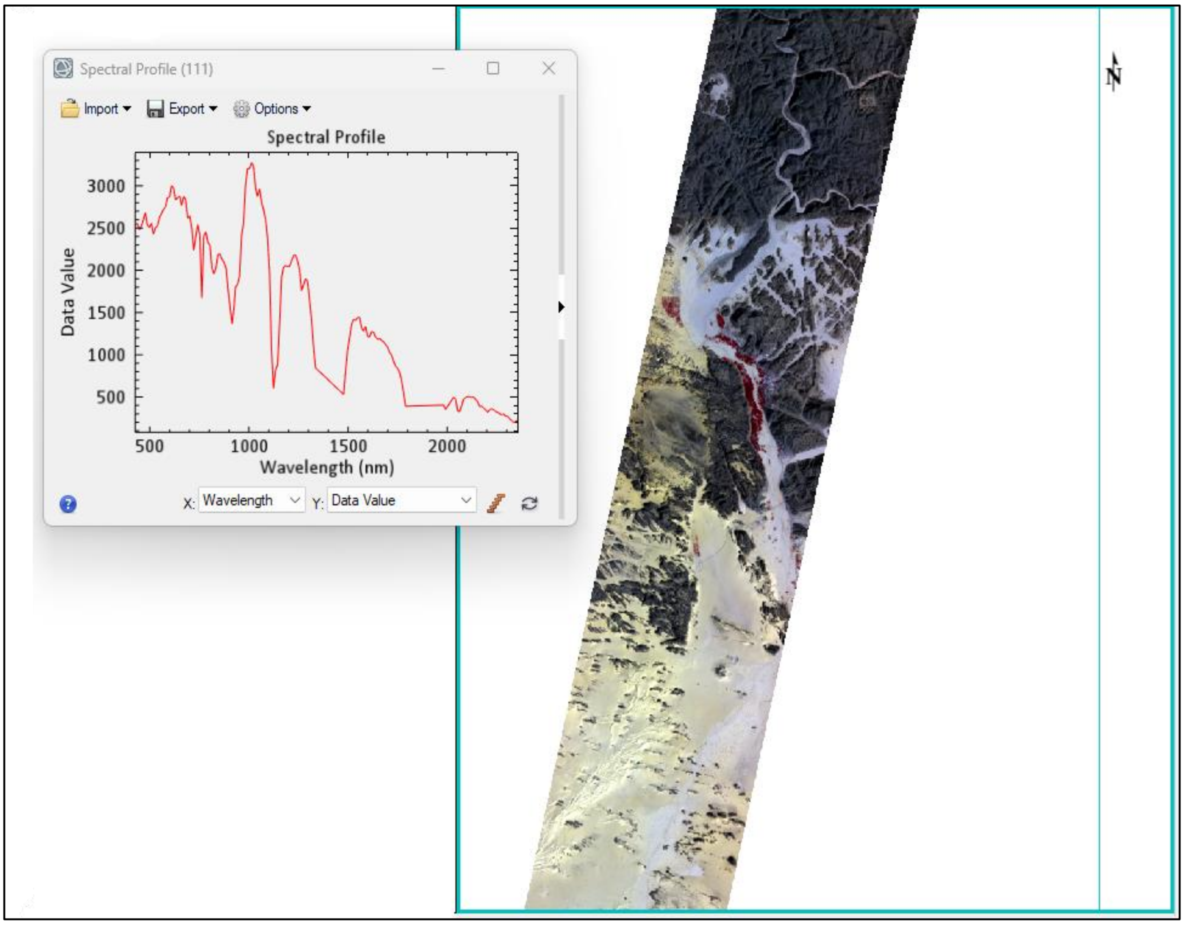


Figure III.07.screenshot of Spectral profile curve after removing any bad bands

When bad bands are removed from a hyperspectral image, the gaps corresponding to those bands are effectively filled in by interpolating or extrapolating the neighboring spectral bands. This process aims to maintain the continuity of the spectral profile curve by estimating the spectral values for the removed bands based on the surrounding data points.
Resulting in a continuous and reliable representation of the scene's spectral information. This refined curve enables more accurate and meaningful analysis of the hyperspectral data.

III.5.2 Atmospheric Correction

The VNIR wavelengths are highly susceptible to the effects of atmospheric absorption and scattering when acquiring data from spaceborne and airborne imaging spectrometers. The atmosphere's composition and thickness exhibit spatial and temporal variations, leading to distortions in the observed reflectance and absorption signals of detected materials (Bedell and Coolbaugh, 2009). To ensure accurate spectral analysis, it is crucial to account for and correct these atmospheric effects before proceeding with further analysis.

In ENVI, a popular software tool for remote sensing analysis, several atmospheric correction methods are available. Here are some commonly used atmospheric correction methods in ENVI:

- FLAASH (Fast Line-of-Sight Atmospheric Analysis of Spectral Hypercubes): FLAASH is a physics-based method that utilizes radiative transfer models to estimate atmospheric properties and correct the imagery. It takes into account factors such as aerosol scattering and absorption, path radiance, and solar angle. FLAASH requires input parameters specific to the sensor and atmospheric conditions and provides accurate atmospheric correction results.

- QUAC (QUick Atmospheric Correction) : QUAC is an empirical method available in ENVI that estimates atmospheric parameters based on statistical analysis of the image data itself. It uses statistical models and assumptions to correct for atmospheric effects. QUAC is computationally efficient and suitable for quick operational atmospheric correction.
- ACORN (Atmospheric Correction Now): ACORN is another empirical atmospheric correction method in ENVI. It estimates atmospheric parameters using a combination of reference spectra and statistical models. ACORN provides a user-friendly interface and can handle a wide range of atmospheric conditions.
- FLAASH-Q (Fast Line-of-Sight Atmospheric Analysis of Spectral Hypercubes - Quick): FLAASH-Q is a simplified version of FLAASH available in ENVI. It offers a quicker atmospheric correction option by using simplified atmospheric modeling assumptions. FLAASH-Q is useful when a fast estimation of atmospheric effects is required.
- Dark Object Subtraction (DOS): DOS is a simple and widely used method in ENVI. It assumes that dark, non-reflective objects in the scene should have a reflectance value of zero. By subtracting the estimated atmospheric contribution from these dark objects, the entire image can be adjusted for atmospheric effects.

The atmospheric correction process typically begins with radiance calibration. Radiance calibration is the initial step in converting the raw digital numbers (DN) obtained from the sensor into radiance values, which represent the amount of electromagnetic energy received by the sensor. This calibration is necessary to establish a quantitative relationship between the sensor's digital values and the physical quantities of interest.

Once the radiance calibration is completed , the next step in the atmospheric correction process is typically the correction of atmospheric effects. This step aims to compensate for the distortions caused by the Earth's atmosphere on the acquired remote sensing data.

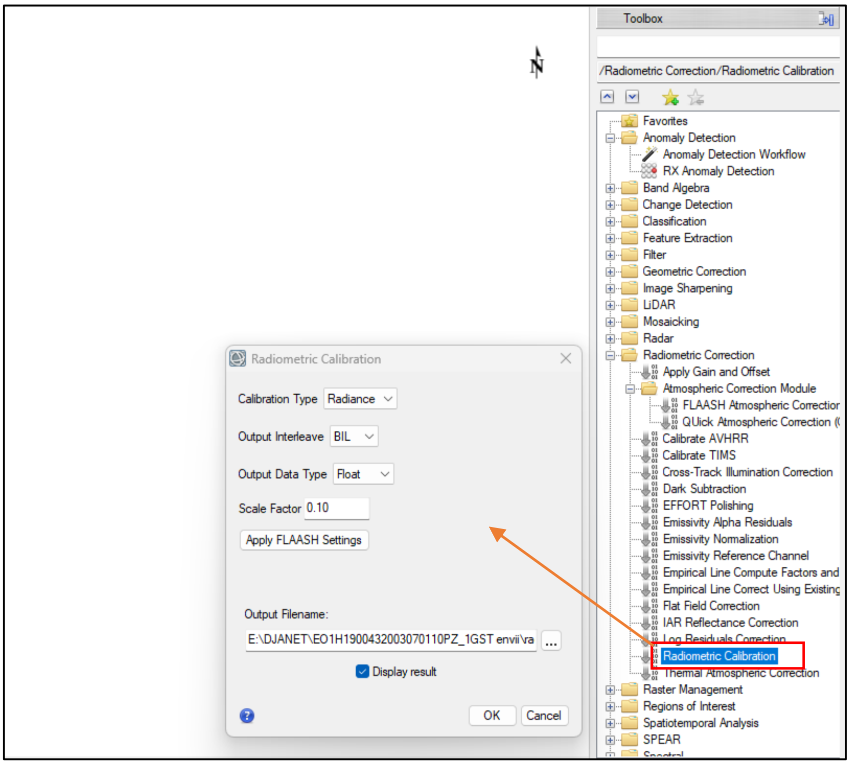


Figure III.08.screenshot of radiometrical calibration steps

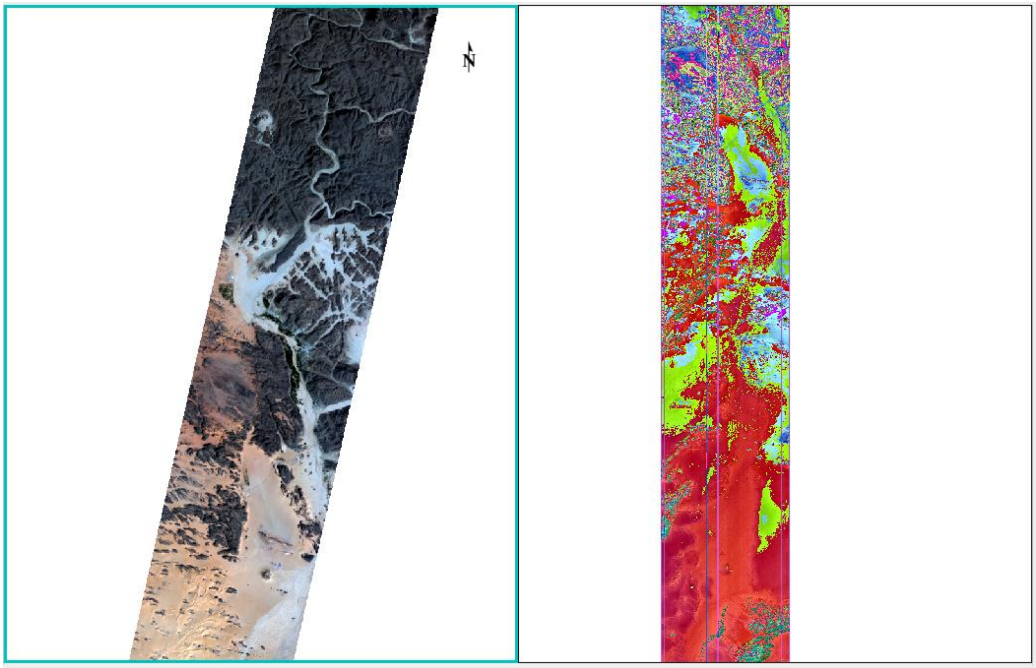


Figure III.09. Screenshot of the hyperspectral image after the radiometric calibration and the atmospheric correction.

Overall, the colors observed in hyperspectral image after the atmospheric correction serve as visual indicators of the unique spectral properties of the geological materials and can aid in the interpretation and analysis of the geological information captured by the sensor later using the ArcGis processing.

III.6 Hyperspectral data pre-processing using ArcGIS

After the previous pre-processing of the hyperspectral data using ENVI we can import the results to the ARCGIS and move to the next steps which are:

1. Georeferencing the hypersepctral image on the geological map of EASTERN HOGGAR

The georeferencing of a geological map is used to accurately relate the features and information depicted on the map to their corresponding locations on the Earth's surface. It involves establishing spatial coordinates and referencing systems that align the map with real-world geographic coordinates.

- In our study case we r going to georeference the eastern Hoggar map **using this tool in ArcGIS**

Figure III.10. Georeference tool

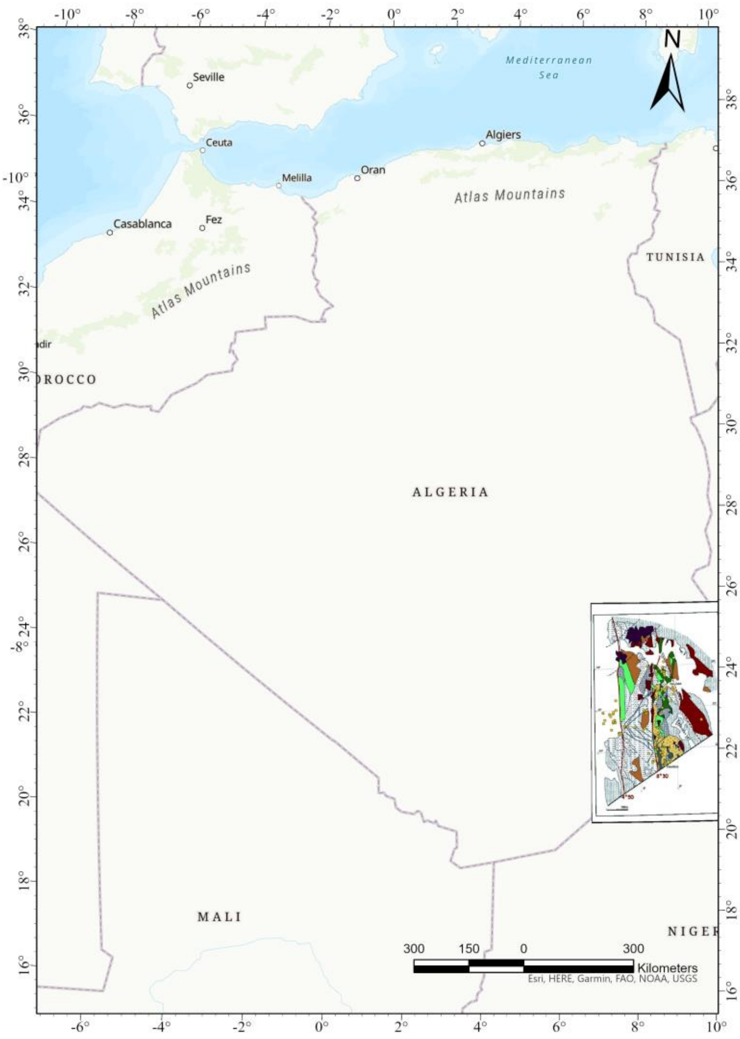


Figure III.11.The Georeferenced map.

- After this the hyperspectral data will be imported and also georeferenced

2. Create composite raster

To enhance the visualization and analysis of the hyperspectral imagery, two sets of composite rasters were generated using the Composite bands function in the software. These composite rasters combine specific bands of the hyperspectral data to create a single image that highlights desired features or spectral characteristics.

The first set of composite rasters, known as the NIR & visible composite, includes bands ranging from “9” to “55”. This composite focuses on the near-infrared (NIR) and visible spectrum bands, which are particularly useful for capturing information related to vegetation health, land cover, and surface reflectance properties.

The second set of composite rasters, known as the SWIR (shortwave infrared) composite, is composed of bands spanning different ranges: “82-96”, “100-119”, “135-164”, “183-184”, “189-212”, and “217-218”. This composite emphasizes the shortwave infrared bands, which are valuable for identifying and mapping mineral composition, geological structures, water content, and thermal properties of the Earth's surface.

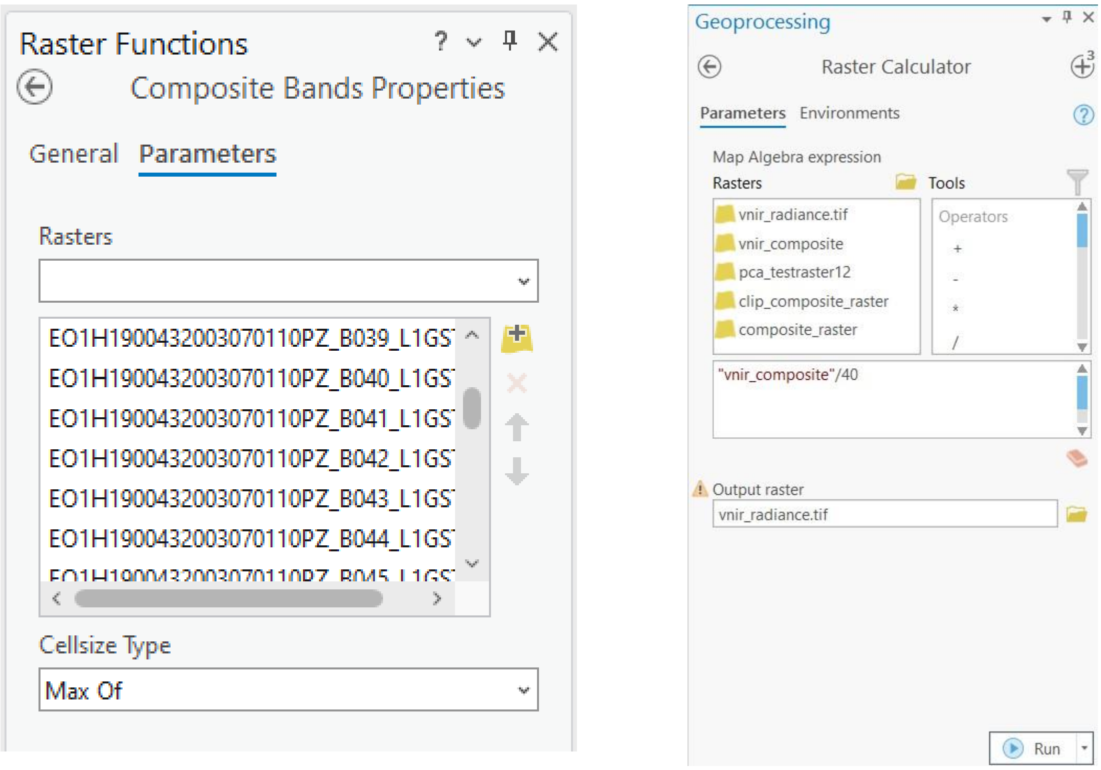


Figure III.12. Creating a composite rasters and the Conversion of DN values to at-sensor radiance

3. To obtain at-sensor radiance values from the pixel DN (Digital Number) values, scale factors will be applied. Specifically, a scale factor of 40 will be used for the VNIR (Visible and Near-Infrared) composite raster, while a scale factor of 80 will be utilized for the SWIR (Shortwave Infrared) composite. The division of the rasters by their respective scale factors will be accomplished using the Raster Calculator tool available in ArcGIS Pro. This process

ensures the conversion of DN values to radiance, facilitating further analysis and interpretation of the hyperspectral imagery.

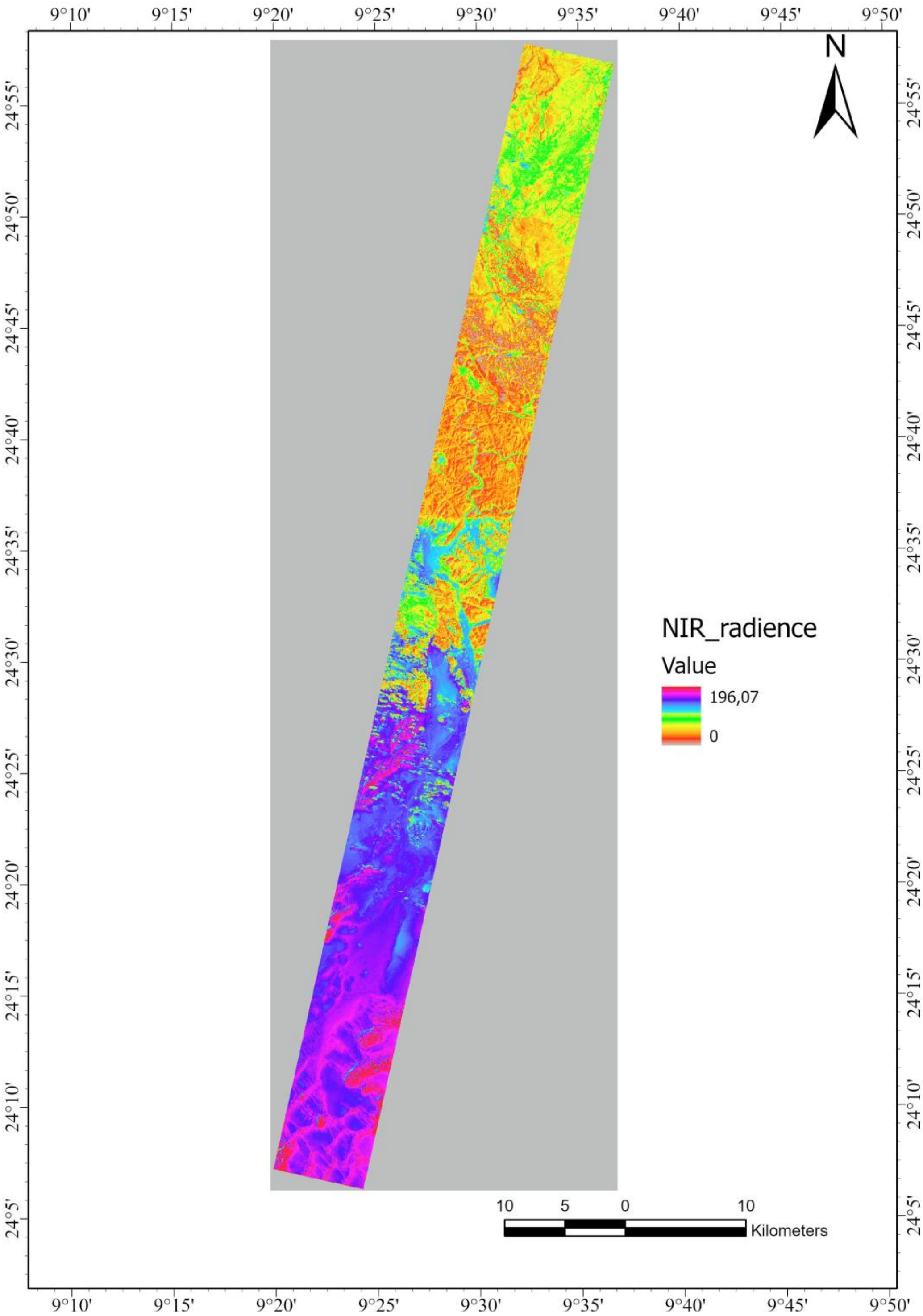


Figure III.13. Layout of the hyperspectral image after creating the composite raster and converting the DN values to a sensor radiance

The hyperspectral image undergoes a transformation that enhances its interpretability and analysis capabilities. By combining specific bands of interest into composite rasters, the image highlights desired features and spectral characteristics.

We can now differentiate between the geological composites from the NIR-radiencein the figure III.13; and to classify the different geological formations, mineral resources, and other geological phenomena ArcGIS offers various classification methods, such as Maximum Likelihood, Support Vector Machines (SVM), Random Forest, or Decision Trees.

4. Hyperspectral image classification using arcgis (supervised vs unsupervised for geological mapping)

Hyperspectral image classification techniques are indeed valuable for geological mapping, and ArcGIS provides several tools and functionalities to perform both supervised and unsupervised classification.

- **Supervised Classification:**

Supervised classification involves the manual assignment of training samples or spectral signatures to known classes in the hyperspectral image. ArcGIS offers tools like the "Train Support Vector Machine Classifier" and the "Maximum Likelihood Classification" tool to perform supervised classification.

a. Collect Training Data: Select representative samples from the hyperspectral image that correspond to different geological classes. For example, if you are interested in mapping different rock types, collect training samples for each rock type.
b. Define Classes: In ArcGIS, create a training sample dataset and assign each sample to a specific class or land cover type. You can define classes such as sandstone, limestone, granite, etc.
c. Train Classifier: Use the training sample dataset to train a classifier algorithm, such as Maximum Likelihood Classifier (MLC), Support Vector Machine (SVM), or Random Forest Classifier. These algorithms learn the spectral characteristics of each class from the training samples.
d. Classify the Image: Apply the trained classifier to the entire hyperspectral image to classify each pixel into one of the defined classes. ArcGIS provides tools like "Classify Pixels Using Supervised Classification" or "Train Support Vector Machine Classifier" for this purpose.

- **Unsupervised classification:**

Unsupervised classification does not require prior knowledge or training samples. Instead, it automatically groups similar pixels based on their spectral properties. ArcGIS provides tools such as the "Iso Cluster Unsupervised Classification" and "K-means Clustering" to perform unsupervised classification.

a. Choose Clustering Algorithm: ArcGIS provides various clustering algorithms like K-means, ISODATA, or hierarchical clustering. Select an appropriate algorithm based on your requirements.
b. Determine the Number of Clusters: Specify the number of clusters you want the algorithm to identify. This can be determined by analyzing the image and having knowledge of the geological context.

c. Perform Classification: Apply the selected clustering algorithm to the hyperspectral image. The algorithm will group pixels with similar spectral characteristics into different clusters.
d. Interpret the Results: Examine the clusters and assign geological classes based on their spectral characteristics. This requires domain knowledge and expertise in geological mapping

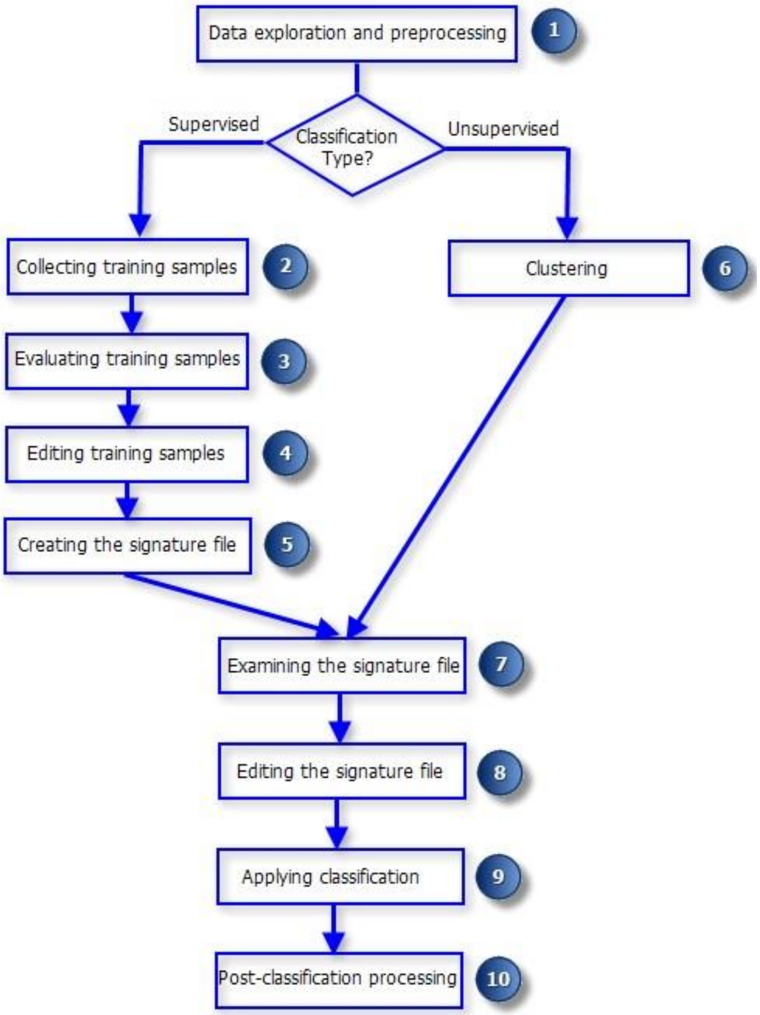


Figure III.14.data classification using supervised and unsupervised methods

In this study, the method that used to classify the geological formation from the NIR-radiance image is *the supervised method*.

We use the classification **wizard tool** from ArcGis (Figure III.15) and choose the supervised classification method also the pixels are going to be treated independently by choosing pixel based classification type.

The next step is building the schema (figure III.16) of the geological formation classes based on the Geological map of eastern Hoggar.

Figure III.15. Classification wizard tool

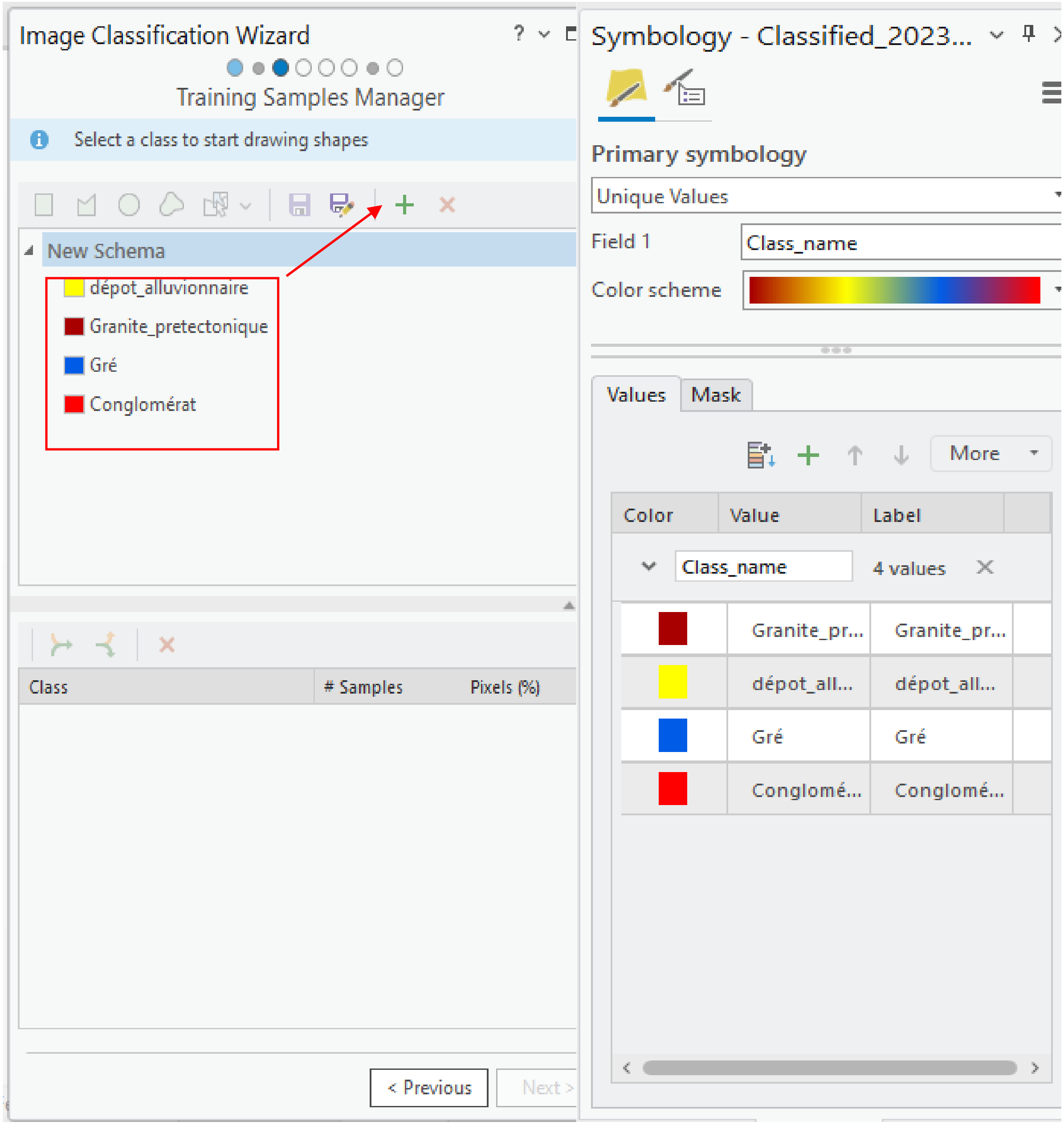


Figure III.16.the tool of building a new schema

Through the analysis of NIR (Near-Infrared) radiance data, we were able to identify distinct geological formations based on their unique spectral characteristics. However, to gain a more comprehensive understanding of the landscape, we employed a supervised classification method. By utilizing this approach, we developed a new map (Figure III.17) that categorizes the identified formations into specific classes according to a predefined schema. This classification process allows for a more organized and meaningful representation of the geological features present in the study area.

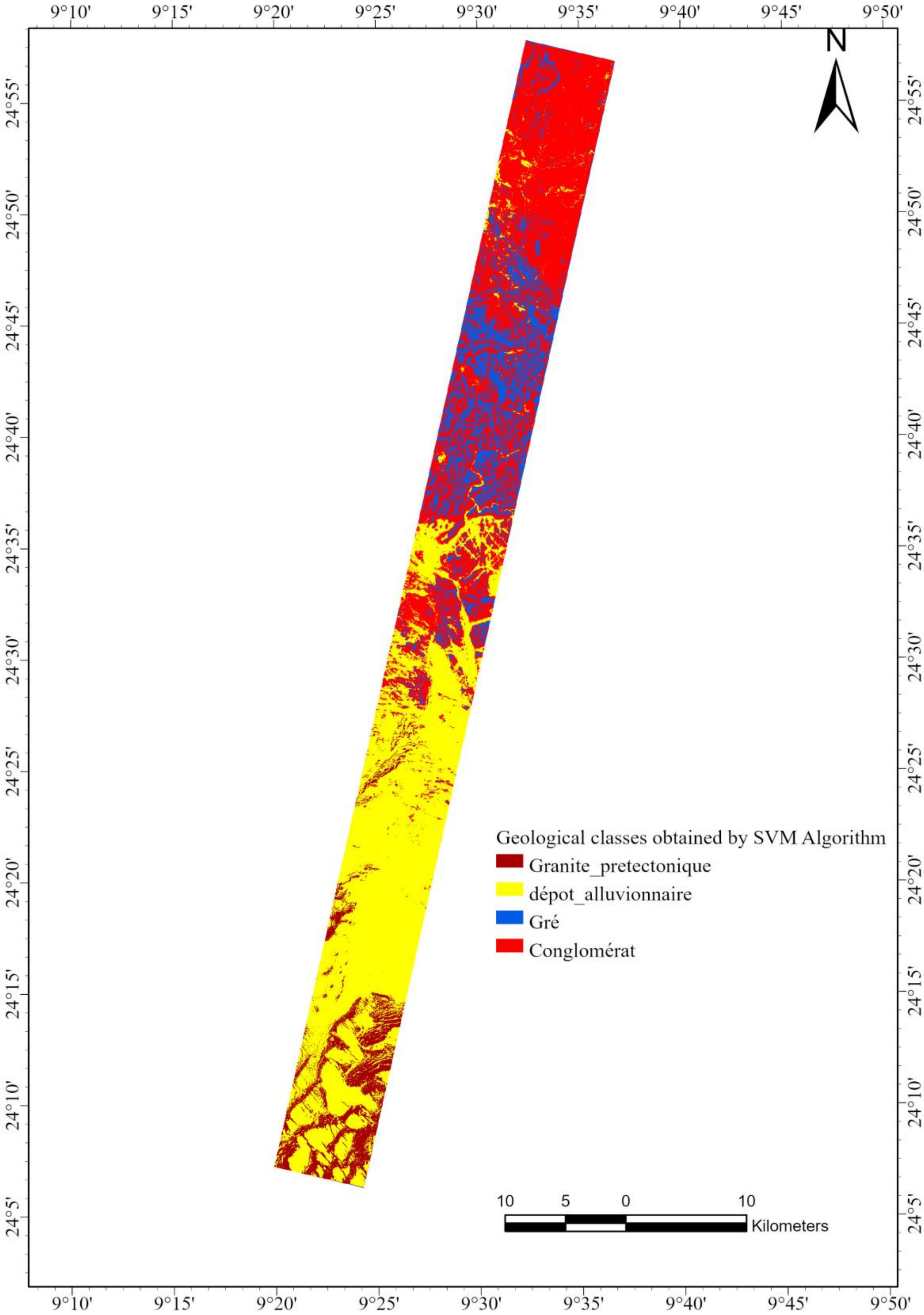


Figure III.17.map of geological classes obtained by SVM algorithm.

The resulting map obtained by SVM algorithm, derived from the comparison between the geological map of Eastern Hoggar and the NIR radiance map, reveals that the geological map contains less information compared to the NIR radiance map. This observation aligns with one of the main goals of this study, which is to demonstrate that many Algerian maps do not capture the entirety of available information, particularly when it comes to geological features and resources. By showcasing this disparity, this study aims to emphasize the need for more comprehensive geological mapping efforts to ensure a more accurate representation and understanding of Algeria's geological resources and their potential.

III.7 Spectral profile

The spectral profile shows how the intensity of light is distributed across the different bands, allowing for the analysis and interpretation of the data. ArcGIS provides tools and functionalities to extract and analyze spectral profiles.

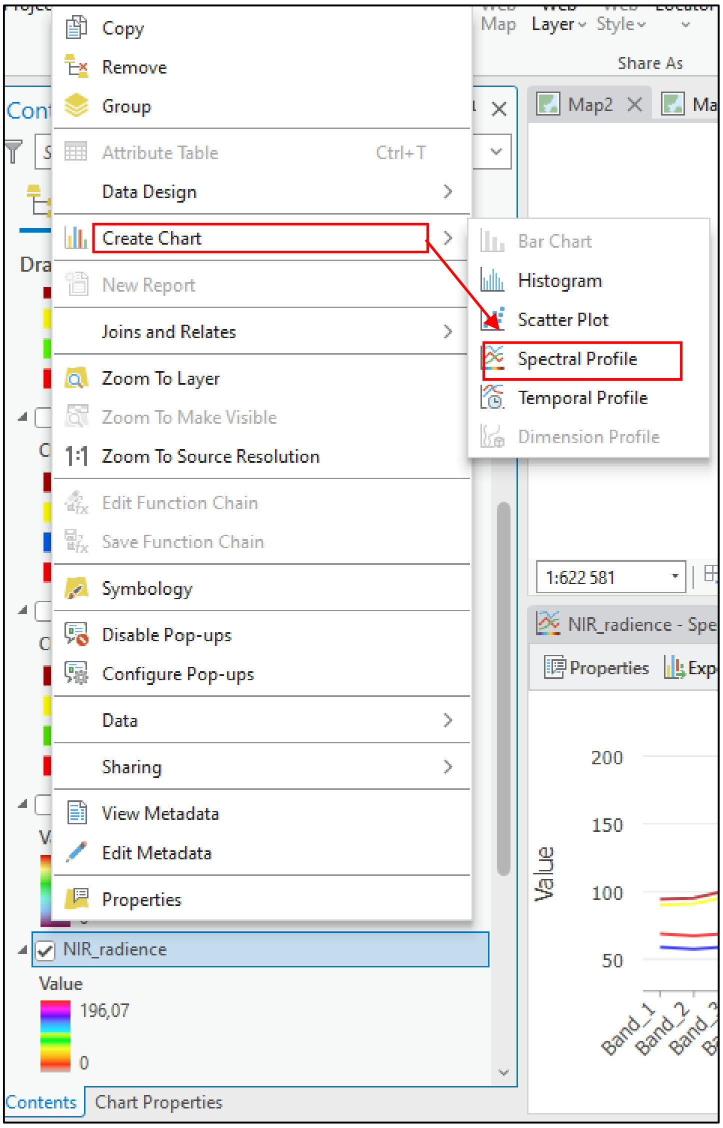


Figure III.18. Screenshot of the steps to create spectral profiles.

The spectral profile show the existence of 4 different geological formation and each formation have specified reflectance value. As it’s shown in the (figure III.19) the alluvial deposits have less reflectance value compare to pre-tectonic granite, and the conglomerates is more reflective than the sandstone.

Spectral profile

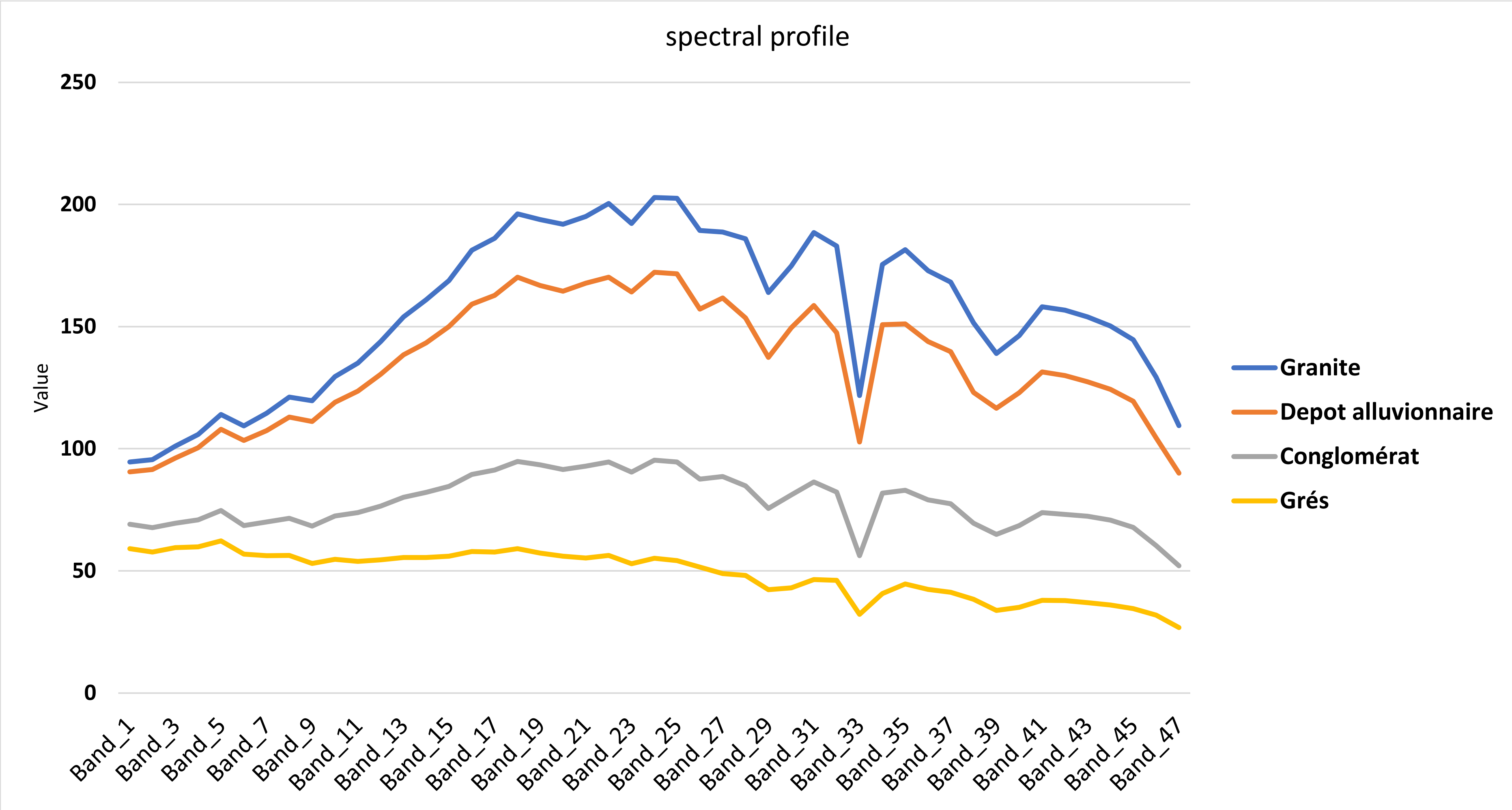


Figure III.19. Spectral profile

The reflectance values of different geological materials, such as alluvial deposits, pre-tectonic granite, conglomerates, and sandstone, can vary due to their inherent composition, physical properties, and surface characteristics.

- Alluvial deposits typically consist of fine-grained sediments, such as silt, clay, and sand, which tend to have lower reflectance values. These materials often exhibit higher water content and smoother surfaces, leading to lower reflectance. Additionally, alluvial deposits may contain organic matter or minerals that absorb or scatter light, further reducing their reflectance.
- Pre-tectonic granite, on the other hand, is composed of coarse-grained minerals, such as quartz, feldspar, and mica, which have higher reflectance values. The larger crystal size and higher mineral content contribute to increased reflectance as they reflect a greater amount of incident light.
- Conglomerates typically contain a mixture of larger, rounded clasts within a matrix of finer-grained material. The presence of these larger clasts increases the roughness and surface irregularities, resulting in higher reflectance values. The varying composition and texture within conglomerates can also contribute to differential reflectance across the material.
- Sandstone, which is composed of compacted sand grains, falls after conglomerates and alluvial deposits in terms of reflectance. It generally exhibits moderate reflectance values, influenced by factors such as grain size, mineral composition, and surface roughness.

The spectral show also a fluctuation and waves due to the existence of minerals and its more clear in the band 33.

Conclusion

This thesis focused on the application of geological mapping using hyperspectral imagery. The first chapter provided a comprehensive overview of the state of the art in geological mapping and its importance for the mining field, showing its significance in understanding geological formations and the specific context of Algerian geology plus comparing the method that was used for the geological mapping in Algeria using the ALSAT-1 sensor.
The second chapter delved into the concept of hyperspectral imaging in geological mapping, which has proven to be a valuable tool for obtaining detailed and precise geological information. By capturing a wide range of spectral data across the electromagnetic spectrum, hyperspectral imaging enables the identification and characterization of different minerals and rock types with enhanced accuracy, emphasizing its advantages over multispectral imagery and its potential for detailed spectral analysis.
The third chapter of this thesis focused on the practical application of hyperspectral image processing in geological mapping. The chapter began by outlining the software tools utilized, namely ENVI and ArcGIS, which are widely recognized and extensively used in the field of remote sensing and geographic information systems.
The practical implementation involved a systematic approach to process a hyperspectral image and generate a geological map. This included preprocessing steps such as atmospheric correction to remove atmospheric effects and radiometric calibration to convert digital numbers (DN) to at-sensor radiance. These preprocessing steps were important in ensuring accurate and reliable analysis of the hyperspectral data.
The resulting geological map was created based on the interpretation of the spectral information and the classification of different geological formations. The classification involved the assignment of specific classes to the identified spectral signatures, allowing for the spatial representation of various geological units within the study area.
Additionally, the chapter displayed the results of the spectral profile analysis, which provided valuable insights into the unique spectral characteristics of different geological materials. By comparing and analyzing the reflectance values of various formations, it was observed that alluvial deposits exhibited lower reflectance values compared to pre-tectonic granite, while conglomerates demonstrated higher reflectance values than sandstone.

This thesis highlighted the ability to generate accurate and detailed geological maps. The findings showed the importance of hyperspectral imagery in capturing subtle variations in reflectance values and identifying distinct geological formations better and detailed than the multispectral image.

Bibliographie

[1] **Geological Survey.Geological mapping. Geological Mapping (gsi.ie)**

[2] ***David R***. (*2004).U, S, Geological Survey. I*ntroduction to Geologic Mapping. Introduction to Geologic Mapping | U.S. Geological Survey (usgs.gov)

[3] Abzalov MZ.(13 July 2016). *Applied Mining Geology.mine mapping.*

[4] **ASAL.**Geological cartography of Algeria at 1/2,000,000eme. Spécifications Alsat-1 | ASAL : Agence Spatiale Algerienne)

[5] N,Bournas,& J. D.Fairhead,& **M.Hamoudi**. (January 2007). Reprocessing and interpretation of the aeromagnetic data of Algeria. (PDF) Reprocessing and interpretation of the aeromagnetic data of Algeria (researchgate.net)

[6] **Rouigia ,I.(**2022/2023).cours économie minier.ENSTI-ANNABA

[7] **Zeggane, H., Samie, R., & Mahtat, M**. (2013). Geological mapping of desert areas using satellite remote sensing. Journal of Environmental Protection,

[8] **Meghraoui, M**. (2000). The tectonic significance of recent seismicity in the Algerian Atlas. Journal of Geodynamics,

[9] **Aksas, M.** (2012). Remote sensing and GIS technology in the geological mapping of Algeria. Journal of Environmental Science and Engineering

[10] **Beldjoudi, H., Bouhadad, Y., & Ouali, J. A**. (2016). The role of geologic maps in the sustainable management of water resources: Examples from Algeria. Journal of African Earth Sciences

[11] **Pandey, PC., Srivastava, PK., Balzter, H., Bhatacharya, B., Petropoulos, GP.**(August 2020).Hyperspectral Remote Sensing,Theory and Applications Earth Observation. Hyperspectral Remote Sensing: Theory and Applications | Request PDF (researchgate.net)

[12] Mineral Spectrometry - American Assay Laboratories (aallabs.com)

[13] What is Hyperspectral Imaging? How does it work? | HAIP Solutions (haip-solutions.com)

[14] Spectral Imaging and Linear Unmixing | Nikon's MicroscopyU

[15] Lu G, Fei B. 2014 Jan .Medical hyperspectral imaging: a review. J Biomed Opt.

[16] https://www.bodkindesign.com/wp-content/uploads/2012/09/Hyperspectral-1011.pdf

[17] Muhammad J, K.2018. Modern Trends in Hyperspectral Image Analysis: A Review

[18] Schurmer, J.H., (Dec 2003), Air Force Research Laboratories Technology Horizons

[19] R.A. Schowengerdt. Remote sensing: Models and methods for image processing, Academic Press, 3rd ed., (2007).

[20] Hyperspectral and Multispectral Imaging | Edmund Optics

[21] Landcover mapping using hyperspectral imagery and deep learning | ArcGIS API for Python

[22] **NDONG, A et ANTONIO, O.** (2021). Cartographie SIG au 1/1.000.000 de la Province métallogénique du Hoggar ; Essai de caractérisation des critères et guides de recherche des minéralisations aurifères . thèses de Master en Sciences de la terre,TIZI OUZOU