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Contribution of remote sensing techniques and GIS to the geological study of Pouni, Burkina Faso

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Abstract
The Pouni region of Burkina Faso is characterised by its Palaeo-Proterozoic formations and Birimian terrains. In contemporary geological studies, the integration of advanced technologies is becoming crucial to improving the accuracy and efficiency of mapping. This article presents an analysis of the Pouni area using remote sensing and Geographic Information Systems (GIS) to produce detailed maps of lithological formations. The study is based on satellite data from the Landsat 5 programme, as well as geological and topographical data. Image processing methods such as colour composition (bands TM7, TM4, TM2) and Principal Component Analysis (PCA) were used to highlight lithological contours and identify distinct geological formations. In addition, the digitisation of lineaments, enhanced by directional filters such as Sobel's, provided a clearer understanding of the geological structures. The results obtained indicate that the integration of satellite data and GIS significantly improves the accuracy of geological mapping, offering significant savings in terms of time and resources. However, field validation remains essential to confirm these results and refine interpretations.

Keywords: Remote sensing, GIS, lithological mapping, Pouni, Burkina Faso

Introduction

Contemporary geological research increasingly relies on the integration of sophisticated technologies to increase the accuracy and efficiency of mapping. Among these technologies, remote sensing and Geographic Information Systems (GIS) have become essential tools for analysing and understanding geological formations. Since their introduction, these technologies have transformed the way geologists approach the study of terrain, offering new perspectives and facilitating the exploration of natural resources (Saibi & al., 2018) [15].

Remote sensing, using sensors mounted on satellites or aircraft to capture images of the Earth's surface, enables large-scale, high-resolution observation of geological features. Satellite images provide crucial data on the composition, structure and properties of geological formations. This information, obtained through various spectral bands, can be used to distinguish different lithological formations and detect underlying geological structures (Chen & al., 2024) [4].

GIS provides a robust framework for the integration, analysis and visualisation of geospatial data. They allow different layers of geographic information to be overlaid and analysed, facilitating the creation of detailed geological maps and the modelling of complex geological structures (Al-Nahmia & al., 2017; Yin & al., 2021) [1, 22]. Integrating remote sensing data into GIS improves the ability to detect and analyse lithological contours and geological lineaments, providing a more coherent and accurate overview of the region under study.

This combined approach makes it possible not only to map geological formations, but also to understand their spatial distribution and their relationship with geological structures. Satellite images and GIS are particularly beneficial in areas where field observations are limited or difficult to carry out. For example, Caruso (2020) [3] has shown that remote sensing techniques can effectively complement traditional geological data, providing valuable insights into lithological formations and geological structures.

Within the overall framework of geological research, recent advances highlight the importance of integrating these technologies to improve the accuracy of geological maps. Work by Sowmya & al. (2017) [19] has illustrated how advanced image processing techniques, such as colour compositing and principal component analysis (PCA), can reveal fine details of geological formations that are often difficult to detect using other methods. In addition, studies by Mohammadpour & al. (2019) [14] have demonstrated the effectiveness of directional filters and image enhancement methods in improving the visibility of lineaments and refining their geological interpretation.

In the case of Burkina Faso, located in West Africa, the geological diversity, marked by complex Palaeo-Proterozoic formations and Birimian terrains (Béziat & al., 2008) [2], greatly benefits from the joint application of remote sensing and GIS. The aim of this research is therefore to study the Pouni region of Burkina Faso using these advanced technologies, in order to gain a better understanding of the geological features of the area.

Research Methodology

1. Presentation of the study area

The study area is located in west-central Burkina Faso in West Africa, in the province of Sanguié, 139 km west of Ouagadougou on national road no. 1. It is located in the square degree of Koudougou. Its coordinates are 11°57'36‘‘ north, 2°32'47‘‘ west. The following map shows the location of Pouni.

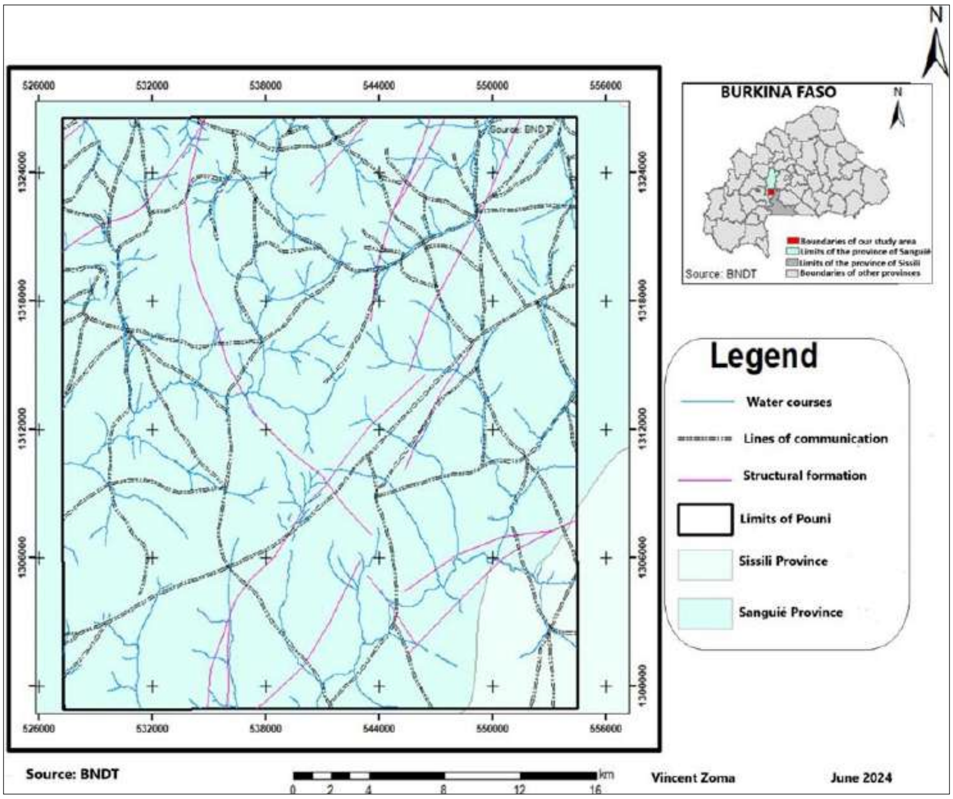

Fig 1: Presentation of the study area

In terms of climate, the Pouni area is part of the Sudano-Sahelian zone, with an average annual rainfall of 750 mm and two very contrasting seasons: a dry season and a rainy or winter season. The seasonal rhythm is controlled by the alternating influence of Saharan winds and oceanic monsoons. The dry season lasts more than six months, between October and May. The Pouni area is made up of open forests, savannahs and grasslands. Vegetation is dense only very rarely. There are no major elevations. Pouni is mainly inhabited by the Nuni, a sub-group of the large Gourounsi family.

As far as the geological context of Pouni is concerned, the study area is characterised by Palaeo-Proterozoic terrain belonging to the Birrimian basement, made up of two major groups: on the one hand, the Birrimian belt made up of volcano-sedimentary, volcanic and metamorphic terrain and basic plutonic rocks; and on the other, granitic formations (granites, tonalites, etc.) intrusive in the Birrimian formations.

The birimian ensemble contains schists, tuffs, amphibolites and ultrabasites, volcanic breccias and gabbro. Granitic formations are mainly represented by tonalite, granodiorite, quartz diorite and a wide variety of granites (blue quartz, muscovite and garnet, biotite).

2. Characteristics of the data, tools and methods used

Several types of data were used in the study, including satellite, geological and topographical data, as well as various software tools for image analysis and processing.

The satellite data comes from the Landsat programme, managed by NASA (National Aeronautics and Space Administration). This programme, designed for civilian use, offers a variety of channels for gathering a wide range of information. The images can be accessed free of charge via the USGS (United States Geological Survey) EarthExplorer website. The image used in this study was captured by the Landsat 5 satellite, referenced in the USGS catalogue as 196/52 and dated 31 July 2010. Table 1 shows the characteristics of the Landsat 5 TM bands.

Table 1: Characteristics of the landsat 5 TM bands

Bands	Wavelength (µm)	Resolution (metres)	Applications
TM 1 – Rouge	0.45-0.52	30	Differentiation between soil and vegetation
TM 2 – Green	0.52-0.60	30	Estimation of vegetation vigour
TM 3 - Blue	0.63-0.69	30	Chlorophyll absorption zone giving the state of differentiation of the vegetation
TM 4– Near Infrared	0.76-0.90	30	Monitoring biomass and submerged areas
TM 5 – Short-wave UV	1.55-1.75	30	Measuring soil and vegetation moisture
TM 6 – IR thermique	10.40-12.50	120	Thermal mapping, soil moisture studies and measurements of heat stress on plants
TM 7 – Short-wave UV	2.08-2.35	30	Mapping large areas, urbanisation trends

The geological data were taken from the 1:200,000 geological mapping of the Koudougou square degree, carried out by the Bureau des Mines et de la Géologie du Burkina (BUMIGEB) in 2003. These data were used to validate the units mapped from satellite images.

The topographic data comes from the National Topographic Data Base (BNDT 2015), also at a scale of 1:200,000, produced by the Institut Géographique du Burkina (IGB). They were essential for finalising the various maps produced in the course of this study.

The data was processed using a number of specialist software packages. ArcGIS software was used to manage the geographical data, in particular the ArcMap, ArcCatalog and ArcToolbox applications. ENVI was used to process satellite images.

The methodology used for this study is based mainly on satellite image processing techniques, which vary according to the objectives being pursued. Among these, 'colour compositing' involved combining several image bands representing different wavelengths to create a colour image. RGB (Red, Green, Blue) coding was used in this study, with the composition of bands TM7, TM4 and TM2, recognised for its geological and mineral interpretation qualities. The result of this composition is illustrated in figure 2.

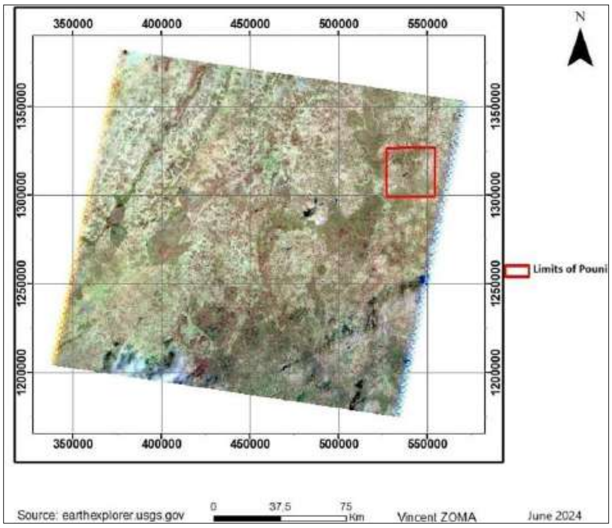

Fig 2: Image of Pouni from the TM7, TM4 and TM2 colour composition

Another important methodological tool is Principal Component Analysis (PCA). This makes it possible to de-correlate the information contained in the different bands, by grouping them into a reduced number of neo-channels, thus facilitating the analysis. PCA is often referred to as a 'false colour' method, as it does not systematically use the three visible bands. Figure 3 illustrates the results of PCA.

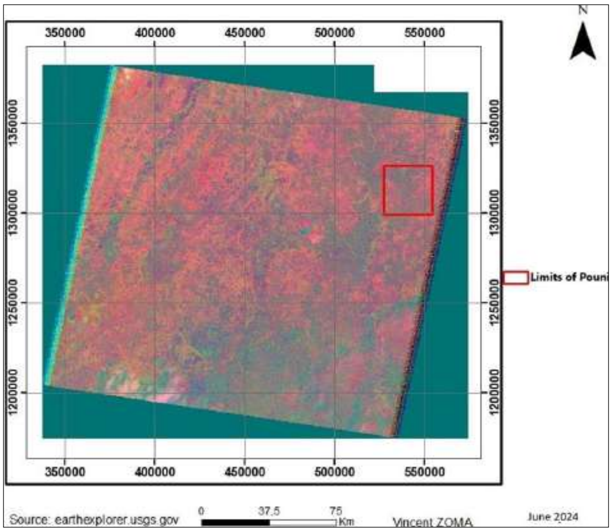

Fig 3: Pouni image from PCA1, 2, 3

The Landsat image scene covers an area of 185 km x 185 km. It was therefore necessary to restrict the field of analysis. This was done with ArcGIS software, using the ArcToolbox 'Clip' tool to extract only the area of interest. Figure 4 shows this delimitation

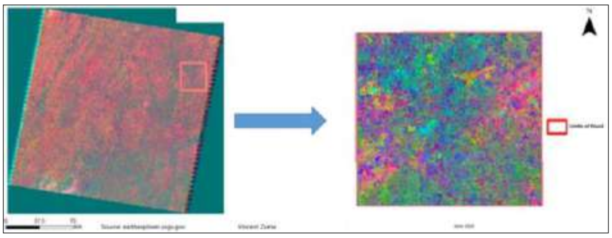

Fig 4: Delimitation of our study area (Pouni)

Research results

1. **Interpretation of data from colour composition TM7, TM4, TM2 and principal component analysis (PCA)**

Data analysis was based on the colour composition of spectral bands TM7, TM4 and TM2, and on Principal Component Analysis (PCA1, PCA2, PCA3). These two complementary approaches revealed the lithological contours of the zone studied.

With regard to the colour composition and detection of lithological contours, the image resulting from the TM7, TM4 and TM2 colour composition was used to identify the lithological boundaries. This delimitation was based on the recognition of groupings of pixels sharing similar numerical values, thus signalling differences in reflectance. In order to accentuate these contours, the histogram enhancement function, known as histogram specification, was applied. This enhancement made it possible to accentuate the contrast between the different geological formations, revealing lithological transitions more clearly.

Using this method, three distinct lithological contours were highlighted, representing significant changes in the geological composition of the area (Figure 5).

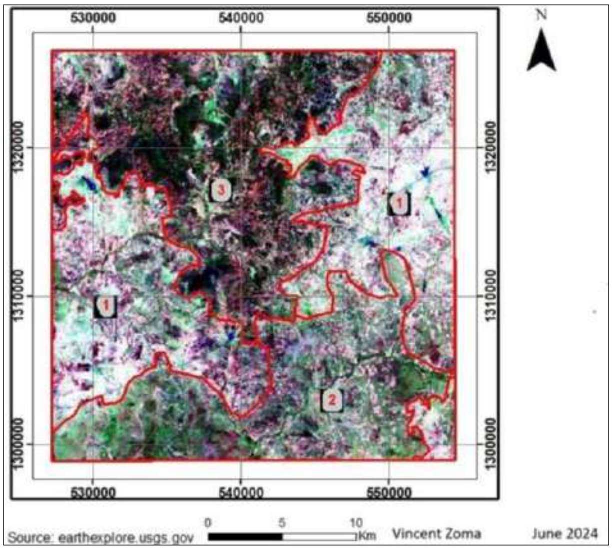

Fig 5: Image obtained from Pouni after applying the 'histogram specification' function to the coloured composition

These contours correspond to well-marked geological boundaries, resulting directly from the improved contrast in the image.

Principal Component Analysis (PCA) produces a false-colour image, making it easier to discriminate lithological contours. Combined with the histogram equalization enhancement function, this method not only identified the three contours already identified via the colour composition, but also revealed an additional contour. The improved accuracy achieved by this process is illustrated by the image shown in Figure 6.

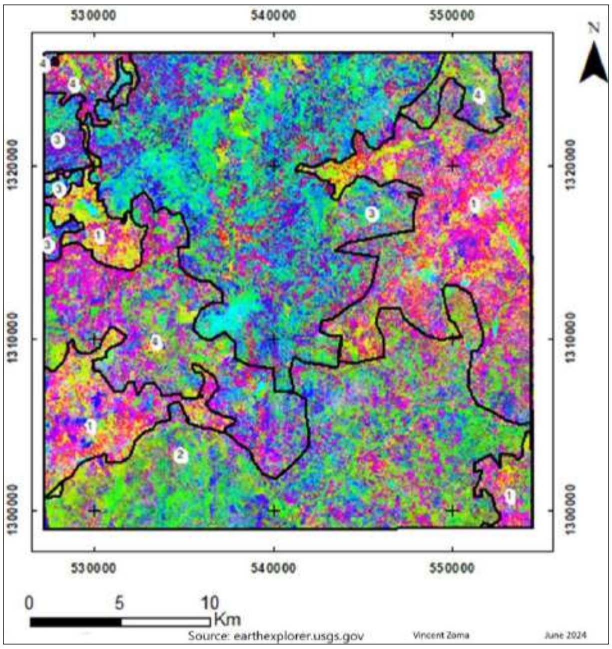

Fig 6: Image of Pouni obtained after applying the 'histogram equalization' function to the PCA

For lithological mapping and unsupervised classification, lithological formations were mapped by visual analysis of images integrated into a Geographic Information System (GIS). Pixels with similar reflectance values were grouped together and digitised to create graphic information layers. This superimposition of the different images resulting from the processing was used to produce a geological map (Figure 7). However, these groupings do not allow the precise nature of the formations to be identified at this stage.

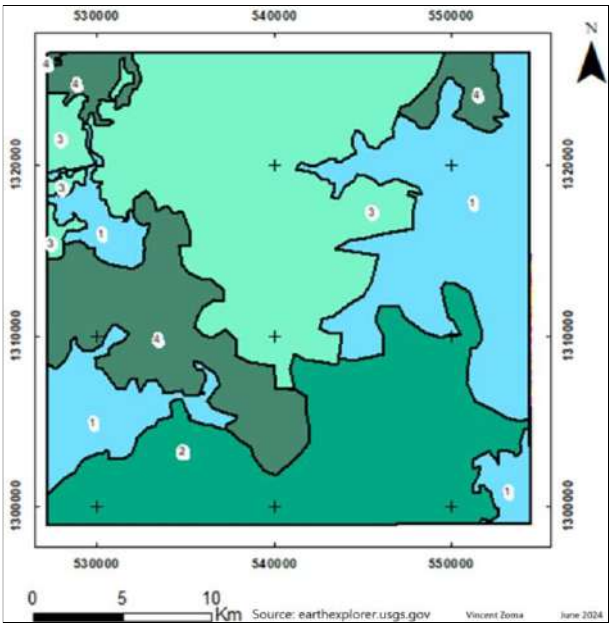

Fig 7: Map of the different geological formations

Satellite images are classified using the Iso Cluster Unsupervised Classification tool, based on an automatic analysis of pixels according to their spectral similarity. According to Lebarbier and Mary-Huard (2008) [11], the aim of this unsupervised classification is to define a typology that allows observations from different populations to be grouped together. By applying this method, four additional contours could be distinguished (Figure 8), thereby enriching our understanding of the study area.

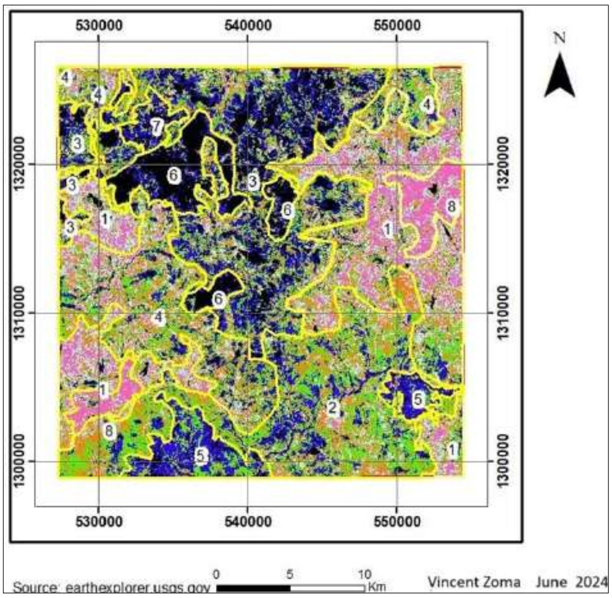

Fig 8: Mapping of Pouni using unsupervised classification

In summary, image analysis using colour composition and Principal Component Analysis techniques revealed three main contours, to which a fourth contour was added using PCA. Unsupervised classification revealed several others. These different methods proved essential for detecting lithological boundaries and provided a more complete view of the underlying geological structures.

The integration of these various approaches established a significant correlation between the contours detected, providing a more in-depth and nuanced understanding of the structure of the image. This multi-dimensional approach has provided valuable information about the distribution of geological formations in the region, while enhancing the ability to interpret data from TM7, TM4 and TM2 colour compositing, as well as PCA.

2. Identification of mapped formations

The image processing process can be broken down into two essential phases: the first, carried out in the office, consists of various image processing operations, while the second, known as 'ground-truthing', aims to verify the interpreted elements in the field. For the purposes of this study, the absence of fieldwork led to the use of existing geological data, derived from the 1:200,000 scale maps covering the study area. This data was superimposed on the image processing results, enabling certain geological formations to be identified by correspondence (Figure 9).

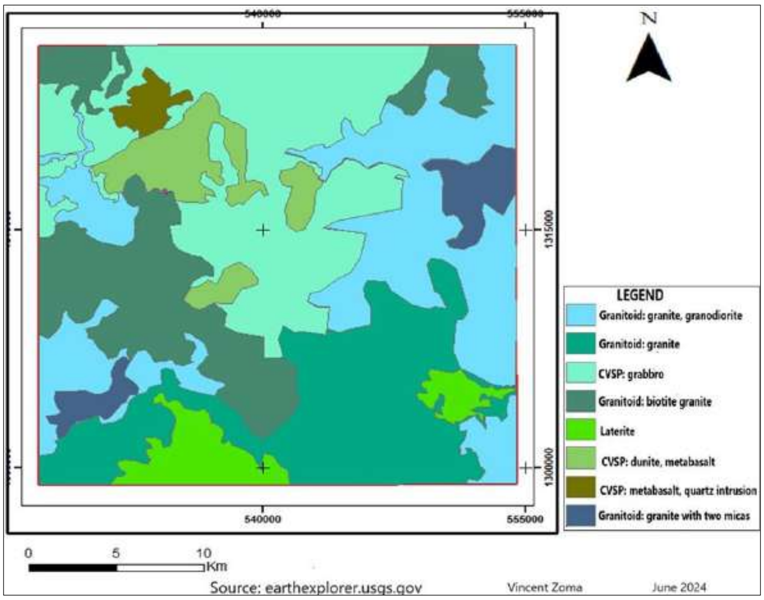

Fig 9: Map of the different formations in Pouni

Groups 1, 2, 4 and 8 correspond mainly to granitoids. Most of the outcrops and boreholes reveal the presence of granite (around 80%), in various forms (gritty, with biotite or two micas), as well as a few intrusions of rhyolite and schistose quartz. On the other hand, groups 3, 5 and 6 belong to the volcano-sedimentary and plutonic rock belt, with a predominance of basic or ultrabasic rocks. These include basalts (16%), fine gabbros (50%), schists, serpentinised dunite and a few quartz and rhyodacite intrusions. Outcrops of laterite have also been observed.

These correspondences demonstrate the ability of digital processing to enhance our understanding of geological formations by complementing traditional data.

3. Lineament mapping

As part of the mapping of structural elements, specific processing was applied to identify the lineaments in the study area. The images used come from the 7, 4, 2 colour composition and the first component of the Principal Component Analysis (PCA1), the latter alone accounting for 98% of the information. Various filters were applied to highlight these lineaments.

The Sobel directional filter (Figure 10) was used to enhance the perception of lineaments by creating a shadow effect on the image, as if it were illuminated by grazing light. This filter enhances the contours of lineaments that are difficult to see under the effect of the light source. More specifically, the Sobel filter is a tool designed to detect contours in an image, by giving greater weight to the central pixels compared with those at the ends in the convolution matrix (Deslandes, 1986; Drury, 1986; Marion, 1987; Ezzine & al., 2012) [5, 6, 8, 12].

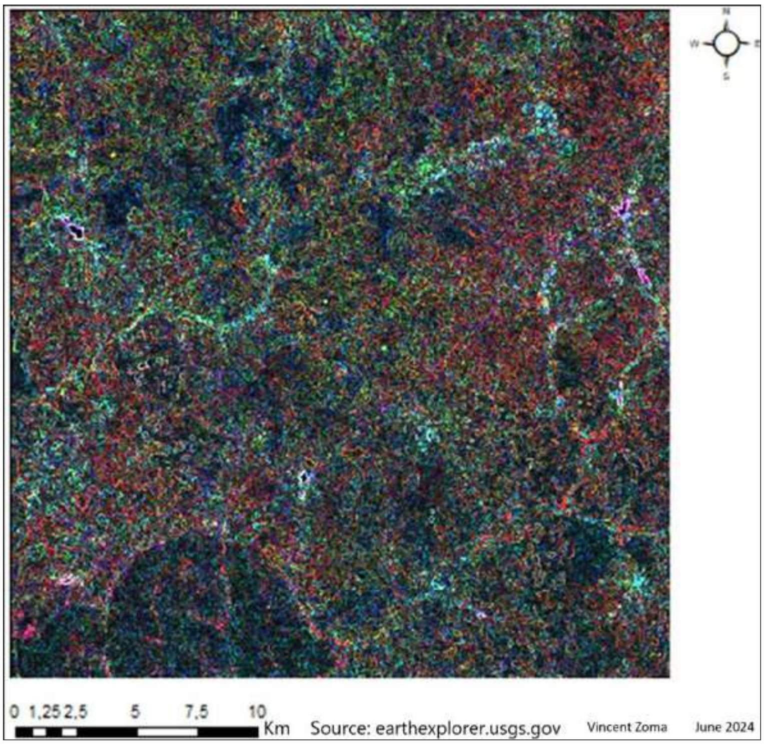

Fig 10: Application of the sobel filter to the Pouni area

In addition, four additional directional filters were applied, oriented at specific angles: north 0°, north 45°, north 90°, and north 135°, with a 5x5 convolution matrix. These filters enhance the lineaments corresponding to lithological or structural discontinuities, by accentuating the shadows cast on the image (Figures 11a, 11b, 11c, 11d).

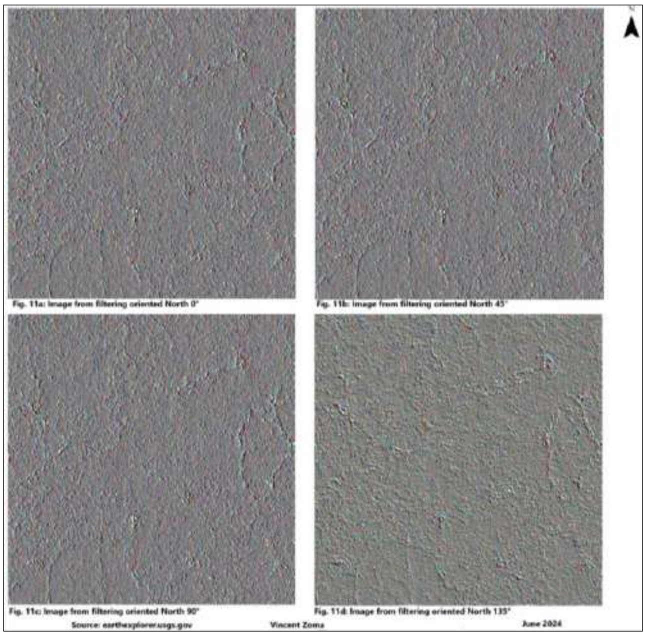

Fig 11: Pouni images from directional filtering

The combined use of these filters provides a better definition of the geological structures in the study area.

4. Digitisation of lineaments

The final stage of image processing in this study concerns the digitisation of lineaments. These lineaments, extracted from the satellite images, are the result of a series of processing operations that have improved the sharpness of the images and highlighted the contours and boundaries. A lineament is defined as a linear or slightly curvilinear structure, observable on a map, that stands out from surrounding features and probably reflects a subsurface phenomenon. These lineaments are often associated with structural features. In filtered images, they appear as boundaries between dark and light areas (Ta & al., 2008; Kabré, 2012) [9, 20]. Discontinuities or abrupt changes in tonality in enhanced images are represented by line segments (Koita & al., 2010) [10].

The lineaments were digitised on the four images resulting from the directional filters applied previously. The lineaments were traced according to the elements indicating their presence, in particular colour contrasts, areas of linear shadow, and interrupted or offset structures, suggesting the existence of a fault or a geological accident. As Saley (2003) [16] points out, the scale of observation can influence the number of lineaments detected as well as their dominant direction. He recommends a scale of 1:200,000 for optimum lineament identification. The results obtained enabled a map of lineaments to be drawn up, some of which were identified as fractures by superposition with pre-existing geological data (Figure 12).

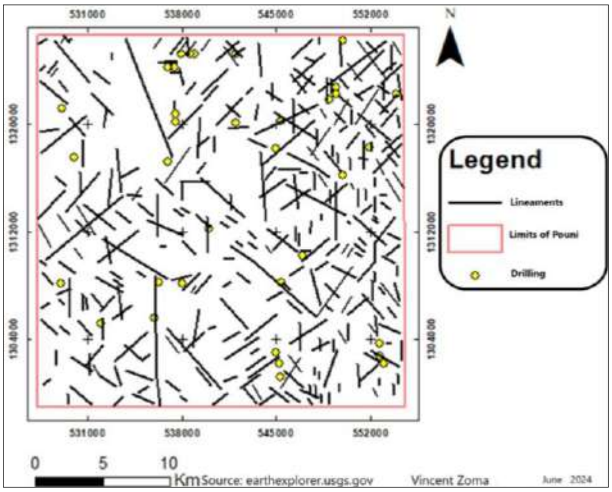

Fig 12: Pouni lineament map

This approach therefore results in the creation of an interpretative litho-structural map. By targeting potentially interesting areas on the basis of the lineament map, the human and material resources required for future prospecting can be reduced, as El Hadani (1997) [7] argues. Figure 13 illustrates this predictive map

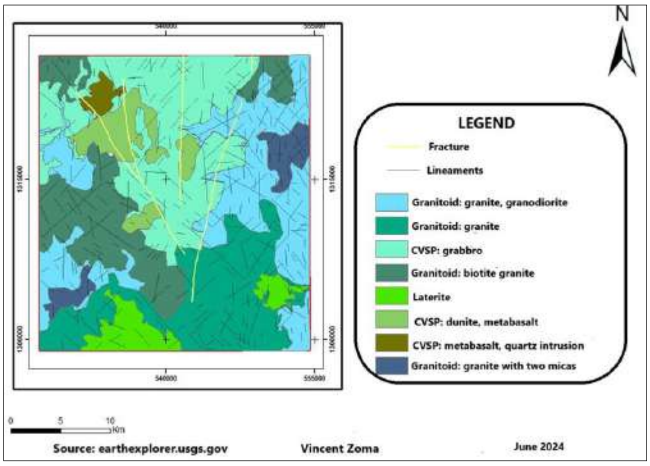

Fig 13: Pouni predictive map

Remote sensing is therefore proving to be an essential tool for geological mapping, bringing substantial savings in terms of time and resources. The image processing techniques used in this study have enabled valuable information to be gathered from satellite images, proving that image enhancement is a crucial process for extracting maximum data. In addition, these data played a key role in the characterisation of geological formations, suggesting that satellite images can represent a major asset in this field.

The integration of Geographic Information Systems (GIS) has also brought significant improvements over traditional mapping methods. These technological advances appear to be a promising approach to optimising the exploitation of geological resources. Pouni's image processing techniques have made it possible to detect a network of lineaments, which are reliable indicators of geological structures. However, although this method has produced satisfactory results, the visual extraction of lineaments remains open to debate.

The work of Yao (2009) [21] has shown, on the basis of research by Minor & al. (1995) [13] and Sanders & al. (1997) [17], that the variability between operators is not as significant as might be thought, contradicting authors such as Siegal and Short (1977). On average, 50% of the objects observed are classified in a similar way by three operators, 40% show minor discrepancies in terms of length, continuity, position or orientation, and only 10% pose real interpretation problems. However, the reproducibility of results between different observers remains a challenge. Automated methods, such as those proposed by Sander (1997) [17], based on pixel alignment identification algorithms, could offer a solution to this subjectivity.

Finally, although the issue of man-made lineaments remains, their extraction is not a major obstacle in this process of geological interpretation.

Remote sensing therefore provides remote data, saving time and resources in geological mapping. Its contribution is therefore not negligible. The processing techniques used during the study made it possible to obtain a great deal of information from satellite images. This means that in order to obtain the maximum amount of information from these images, a process of image enhancement is required. Furthermore, the data obtained from satellite images has indeed played a major role in characterising geological formations. This observation suggests that satellite images can be a valuable tool in the geological mapping process. Finally, the integration of GIS technologies appears to have brought significant improvements over traditional geological mapping methods. These findings suggest that the adoption of cutting-edge technologies represents an effective approach to optimising the exploitation of geological resources.

Conclusion

The geological study of the Pouni region, carried out using remote sensing techniques and the integration of Geographic Information Systems (GIS), has revealed a precise map of the lithological formations. Thanks to satellite images, particularly those from the Landsat 5 programme, and the use of processing techniques such as colour composition and principal component analysis (PCA), the lithological contours were clearly identified. The different approaches used revealed several geological formations, confirming the complementary nature of data from satellite images and existing geological data.

The digitisation of lineaments has helped to identify geological structures that are crucial for understanding underground phenomena. The application of directional filters, such as the Sobel filter, has enhanced the identification of lineaments and discontinuities, while optimising the geological mapping of the region. This study shows that the combined use of remote sensing and GIS is a powerful tool for geological analysis and prospecting. The methodological approach adopted offers significant savings in terms of time, resources and accuracy in identifying geological formations and structural structures.

In short, the use of satellite image processing techniques, combined with GIS, shows promise for modern geological mapping. However, the need to confirm these results in the field remains paramount in order to validate interpretations and refine discoveries. The results obtained show that the adoption of new geospatial technologies represents a significant step forward in optimising the exploration and exploitation of geological resources.

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