

Design of Geological Sketch Map in a Forested Area Using the Advanced Optical Remote Sensing Techniques and the Petrography: Kambele and Surroundings Example (Batouri Gold District, Eastern Cameroon)

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Received May 03, 2024; Revised June 05, 2024; Accepted June 12, 2024

Abstract The objective of this study is to design the geological sketch map of the Kambele sector and surrounding areas using object-oriented classification (OOC) and field observation data. Kambele is a vast mining field located in the center of the Batouri gold district in Eastern Cameroon. The method for lithological mapping consisted of the segmentation and supervised classification of the Landsat 8/9 OLI image, then the directional filtering of the SRTM image for the extraction of Faults. The derived data were then cross-referenced with field observation points in GIS Software. The major result includes the geological map of Kambele; this will contribute to improve the geological and mining information of the sector.

Keywords: Kambele, advanced remote sensing, Petrography, forested areas, applied geomatics, sketch map

Cite This Article: Bissegue Jean Claude, Ravindra Nath Tiwari, Namit Kumar Jha, and Tchameni Rigobert, "Design of Geological Sketch Map in a Forested Area Using the Advanced Optical Remote Sensing Techniques and the Petrography: Kambele and Surroundings Example (Batouri Gold District, Eastern Cameroon)." *Journal of Geosciences and Geomatics*, vol. 12, no. 3 (2024): 55-61. doi: 10.12691/jgg-12-3-1.

1. Introduction

Large-scale geological mapping represents a major asset in any sustainable development strategy for the mineral industry, since it is committed to improving existing geological and mining information. To design a geological map, geologists often obtain information from sampling, field observations, drilling, soil studies, vegetation studies, seismic recordings or increasingly nowadays, the modern tool of geomatics includes remote sensing, GIS and digital cartography. Remote sensing is still used successfully in desert areas since the rocks are often bare in most cases and on the other hand; it represents a real challenge in forested areas because of the vegetation and the layer of soil which hide the rocky base. Thus, in these regions researchers have often used optical remote sensing using vegetation as indicators of geological objects [1]. The Kambele sector located in the equatorial forest of Eastern Cameroon is a vast mining field which has not until now been the subject of detailed

geological mapping using remote sensing. In this study, we used object-oriented-classification (OOC) which is an advanced remote sensing technique in order to produce the geological map of the Kambele sector and surrounding areas.

2. Study Area

2.1. Localisation

The study area is located in the center of the Batouri district, capital of the Kadey department in the East Cameroon region. It is bounded between 4°20' and 4°30' North latitude and between 14°20' and 14°30' East longitude (Figure 1). The main villages are: Ndem, Djira, Kambele and Ndoumimbe. Access from one village to another is via roads or forest tracks. The sector is under the influence of a hot and humid equatorial climate of the classic Guinean type. The vegetation presents alternations of grassy savannahs, gallery forests along the hydrographic network and the large dense forest in the South.

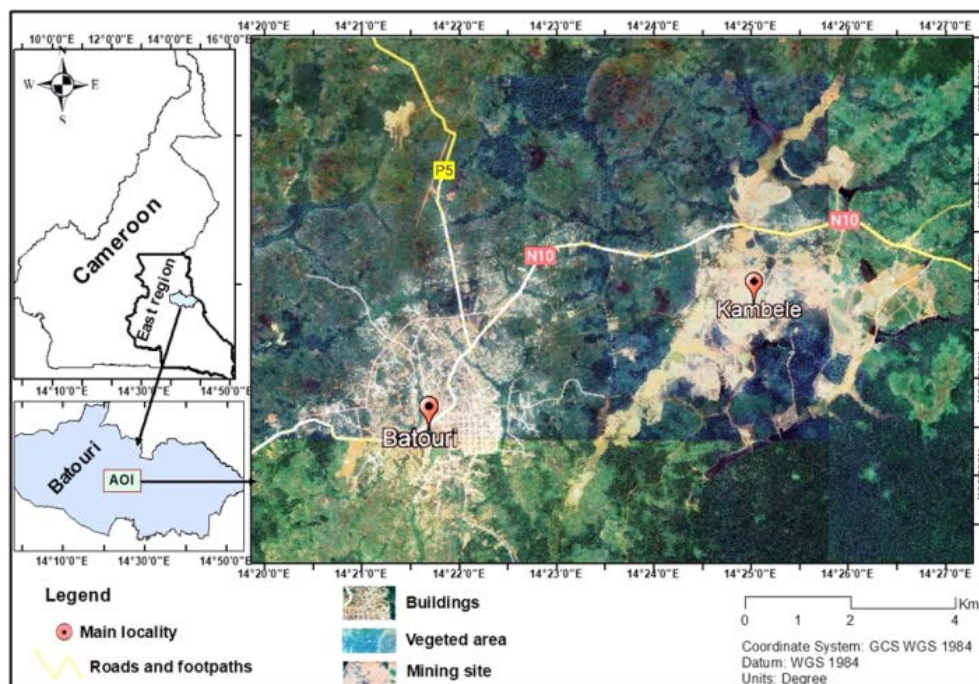


Figure 1. Location map of the study area edited from Google Earth aerial photography

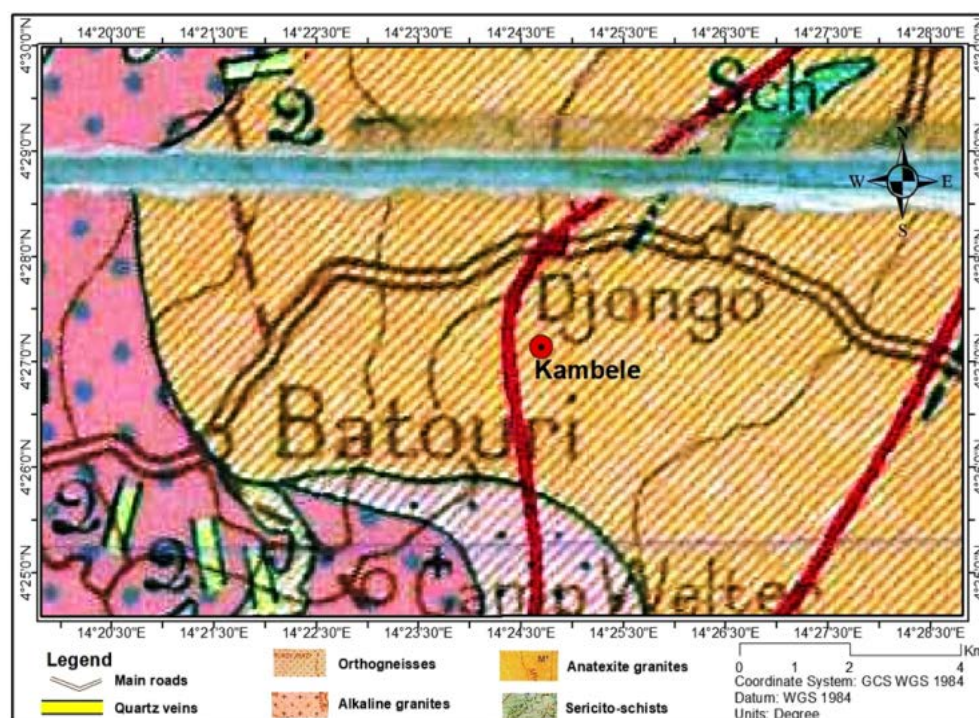


Figure 2. Old geological sketch map of study area after Gazel and Gérard (1954)

2.2. Local Geology

The Batouri area is part of the Adamawa-Yade Domain (AYD) of the Pan African fold belt in Cameroon [2]. Adamawa-Yade domain is bounded to the North by the Tchollire Banyo shear zone and to the South by Sanaga shear zone towards the Yaounde domain. The geology of Batouri is particularly dominated by syn- to late tectonic granites locally crosscut by systems of shear zones [3,4]; Figure 2. The metamorphic rocks include schists, gneisses, metagranites, migmatites and late-tectonic foliated granites of indeterminate ages. The shear zones intersect the foliation in the matagranite having been affected by

hydrothermal alteration near the quartz veins [5,6]. Dear Editor, please insert Figure 2 here at end of paragraph.

3. Materials and Methods

3.1. Data Source

This research has used raw data from <https://earthexplorer.usgs.gov> website, and rock samples and their thin sections from petrographic studies as they are detailed in Table 1. Two types of geospatial data used include Landsat 8/9 OLI and SRTM data (Figure 3)

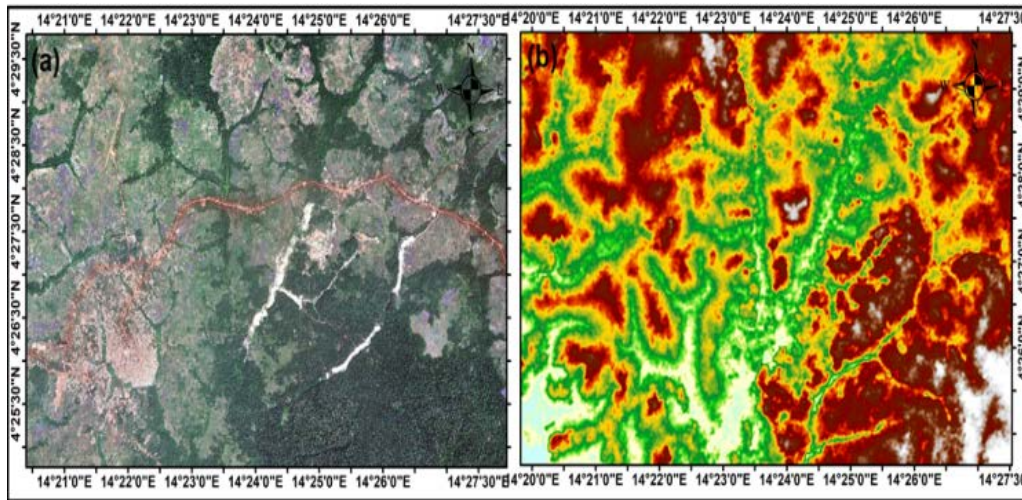


Figure 3. Images (satellite data) used in this study. a) Multispectral image of Landsat 8/9 OLI. b) Gray level image of SRTM dem data

Table 1. Data source table

Data	Resolution	Source
Landsat 8/9 OLI	30 m	Earthexplorer.usgs.gov
SRTM	30 m	Earthexplorer.usgs.gov
Rock samples	Centimetric	Field survey
Thin sections	30 um	Laboratory

3.2. Data Pre-processing

One tile of Landsat 8/9 level 1T satellite recorded by the OLI (Operational Land Imager) sensor was acquired. The Pre-processing step consisted of Non-Linear contrast stretching using histogram equalization as a contrast stretching technique performed in ArcMap 10.4 software. A correction of the SRTM scenes using the “Hillshade” function of the Spatial Analyst extension of ArcGIS was applied to produce raster images with gray values varying from 0 to 255. The study area was immediately subsetting from the corrected images.

3.3. Data Processing

3.3.1. Faults Analysis Method

The detection of structural features was done from SRTM data imported into the ArcGIS software. The SRTM-DEM technique for structural interpretation is on the basis of hillshade image with various elevations and slope gradient. The procedure was performed only in one step; the shaded relief image was created for one sun azimuth and angle of 135°. The principle of this technique recommends that areas perpendicular to the sun angle are illuminated the most while the areas with high angle or greater than 90° are shaded. At the end, visual and manual interpretations were required to extract significant fault structures.

3.3.2. Lithological Features Analysis Method

In this study, supervised classification was used to discriminate the lithological units of the Kambele sector and surrounding areas. Indeed, according to [7], supervised classification constitutes the best method for automatic extraction of surface boundaries. This method of analyzing satellite data allows the extraction of

thematic information for the discrimination, recognition and identification of lithological units. Furthermore, in tropical and temperate climatic zones characterized by high forest cover, high spatial resolution satellite imagery makes it possible, due to the plant stratum, to reveal mineralized zones, to highlight features of regional tectonics and more generally lithological types [8]. The logic is based on the fact that the quality of vegetation depends on the type of soil, which itself depends on the type of underlying parent rock; although, the climate and relief of the environment have a non-zero effect [9]. The supervised classification approach adopted is that of object-oriented classification (OOC). The principle of this classification method is to consider the element to be classified as a group of pixels called “object”. OOC includes three (03) steps: image segmentation, pre-classification and classification.

3.3.2.1. Image Segmentation

Segmentation is a process by which pixels are grouped into segments according to their spectral similarity. Image segmentation is also known as process of isolating objects of interest from the rest of the scene [10]. In this study, the segmentation method is based on properties of intensity values and algorithm used groups similar pixels into objects on the basis of texture, context and geometry. The minimum segment size in pixels was the most important parameter used, when it increases, the generalisation also increases.

3.3.2.2. Pre-classification

This step permitted to identify the types of land cover via the spectral signature of the objects. It takes place in three stages: the merging of regions, the choice of attributes and the determination of learning samples or training sites or even regions of interest (ROI). To preserve spatial detail, similar adjacent regions are grouped using only the Merge Level parameter. The attributes to be taken into account during the classification are predefined in advance; three (03) were retained: the spatial, spectral and textural attribute. Then, the calculation of the NDVI vegetation index [11] was used in addition since it is a good indicator for monitoring the state of the forest cover.

3.3.2.3. Classification

The classification begins with the choice of the attributes that one want to integrate into it. Concerning the determination of attributes, [12,13] assumed that the spectral variability within mixed pixels was only due to variations in land cover within the pixels themselves and not to the evolution of vegetation. For our study, we kept the surfaces for the spatial attribute, the mean and variance for the texture and the standard deviation, the minimum and the maximum for the spectral attribute. Finally, we therefore carry out the classification itself, using the K-nearest neighbor algorithm. The Figure 4 shows the main stages of classification.

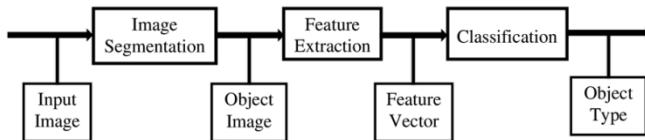


Figure 4. Image processing flow based on Object-Oriented Image Analysis Classification

4. Results and Discussion

4.1. Result of the Fault analysis

To assess the constituent elements of the landscape and the distribution of major structures in the study area, the analysis was based on the visual interpretation by multi-criteria combination of the gradient or shaded filter applied to the SRTM image (Figure 5). The lighting of the ridges or thalwegs by an inclined sun induces a shadow effect on one of their sides. The resulting contrast in brightness is reflected in the image by a limit separating two reflectance domains. Geometric criteria coupled with morphological and topographical criteria have enabled the identification of structures.

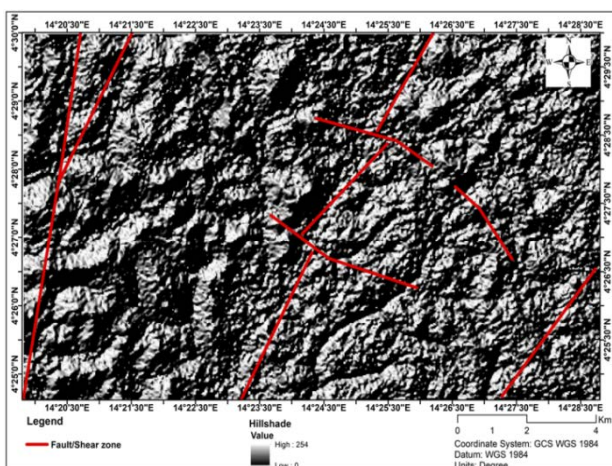


Figure 5. Major fractures digitized on filtered SRTM-DEM topographic background

A comparison of the layout of the discontinuities with field data and existing maps thus allows us to validate the discontinuities of the interpretation. The compilation in the GIS software of layers of field data (geological and geological) to maps of the prospect of Kambele carried out by [4] and geological reconnaissance [3] placed in the same

reference system; shows that the distribution of clues and outcrops offer a very discontinuous image of the structures.

4.2. Result of Image Segmentation

In an OOC approach, classification requires a preliminary step which is that of image segmentation. The goal of image segmentation is to create image segments with maximum homogeneity [14]. It is then possible to simultaneously represent the information contained in the image in several layers made up of objects and each corresponding to a given scale [15]. For the classification of the Landsat 8/9 OLI image, the segmentation was done on the eight visible bands with a spatial resolution equal to 30 m (Figure 6). This procedure made it possible to produce homogeneous entities adapted to the envisaged classification.

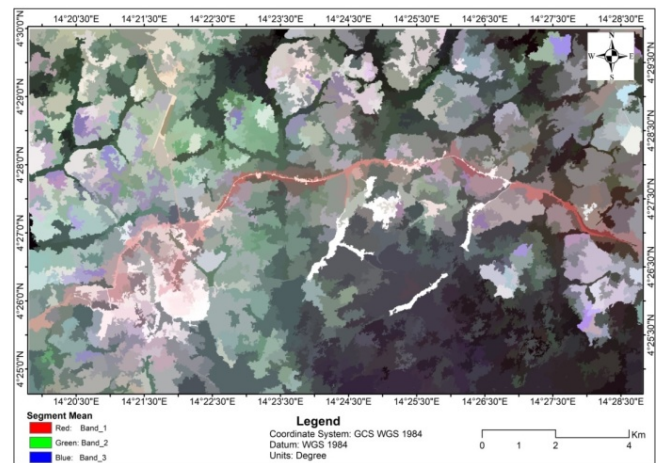


Figure 6. The result of segmentation using different similarity tolerance (10, 150)

4.3. Result of NDVI Analysis

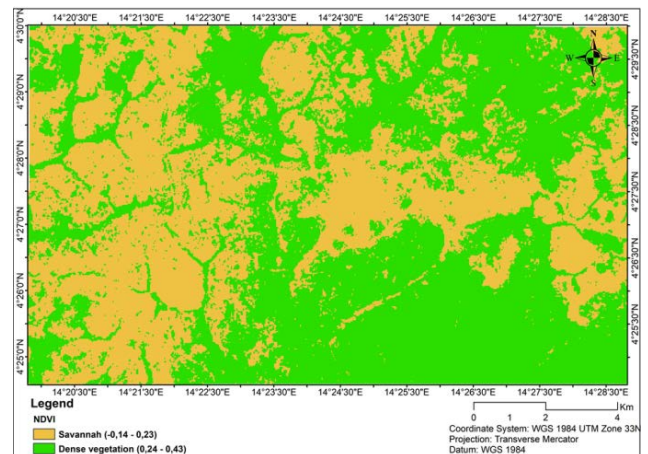


Figure 7. NDVI map of the study area showing two classes of objects

The NDVI is a remote sensing technique that measures the health and density of vegetation in a given area. Studies have demonstrated that NDVI is effective to differentiate savannah, dense forest, non-forest and agricultural fields and to determine evergreen forest versus seasonal forest types [16]. The calculation of the NDVI vegetation index (Tucker, 1977) was used in addition since it is a good indicator for monitoring the

state of the forest cover. In this case, only the reflectances measured in channel 5 (PIR) and 4 (R) were combined, the required values including NDVI= -0,14- 0,23 and NDVI=0,24- 0,43, correspond respectively to two classes of objects namely shrub savannah and dense plant cover (Figure 7). Dear Editor, please insert Figure 7 here at end of paragraph.

4.4. Result of Classification

The classification of the Landsat image according to the object oriented approach with the first step, the segmentation parameterized by the bands in the visible; allows obtaining a very good quality result (Figure 8). In fact, there is a good individualization of the continuous forest fabric in the South of the map, thus, in the North; a continuous savannah fabric is individualized with transitions into forest along the watercourses. Given this composite aspect of the savannah tissue class which is discontinuous in places, often represented by isolated pixels, there is therefore a possibility of poor aggregation of pixels. The resulting objects are likely to group together pixels with small radiometric differences. The homogeneity and good discrimination of the dense forest zone and also that of the savannah also suggest the uniformity of the lithology.

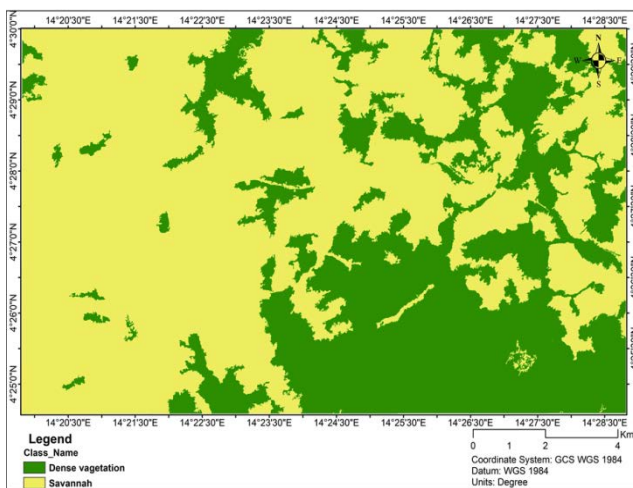


Figure 8. Supervised classification by OOC method of the Landsat 8/9 OLI image of the study area

4.5. Result of Petrographic Study

Field survey and laboratory works was carried out firstly to check in each observation point on the ground the correspondence of the lithology type with the classes of objects identified on the satellite image by OOC method and secondly to validate the remote sensing methodology approach adopted in this research.

Petrographically, the field and laboratory works of [17] showed that the Kambele sector and surrounding area is made up of undeformed or slightly deformed granitoids and tectonites. Tectonites are made up of protomylonites and mylonites associated with the functioning of shear zones. The Granitoids are mainly composed of alkaline granite and granodiorite (Figure 9). The thin sections cut from the samples of these rocks clearly revealed the specific characteristics of these rocks.

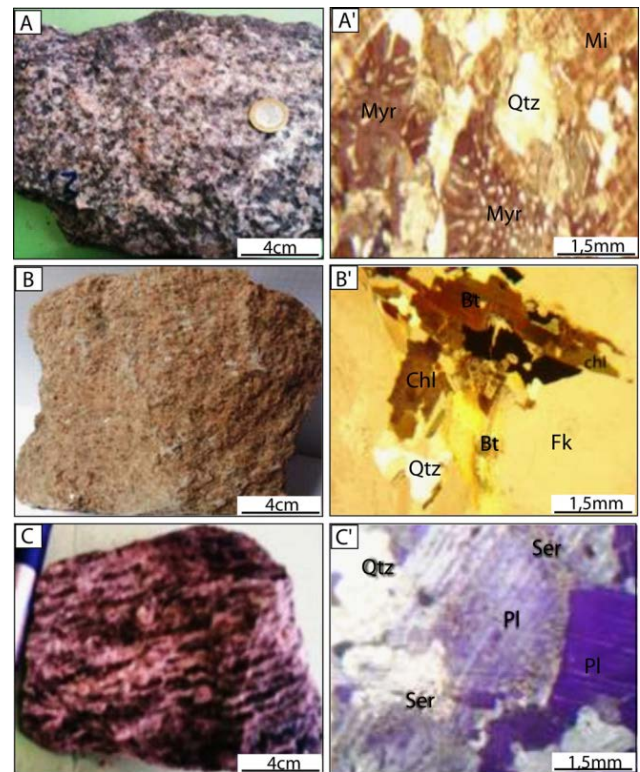


Figure 9. Main Rock samples and equivalent thin sections of study area. AA') Sample and thin section of granodiorite. BB') Sample and thin section of alkaline granite. CC') Sample and thin section of Mylonite

4.6. Validation of Geological Contours

In order to validate the geological contour limits extracted by optical remote sensing techniques, two sets of data were crossed in the GIS software: the image classified by OOC and the observation points of the outcrops collected in the field. By comparing the distribution of observation points on the classified image with the limits of the object classes (Figure 10), we notice that the granitoid outcrops are preferentially positioned on the dense forest class; on the other hand, the alkaline granite points are more aligned with the savannah class. This observation is well correlable with field observations during which [17] clearly presented the geographical location of the Batouri granitoids.

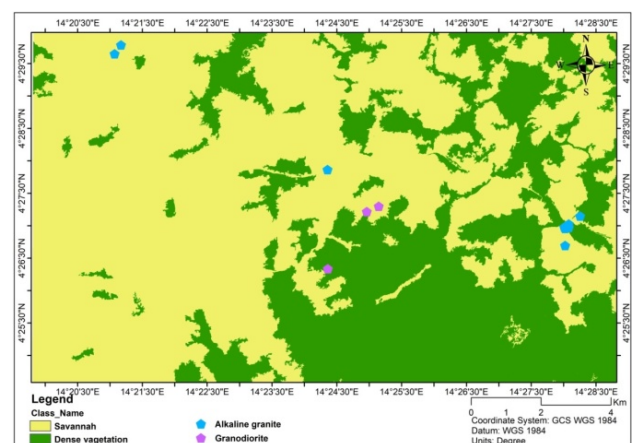


Figure 10. Validation of contours by comparing the classes of the OOC map versus petrographic observation points in the field

4.7. Geological Mapping

The determination of the geological groups was done through the analysis of the hues, textures and shapes on the classified image of Landsat 8/9 OLI. The classified image thus made it possible to increase the contrast between the targets and their environment. The study area being a peneplain covered with vegetation and lateritic cover, the texture on the image strongly depends on these; it is in places smooth to finely coarse. According to [18] and [19], we use the term geobotanical anomaly to designate any local spectral modification of a plant cover, to which we attribute a geological significance. Thus, the petrographic nature of the substrate is materialized in the image by the particular reflectance of the vegetation. The classification process produced final thematic classes which were assigned geological significance. The boundaries of lithological units are marked, either by color contrast or by the alignment or grouping of samples. Mapping geological units consists of the identification of physiographic units (homogeneous regions) and the determination of the lithology of the bedrock. It is made possible by visual photo-interpretative analysis allowing good discrimination and recognition of lithological units. The base of Kambele thus mapped (Figure 11), therefore presents two lithological types: alkaline granite whose area extends to the West, North and NE of the study area and granodiorite of an area restricted area which extends from the Center to the East and scattered throughout the study area. The method adopted in this study turns out to be relevant since the result obtained fits correctly into the logic of the lithological map sketch proposed by [20].

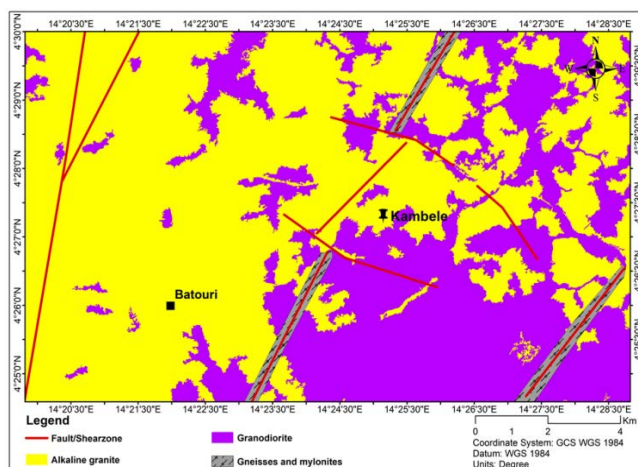


Figure 11. Geological Sketch Map of kambele and surroundings designed from OOC

5. Conclusion

This study consisted of the development of a method for designing geological map in forested areas using an advanced remote sensing technique. The objective was to design the geological sketch map of the Kambele sector and surrounding areas. The method consisted of supervised segmentation and classification of the Landsat 8/9 OLI image using the OOC, then directional filtering of the SRTM image. At the end of this investigation, the geological sketch map of Kambele was published. This

new map will certainly contribute to the improvement of the geological and mining information needed by mining operators in this sector.

Conflict of Interest

The authors declare no conflicts of interest relevant to this study.

Data Availability Statement

This manuscript uses publicly available Landsat 8/9 OLI and SRTM data, downloaded from the USGS server. Methodological approach used in this study will be made available on request from the first author.

ACKNOWLEDGEMENTS

We are thankful to the Noble Training and Research Institute named «NETRA institute of Geo-informatics Management and Technologies Foundation, Dwarka Mor, New Delhi» for having provided high training quality to the first author.

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