

Characterization of Lineaments by Remote Sensing and GIS: A Case of Soa Municipality

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Abstract

Soa is a town located in the Mefou and Afamba division of the center region of Cameroon. This locality belongs to the Yaoundé series, which is one of the metamorphic formations of the Pan-African chain. The characterization of lineaments is an important approach in the prospecting of groundwater. With the understanding of the state of fracturing of the sub-surface in the basement zone, an approach was proposed in order to map the fractures of the cracked part of the Soa municipality, thanks to remote sensing and the geographic information system (GIS). After acquisition of the Landsat image (scenes LC09_L2SP_185057) on December 22, 2021, the image will be subject to different operations, which include: pre-processing, processing in order to visualize the image, to improve it and above all to enhance the structures targeted by this study (lineaments). The lineaments observed will be extracted manually according to four directions, which are in fact the directions of the SOBEL 7X7 filter used during the processing of the image. After assembly of all the extracted lineaments, the lineament map is obtained. The validation process carried out thereafter is to grant these lineaments a geological nature, which will lead to the fracturing map. This map has 803 fractures, hence the size is between 0.09 km and 5.55 km oriented according to three preferential directions ENE-WSW, ESE-WNW and SE-NW. The establishment of the water potential map of the study area by densifying the fracture network will allow us to have an overview of the groundwater resource of each locality of the municipality. This is how localities like Soa and Nkolfoulou I have low supply of groundwater, while the localities of Akak and Ebogo II are rich.

Keywords

Remote Sensing, Aquifer, Fracture, Lineaments

1. Introduction

The Earth is commonly referred to as the blue planet because it is composed of 70% water and 30% habitable areas for humans and non-aquatic animals. This is because water is an abundant resource on this planet. However, in some areas of the globe, water is a scarce commodity for domestic use, industrial activities, agriculture, and livestock farming.

In Cameroon, problems related to access to water are common in most cities [1]. This hinders the well-being of the population and therefore the country's development. Among the solutions observed to resolve the problem of drinking water supply is drilling. In some regions of the country, numerous projects have been implemented, such as the 3000-borehole drilling project in 2019, negotiated between the Cameroonian government and the French law firm Vergne Hydro, and a Japanese grant estimated at 4.6 billion CFA francs for the drilling of 189 boreholes in the north between 2012 and 2013, an area known for its intense dry season. Drilling a borehole is not an easy task. It therefore requires a thorough knowledge of the environment, from a geological, structural, and hydrogeological perspective. Studies conducted by experts are therefore necessary before any drilling. It is very unfortunate to find dry wells or unproductive aquifers. All these difficulties are due to a poor study of the investigation area. Hence, the interest of this study lies in the in-depth research on the existence of productive aquifers before drilling a borehole. The main objective of this work is therefore to locate geological structures likely to contain water. Many methods are used to define areas suitable for drilling, but the choice of these methods is often conditioned by the scale of the task and the cost of the operation. More and more experts are trying to reduce the space available for fieldwork while still being efficient. Remote sensing is a method offering many advantages, used in many fields, including structural geology, mining and oil exploration [1] and in hydrogeological studies [2]. It allows the location of geological structures and the mapping and characterization of linear structures in a simple and precise manner. Linear structures identified on the surface using satellite images are an important source of information, which, after processing, can reveal the state of subsoil fracturing thanks to the lineaments associated with the fractures, thus constituting a real flow of fluids in the fractured rocks. This method is applied in the municipality of Soa.

2. Study Area

2.1. Localization

The town of Soa is located in the center region, Mefou and Afamba division, 14

km northeast of Yaoundé; at 3°59 Latitudes North and 11°36 Longitudes, covering an area of 325 km² (Figure 1). It is limited to the south by the municipality of Nkolafamba and the town of Yaoundé V, to the west by the commune of Obala, to the east by the municipalities of Esse and Awaé and to the north by the municipalities of Obala and Edzendum. The town of Soa has forty villages, including thirty-seven in rural areas and three in urban areas, distributed in four groups (Mbende, Ntouessong, Ebang and Ngali). The climate of the locality of Soa is of the wet equatorial type, having four seasons, two rainy and two dry seasons. The relief is that of a dissected plateau which bowed from the center to the north. The average altitude is 675 m [3].

The soils are mostly ferralitic, acids, clayey and red or yellow in color depending on the duration of the wet season. The hydrographic network is organized around the Afamba river and its main tributaries that are Mbende, Mbele and Foulou. Several streams flow through the town and drain towards river Sanaga in the north.

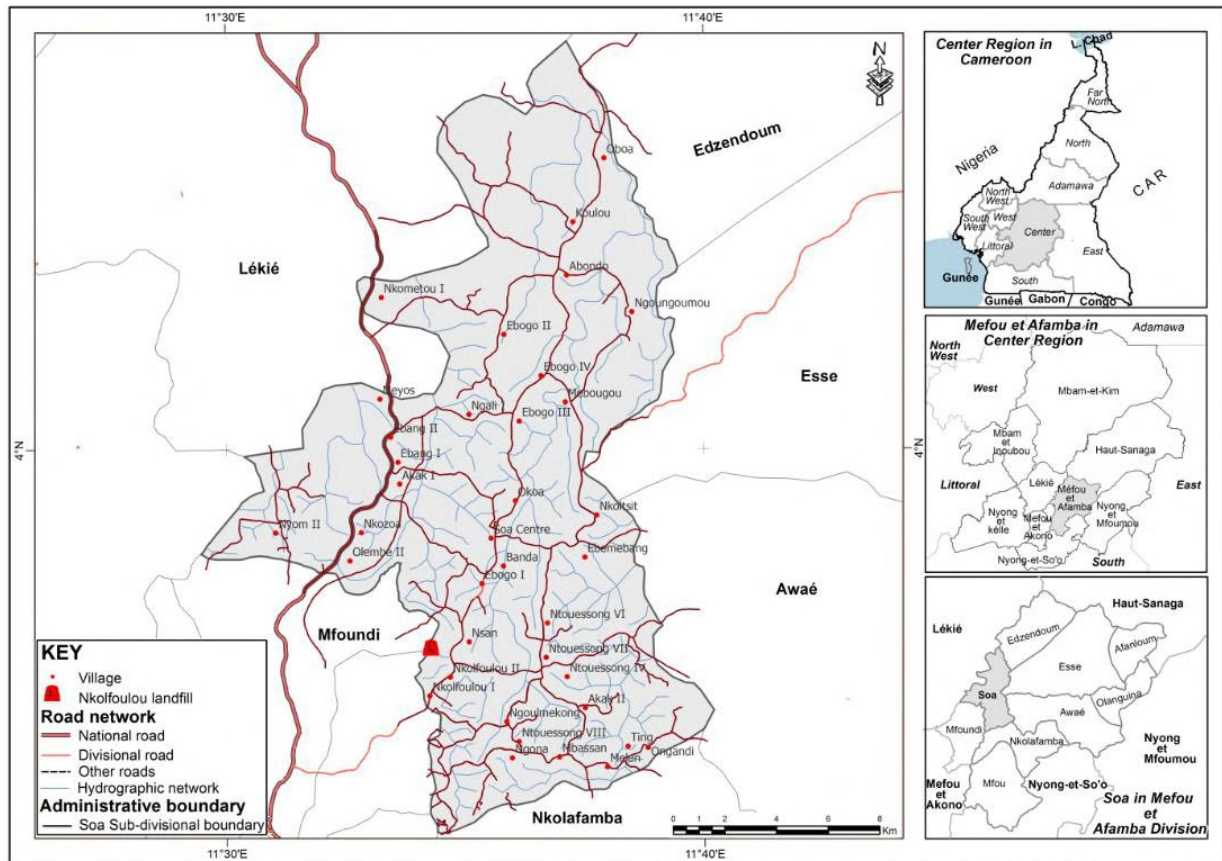


Figure 1. Localization map of study area. Source: <https://earthexplorer.usgs.gov/>.

2.2. Geology of the Soa area

The geological formations [3] all belong to the old base include ectinites and migmatites in the municipality (Figure 2). These formations are represented by: Am-

phibolites of the Volcano-Sedimentary Sédiment of Age born-Mosoarchaeon; The Yaoundé—paragneiss formation (migm), a grt ± ky (± micaschists) of the volcano-sedimentary stenien-Tonien series; Gneiss Migmatites with Tonalite granodioritic; Gneiss Migmatites (Monso) Granitic, a fault of direction NNE-SSE.

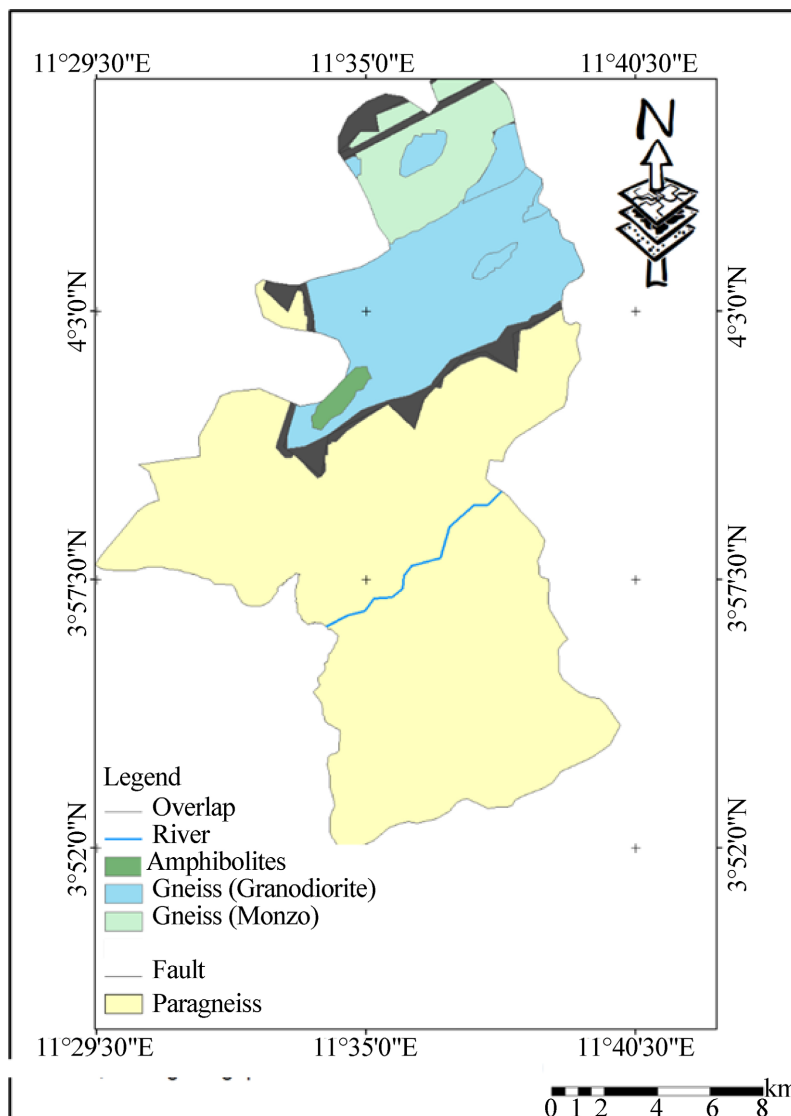


Figure 2. Geological map of the study area. Source: [3].

2.3. Hydrogeological Study

The Soa municipality is located in the basement area and taking into account the gneissic granito context of the area, we retain the alteration profile of the base rocks defined by Wyns *et al.* (2004) [4] and Dewandel *et al.* (2006) [5]. We therefore have a layer of essentially capacitive office alteritis from top to bottom (when saturated with water), surmounted by the barrier layers, a transmissive cracked layer, composed of hard rock and presenting cracks, mostly sub-horizontal in granite. However, the work on the aquifers of the Cameroonian base is still embryonic; the

validity of this hydrogeological conceptual model developed on the basis of the works made out of the country is not yet proven [6].

3. Methodology

Fractures can be mapped using satellite and aerial photography [7]. However, there is no database representing these different fractures also, we will use remote sensing in order to spatialize lineaments thanks to the measurement of ground reflectance [8] [9]. The lineaments sought here are of sub-rectilinear form and can be the representation on the surface of geological structure (fault, fracture) resulting from brittle tectonics. However, the identification of these lineaments can be difficult because of the deposit of porous formations and plants that cover the rocky base and make the detection of fractures imprecise [10]. The methodology used will therefore include pre-processing operations, image processing, manual extraction of lineaments and validation of lineaments.

Fracture-density mapping is a crucial step in hydrogeological studies, especially when assessing groundwater potential in fractured rock terrains. A moving window is applied across the study area to calculate local fracture density. Common sizes range from 3×3 to 11×11 pixels, depending on the resolution of the input data and the scale of geological features. Larger windows smooth out local variations but may obscure small-scale fracture zones; smaller windows preserve detail but can introduce noise. Then, a Gaussian kernel is often used to weight the influence of fractures within the window, giving more importance to those near the center. Other kernels, like uniform (boxcar) or exponential decay, may be used depending on the spatial distribution of fractures and the modeling goals.

Fracture density values (e.g., number of fractures per unit area) are normalized and divided into classes: Low: Typically, below the 33rd percentile; Medium: Between the 33rd and 66th percentiles; High: Above the 66th percentile.

Fracture density is a proxy for groundwater movement and storage in hard rock terrains.

- Low Density → Low Potential
 - Fewer fractures mean limited pathways for water flow and storage.
 - Often corresponds to compact, unfractured rock.
- Medium Density → Moderate Potential
 - Indicates a balanced network of fractures that can support moderate groundwater flow.
 - May be suitable for small-scale water extraction.
- High Density → High Potential
 - Dense fracture networks enhance permeability and storage.
 - Ideal zones for groundwater recharge and extraction.

3.1. Image Processing

The image used is captured by Landsat 9. The scene LC09_L2SP_185057_20211222_20220121_02_T1_SR has been used in this study.

In order to overcome the problems caused by cloud cover, the image was taken in the dry season on December 21, 2022. Stacking or combination of image bands, the application of colorful compositions, as well as the mask, will be carried out for visualization.

The scene LC09_L1TP_2021_2022_02_T1 presents essential information contained in several bands; In order to bring out our linear structures, the bands that concern us here are the bands in the spectral domain: the visible (2, 3, 4), and those of the infrared (4, 6, 7). Stacking is the operation that will consist of combining these different bands into a single band.

The application of mask consists of merging a raster with a polygon that represents our area of interest, in a shapefile format, to finally have the only information of the image contained in the area considered

This technique consists in displaying stacked bands in the basic RGB channels (red, green, blue) in order to better distinguish the different structures.

The technique called “Pan-Sharpening” improves the image; it refers to the fact that most passive optical sensors of satellites have a “panchromatic” band that records data on the brightness in all visible strips and a spatial resolution higher than individual-colored bands. For example, the sensors of the Landsat 8 - 9 satellites have blue, green and red bands, all with a spatial resolution of 30 meters, and a panchromatic band which records blue and green light as well as red light, with a spatial resolution of 15 meters. For modern high-resolution sensors, the difference in spatial resolution is even larger, WorldView-2 with colored bands with a resolution of 2 meters and a panchromatic band with a resolution of 50 cm. Basically, we can therefore combine the color information of individual-colored bands with the spatial details of the panchromatic band; with this technique, we can reveal details (new data) where there is none in origins data.

3.2. Pre-Processing of the Landsat Image

The image processing operation will include the main component analysis (ACP) as well as filtering techniques in order to lift the veil on linear structures.

The main component analysis is a type of mathematics bands; it is a calculation involving a weighted sum of the soundtracks, which is similar to a point cloud and each point of the point cloud is a pixel of our image, which is represented according to its value in one band on the X axis and another band on the Y axis. Points with high values in a band tend to also have high values in the other band, and the majority of the distribution of points follows an imaginary line ranging from bottom left to top right of the chart.

The orientation of this imaginary line is called the first main component (PC1); But there is also an orthogonal variation (perpendicular) to PC1, which is the main component, PC2, but the PC1 component brings together most of the information. We use ACP to enhance the image while reducing information redundancies.

Image filtering is a modification of spatial frequencies (local contrasts) where the radiometric value of a pixel is transformed in relation to its neighbors. It is an

operation that uses the Convolution matrix for enhancing certain specific details of an image. The concept of convolution indicates an application that expresses a combination of gray tones of a pixel related to those of its neighbors. Filters are used mainly in order to remove noise (interference), intensify spatial frequencies, in this case, high frequencies such as lineaments, in order to make the themes or components of two or more themes contiguous for a good visual interpretation of the image. The Sobel filter highlights the strong reflectance transitions and high space frequencies generally associated with fractures [11]-[14]. The filters used in our work are the Laplacian to enhance the image and directional Sobel 7×7 filter in the aim of accentuating lithological and structural discontinuities; The latter was applied according to 4 directions, namely N-S, E-W, NE-SW, and NO-SE.

All of the lineaments observed here have been manually extracted in order to establish the lineament map of the Soa locality. These lineaments have the form of a line segment and will probably correspond to those linked to tectonics since the lineaments of anthropogenic origin (track, road, etc.) will be eliminated [15] [16]. However, in order to grant these lineaments a geological origin, a validation will be carried out on the basis of a reliable source like the geological map of Cameroon.

The objective of validation of lineaments is to transpose the results obtained, namely lineaments, to geological reality on ground using the geological map of Cameroon in order to qualify them as fractures. So, we will first eliminate the lineaments of anthropogenic origin, then we will compare our results with the different geological cards used in this work.

The spatial analysis of the lineaments will consist firstly in studying the direction of deformation of fractures, which will be measured using a compass rose. Then we will proceed to the distribution of water potential through an analysis of fractures density. The goal is to establish a water potential card in the Soa municipality.

The materials used were: the computer, which permits to download and process the image, Software such as Global Mapper, GIS data processing software (geographic information system), Erdas Imagine 2014, Argis 10.8, Geographic Information Software.

3.3. Data

The LC09_L2SP_185057 scenes of December 22, 2021, downloaded from the USGS site, are the image on which pre-processing of lineaments will be carried out. It is coded on 16 bits with a resolution of 30 m and is represented with the coordinate system degree, minute, second. It has 11 bands divided into two sensors: OLI-2 and TIRS-2. **Table 1** and **Table 2** present the characteristics of these different bands. However, based on this work, only the first 7 bands (2, 3, 4, 5, 6, 7, 8) are of interest. Hence, the digital field model of the zone will be added, which is very important in the geomorphological presentation of the study area as well as the extraction of its hydrographic network.

Table 1. Characteristics of OLI Landsat-9 sensor.

Spectral band	Wave length	Spatial resolution
Band 1: Aerosols	0.433 - 0.453 μm	30 m
Band 2: Bleu	0.450 - 0.515 μm	30 m
Band 3: Green	0.525 - 0.600 μm	30 m
Band 4: Red	0.630 - 0.680 μm	30 m
Band 5: Near Infrared	0.845 - 0.885 μm	30 m
Band 6: Mid-Infrared 1	1.560 - 1.660 μm	30 m
Band 7: Mid-Infrared 2	2.100 - 2.300 μm	30 m
Band 8: Panchromatic	0.500 - 0.680 μm	15 m
Band 9: Cirrus	1.360 - 1.390 μm	30 m

Table 2. Characteristics of TIRS Landsat-9 sensor.

Spectral band	Wave length	Spatial resolution
Band 10	10.30 - 11.30 μm	100 m
Band 11	11.50 - 12.50 μm	100

The geological map provides information on the geological formations that are encountered in the area as well as tectonic structures such as faults, fractures and veins if they present in the area. In this work, the documents N°NA 32NE-E22 from Yaoundé-E and N°NB 32SE-E29 of Douala-B for geological map recognition of Cameroon with scale: 1/500,000 drawn and published by the direction of mines and geology of Cameroon in 1952.

4. Results and Discussion

4.1. Results

All of the pre-processing operations applied to the data obtained in band led to the visualization of the image in two angles (**Figure 3**): the image of the infrared domain and that of the visible area. We observe on these two images very clear limits, formed by clear and dark areas, these are lineaments [2] [17]. These limits are within a color contrast that differs depending on whether you are in the visible area or in the infrared area. This color contrast is the result of the application of the real color compositions (2, 3, 1).

Figure 4 presents three images: that of the ACP in the infrared domain, the visible field and the ACP of the final image, respectively. These low-detail images are marked by the enhancement of major limits (formed by clear and dark areas), unlike the minor limits, which are less obvious.

Figure 5 shows the SOBEL 7X7 filter applied according to the E-W direction, as well as some lineament materialized from this filter. The lines or lineaments observed on this image are almost all enhanced while respecting the existing dom-

inance order at the start and these manually materialized lineaments are accentuated towards the NE-SW and N-S directions.

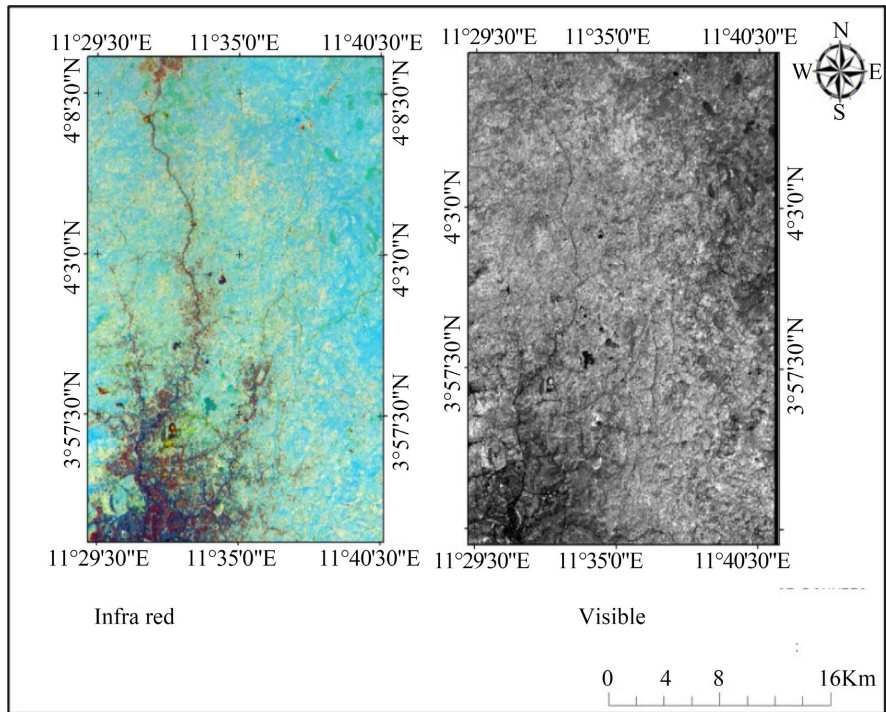


Figure 3. Raw image. Source: <https://earthexplorer.usgs.gov/>.

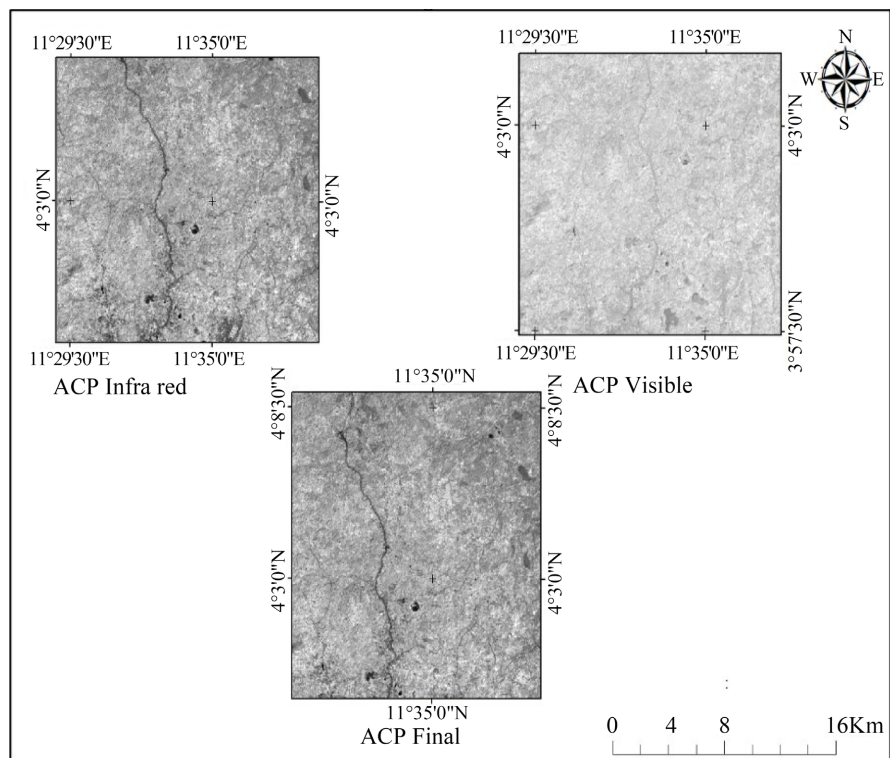


Figure 4. ACP fracture enhancement. Source: <https://earthexplorer.usgs.gov/>.

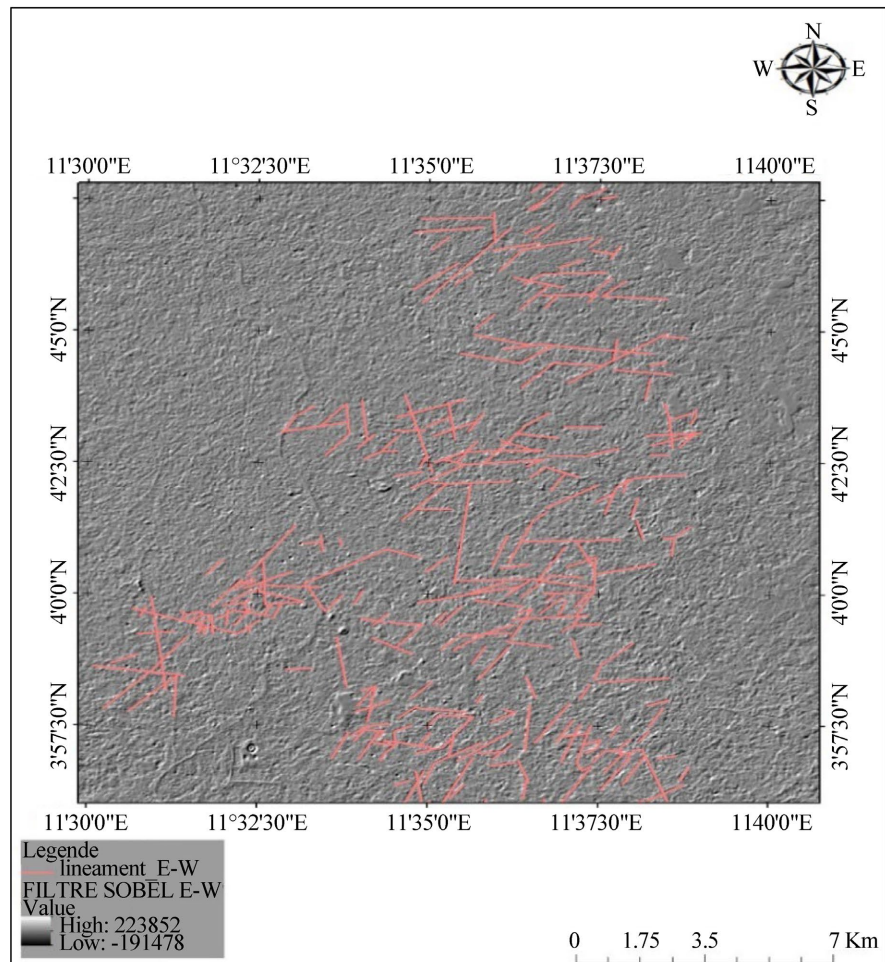


Figure 5. Sobel E-W filter. Source: <https://earthexplorer.usgs.gov/>.

The rectilinear and sub-rectilinear forms observed and digitized manually in each direction were considered to be lineaments. **Figure 6** presents the whole lineaments extracted from the image circumscribed by the administrative limit of the SOA municipality.

Figure 7(a) presents the fracturing map; the lineaments on this map represent a fracture network, resulting from the elimination of anthropogenic lines (track, road). These fractures obtained are estimated at 803 lineaments in kilometeric size between 0.09 km and 5.55 km. The total length of the mapped lineaments is 1010.03 km with an average length of 1.26 km. The largest number of lineaments have sizes between 0.09 km and 1.46 km. **Table 3** represents the distribution of these lineaments throughout the study area. The analysis of density of these fractures presents a distribution of the concentration of fractures in the studied area (**Figure 7(b)**).

The directional analysis of fractures is made thanks to the compass rose. It allows the visualization of the spatial organization of lineaments by highlighting the most represented directions (**Figure 8**). We have 18 classes of directions according to their orientations set out on the basis of angular growth of 10° as a preferential

direction, we observe three major fracturing directions provided by the directional rose diagram: ENE-WNW direction with total lineaments measured at 111.96 km, the ESE-WNW direction with 91.44 km of lineaments and the SE-NW direction with 85.84 km.

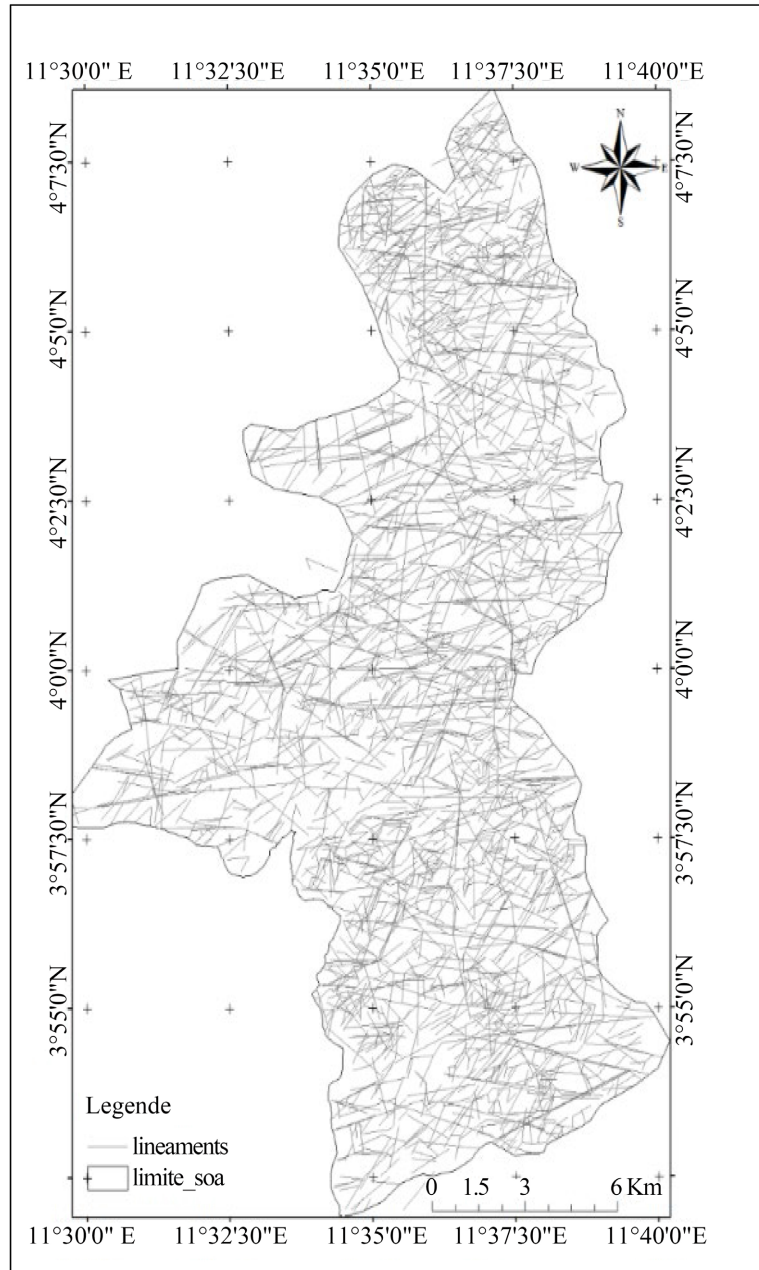


Figure 6. Lineament map. Source: <https://earthexplorer.usgs.gov/>.

The water potential prospecting map of the SOA municipality (**Figure 9**) gives us the distribution of the water resource within the said municipality. This map is obtained by superimposing the fracture map, the hydrographic network map, the density map, as well as the localities contained in the study area.

Table 3. Lineaments distribution.

Class in km	[0.09; 1.46[[1.46; 2.82[[2.82; 4.19[[4.19; 5.55[Total
No. of lineaments	560	188	44	11	803
Percentage (%)	69.7	23.4	5.5	1.4	100

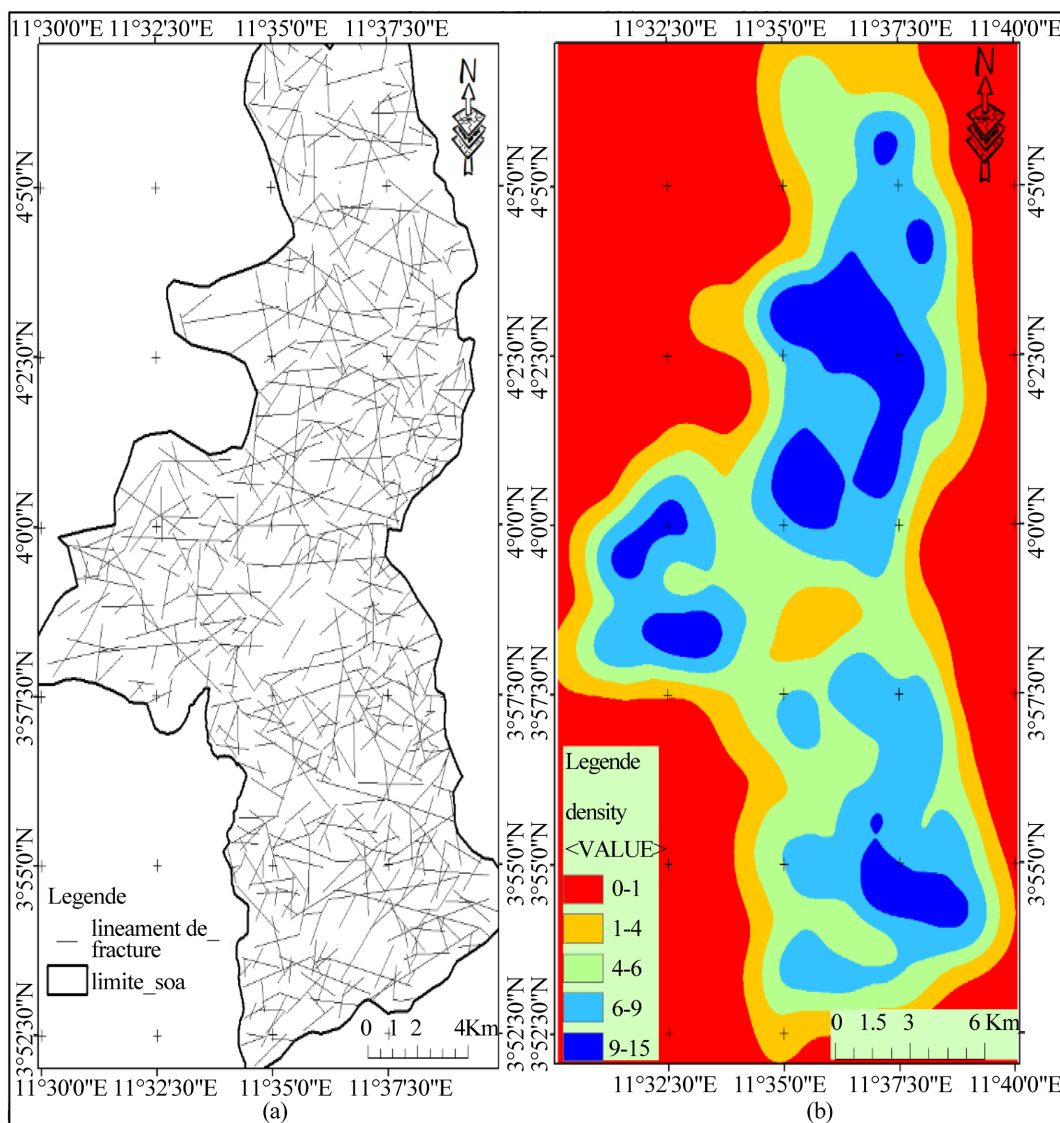


Figure 7. (a) Fractured map; (b) Fracture density map. Source: <https://earthexplorer.usgs.gov/>.

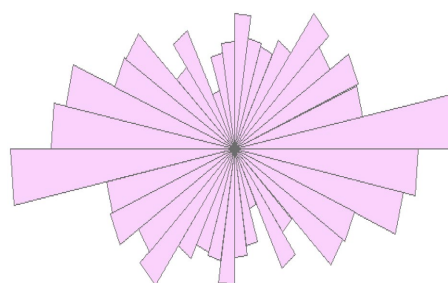


Figure 8. Directional rose diagram of lineaments.

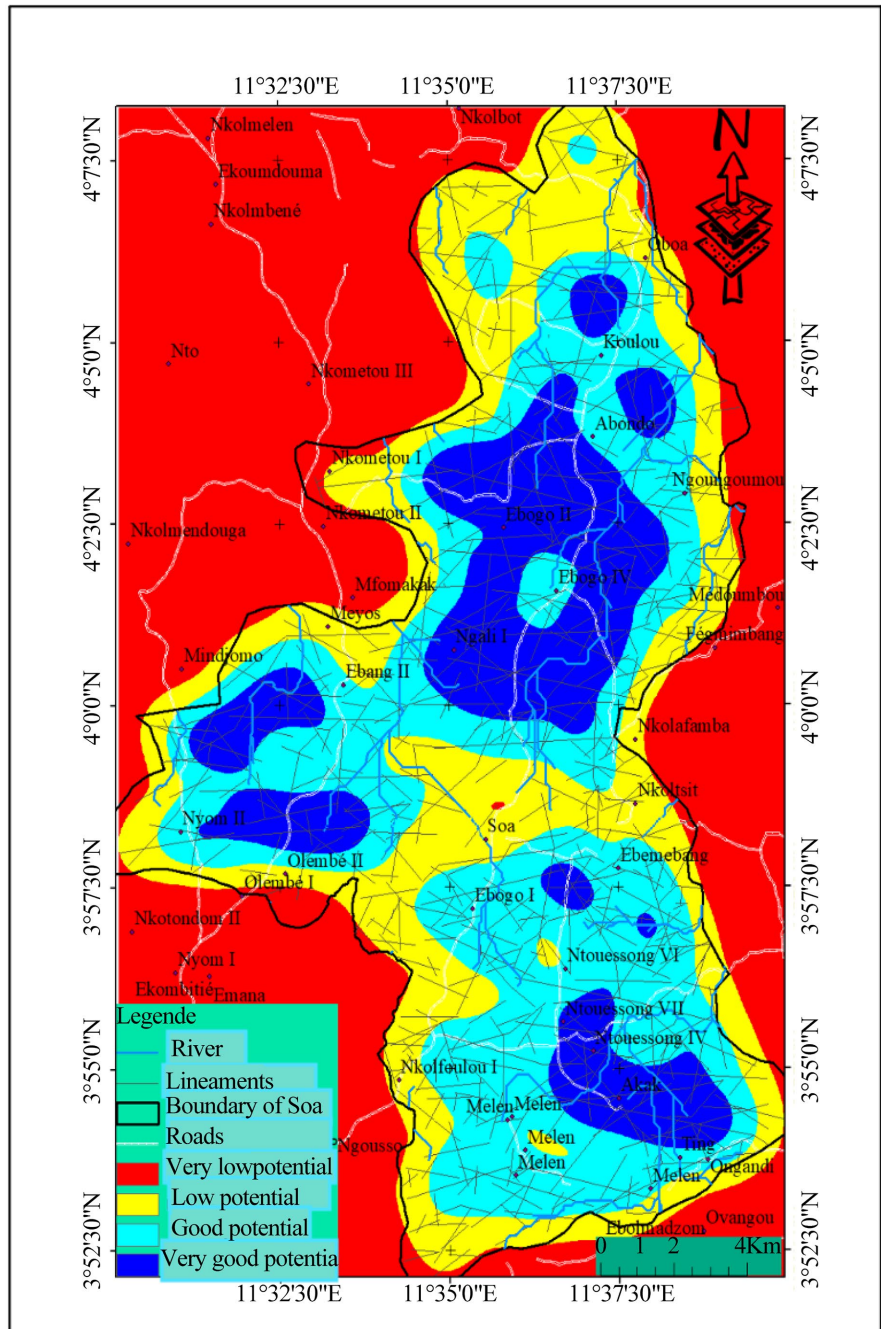


Figure 9. Prospecting map of water potential. Source: <https://earthexplorer.usgs.gov/>.

4.2. Discussion

The discontinuities obtained on the image from the Stack of bands of two spectral areas, that is, that of the visible area, and that of the infrared, make it possible to visualize and identify the lineaments as indicated by the work of Kouamé *et al.* (1999), Ta *et al.* (2008), N’go *et al.* (2010), Koita *et al.* (2010) [17]-[20]. Hence, the discontinuities shown here are in the form of a very clear limit, formed by clear and dark areas, which is similar to the lineament described by Ta *et al.* (2008) [17].

The application of colorful compositions on the image makes the lineaments presupposed, as shown by Dickens *et al.* (2021) and N'go *et al.* (2010) [19] [21]. The enhancement of the main fracturing (hydrographic network) is explained by the function of the ACP, which is to reduce information redundancies, thus the essential information and the results obtained are in perfect agreement with the selective ACP procedure proposed by Ta *et al.* (2008) [17]. The distribution of lineaments in Soa area demonstrates that the lineaments decrease in number when their sizes increase and more than 60% of the lineaments have a size between 0.09 km and 1.46 km. Lineaments of smaller sizes could be qualified as secondary lineaments hence, their role is very important in the circulation of groundwater. These lineaments play role of interconnection between the main fractures [22] existing in the area. Localities like Soa and Nkolofoulou I, have low water potential, unlike locality of Akak. This can be explained by the low fracturing density in these localities and also the fact that the digital field model of the study area presents less data of the hydrographic network. The observed areas with good hydrogeological potential highlight major linear discontinuities that perfectly overlapped with the hydrographic network. This leads us to consolidate the idea that in basement zones, the hydrographic network is part of the fracture network [18].

5. Conclusions

The objective of this work was to characterize the lineaments of Soa municipality thanks to the contribution of remote sensing and GIS in order to provide a modest solution to the problem of having access to drinking water in this area, hence making a contribution to the knowledge of the structural lineaments of the Soa municipality.

Remote sensing makes it possible to map the lineaments and to establish a groundwater prospecting map through the visualization of images from Landsat 9, thanks to the pre-processing operations, through the application of the colorful compositions, as well as the identification of a linear structure.

The results obtained as a result of the various remote sensing stages are characterized by the presence of discontinuity represented by the net limit formed by dark and clear zones (Figure 3). These limits throughout this work will be specified as follows: First of all, by the enhancement ACP (Figure 4) on which the major lineaments appear, and then by the lineaments shown by 4 directional filters of the Sobel 7×7 , including the 3 Sobel E-W filter (Figure 5).

The map of lineaments (Figure 6) is the result that highlights all the lineaments observed and extracted. It is the basis for bringing out the fracturing map (Figure 7(a)), which highlights fractures resulting from the validation method. The densification of fractures will give us the density map, which highlights the level of soil fracturing (Figure 7(b)).

The analysis of the spatial and directional fracturing map reveals that in the Soa municipality, 11 major fractures have sizes between 4.19 and 5.55 km in length and 560 fractures of minor size have lengths between 0.09 and 1.46 km. From a tectonic

point of view, preferential fracture directions on the fracturing map are ENE-WSW, ESE-WNW and SE-NW with a total length of the lineaments estimated at 111.96 km, 91.44 km and 85.44 km.

The water potential map of the study area (**Figure 9**) shows potentials that vary according to the areas, hence localities like SOA and Nkoulfoulou I are potentially poor in groundwater, while locality of Akak is potentially rich in groundwater.

The map mentioned above, coupled with productive drilling data, would have had the effect of validating the results and defining new drilling sites. Unfortunately, drilling data were unavailable. However, we consider the results obtained as being reliable with respect to the methodology used. Also, as perspective, the following methods can be used for validation; in particular, the geophysical method and the structural method, the use of technical drilling sheets, which are of major importance in the knowledge of the hydrodynamic behavior of aquifers.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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