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RESEARCH ARTICLE

CONTRIBUTION OF SATELLITE IMAGERY TO THE MAPPING OF POTENTIALLY WATER-BEARING FRACTURE NETWORKS IN THE COMMUNE OF TANGHIN DASSOURI (CENTRAL BURKINA FASO)

Hassami Ouédraogo[1], Césard Millogo[1-2*], Sayoba Kafando[1] and Samuel Nakolendoussé[2]

[1]Laboratoire Géosciences et Environnement (LaGE), Département des Sciences de la Terre, Université Joseph KI-ZERBO, Ouagadougou; [2]Unité de Formation et de Recherche en Sciences Appliquées et Technologies, Université Daniel OUEZZIN-COULIBALY, BP 139, Dédougou, Burkina Faso; Burkina Faso

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**Corresponding author:*
Césard Millogo

ABSTRACT

The groundwater resources of crystalline bedrock regions are primarily located within lithostructural discontinuities. While traditional methods of photo-interpretation of satellite imagery are widely employed, they are often constrained by factors such as cloud cover, dense vegetation, and the subjectivity of the interpreter. To mitigate these biases, an automated approach employing the PCI LINE module of PCI Geomatica has been adopted to extract lineaments from Landsat-7 ETM+ imagery, aiming to enhance the reliability of fracture network mapping. The study area, which encompasses the municipality of Tanghin Dassouri, is situated in the central region of Burkina Faso and is dominated by granitoids. It is traversed by a complex network of tectonic structures (faults and shear zones) that may facilitate the presence of groundwater reservoirs. The automated extraction of lineaments has identified a total of 427 fractures, with lengths ranging from 16 meters to 4814 meters, and has revealed three primary directional classes: NW-SE, N-E, and E-W, corresponding to major orogenic phases. These findings were validated by electrical resistivity profiles, which confirmed the presence of conductive structures interpreted as shear zones, likely to contain groundwater. The results of this study indicate that remote sensing, when combined with automated lineament extraction and field verification, is an effective tool for identifying aquifer fractures and optimizing the location of high-yield boreholes in crystalline areas. The integration of these techniques can significantly improve groundwater resource management strategies in the Tanghin Dassouri region and beyond.

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INTRODUCTION

Remote sensing, with its synoptic view, allows for the study of vast geographical areas and serves as a powerful tool for the analysis of fracturing (N'guessan et al., 2015). In the crystalline basement, the primary groundwater resources are located within rock fractures. Previous research efforts, particularly those focused on high-flow drilling, have primarily concentrated on the mapping of lineaments for enhanced hydrogeological exploration. These studies typically follow a standard methodology, primarily based on optical satellite imagery from Landsat's TM/ETM+ sensors, which allows for lineament extraction via photointerpretation (Savadogo, 1984; Nakolendoussé, 1991; Koussoubé, 2003; Yaméogo, 2008; Yao, Grobla et al., 2011; Otchoumou et al., 2013; Millogo, 2019; Kafando, 2020). Although these optical images facilitate the characterization of the soil surface condition, they do not always provide optimal observation of lineament structures in tropical environments due to cloud cover and the pedo-vegetal layer.

These studies, all based on visual interpretation and manual lineament mapping, are heavily dependent on the analyst, with results varying according to the analyst's experience, skill, and the scale of the studied dataset. To mitigate the biases inherent in photointerpretation, an automatic approach can be adopted to enhance the reliability of the lineament network extracted from images (Yao et al., 2011; Sedrette and Rebaï, 2016; Christian et al., 2019; Louaya and Mohamed, 2024). This processing method reduces subjectivity and the time required for visual image analysis, the results of which are rarely reproducible in identical terms. Several algorithms have thus been developed for the automatic extraction of lineaments using satellite imagery. This study is based on the hypothesis that the automatic extraction of lineaments using the PCI LINE module applied to Landsat-7's optical ETM+ imagery can effectively map and characterize fracture networks conducive to high-flow drilling operations. For this purpose, we have selected the commune of Tanghin Dassouri as the case study area.

The results obtained will provide invaluable insights for practitioners in optimizing the mobilization of groundwater resources.

PHYSICAL AND GEOLOGICAL CHARACTERISTICS OF THE TANGHIN DASSOURI MUNICIPALITY: The rural municipality of Tanghin Dassouri is located in the central region of Burkina Faso, covering an area of 315.5 km². It is accessible from Ouagadougou via National Road N°1. The municipality consists of thirty-one (31) villages and is bordered to the North, South, East, and West by the municipalities of Pabré and Sourgoubila; Komki-Ipala; Ouagadougou; and Bingo and Kokologho, respectively. The climate is classified as Sudanese-Sahelian, characterized by the alternation of two (02) highly contrasting seasons: a dry season from November to May, during which the area is subject to the continental trade wind or harmattan, and a rainy season from June to October. Regarding temperature, the highest values are observed in April-May (43°C), and the lowest in December-January (18°C) (Bonssara et al., 2023). The annual rainfall in the municipality varies in terms of the total amount of precipitation, with the average annual rainfall being 862 mm. Tanghin Dassouri is located in the northern Sudanian phytogeographical zone, which is the most intensively cultivated area in Burkina Faso due to the high demographic pressure (Millogo and Guinko, 1996). This zone is highly anthropized, with the savanna often presenting an agricultural landscape (Guinko, 1984), dominated by large trees belonging to protected agroforestry species. Numerous temporary streams cross the municipality. These watercourses direct water to other regions, and their waters infiltrate rapidly, forcing the population to rely on underground sources (Figure 1). The geology is essentially dominated by granitoids, which occupy most of the study area (Kafando, 2020). These granitoids can be divided into two main groups: Late granitoids, which are the most representative formations and occupy almost all of the study area. Early granitoids, in the form of large windows and inclusions within the late granitoids. These formations are made up of granodiorite, tonalite and quartz diorite. The commune of Tanghin Dassouri is located in the western part of the Ouagadougou sheet and is essentially made up of porphyroid granites, quartz diorites and granite. The commune is criss-crossed by a network of tectonic megastructures (faults, shears), which in places could favour the development of major groundwater reservoirs (Figure 2). The use of satellite data and electrical geophysical data could help to highlight the fracturing network in the Tanghin Dassouri commune.

DATA AND METHODS

Data and processing tools: Before fieldwork, a preparatory phase is necessary, which involves reviewing the existing bibliography and databases. The data used for lineament extraction are derived from orthorectified satellite images, consisting of two ETM+ scenes from Landsat-7 (Path 195, Row 051 on 16/12/2009 at 08:52:28, and Path 195, Row 052 on 29/01/2010 at 09:25:56), covering the entire square degree of Ouagadougou. The choice of these data is driven by their significance as a source of important geological information. Landsat-7 is equipped with the ETM+ (Enhanced Thematic Mapper Plus) multispectral sensor, which records the reflectance of the Earth's surface across seven (07) spectral bands, including four (04) (TM 1, 2, 3, 4) in the Visible and Near Infrared, two (02) (TM 5, 6) in the Mid Infrared, one (TM 7) in the Thermal Infrared, and one band (TM 8) in Panchromatic mode. The spatial resolution of the TM sensor is 30 m for all bands, except for the thermal infrared, which has a resolution of 120 m. The following software tools were used: PCI Geomatica software, with its LINE module, for the automatic extraction of lineaments; and ArcGIS software for extracting statistical parameters of the lineaments (number and length), and for creating directional rose diagrams with angular fractions of 10 degrees.

PCI LINE algorithm: Lineament extraction using the PCI LINE algorithm is performed on a single spectral band and generates polylines and segments based on six (06) parameters (Table 1): RADI (Radius of filter in pixels), GTHR (Threshold for edge gradient), LTHR (Threshold for curve length), FTHR (Threshold for line fitting error), ATHR (Threshold for angular difference), and DTHR (Threshold for linking distance). This procedure, based on the Canny algorithm, consists of three steps (Sedrette and Rebaï, 2016). The first step involves edge detection, which removes image noise by applying a Gaussian filter whose kernel is defined by the RADI parameter. The second step consists of thresholding to obtain a binary image, with the threshold value determined by the GTHR parameter. The third step involves curve extraction, subdivided into three phases: (1) enhancement is applied to the binary image to produce skeletal curves, with curves shorter than the LTHR parameter value being eliminated during processing; (2) the extracted pixel curve is converted to vector format by adjusting segment pieces, and the resulting polylines approximate the original pixel curve, with the fitting error (distance between the two) specified by the FTHR parameter; (3) finally, the algorithm links pairs of polylines that satisfy the ATHR and DTHR parameters.

Satellite image processing methodology: The preliminary phase of processing the orthorectified satellite images involved, prior to mosaicking the two ETM+ scenes, dynamic contrast stretching and histogram equalization of the scenes with highly differing contrasts due to the acquisition dates. This also included resampling the ETM+ images to a 30 m resolution. After enhancing the ETM+ images using the ENVI software, the images were exported to PCI Geomatica for lineament extraction. The parameters of the LINE module were set to optimize the automatic extraction of lineaments in the basement zone (Christian et al., 2019). For our study area in the Tanghin Dassouri municipality, the size of the Gaussian filter, represented by RADI, was set to 20 pixels to accentuate image discontinuities, and the GTHR was set to 90 pixels to obtain the binary image. The pixel curves (lineaments) were extracted from the binary contour image and converted into vector format with the following connectivity criteria: LTHR = 1.5 km (pixels), FTHR = 10 pixels (0.3 km), ATHR = 15°, and DTHR = 100 pixels (3 km) to account for the continuous nature of the lineaments. It should be noted that a lineament control phase was carried out after the extraction. This phase involved displaying artificial or anthropogenic linear structures (railways, roads, tracks, telephone lines, parks, etc.), which were previously vectorized to avoid their inclusion, and eliminating these structures from the map obtained through automatic extraction via simple overlay. This preliminary structural map was then overlaid with other existing maps, as well as Google Earth, followed by the removal of non-geological lineaments to finally generate the final lineament map of Tanghin Dassouri municipality.

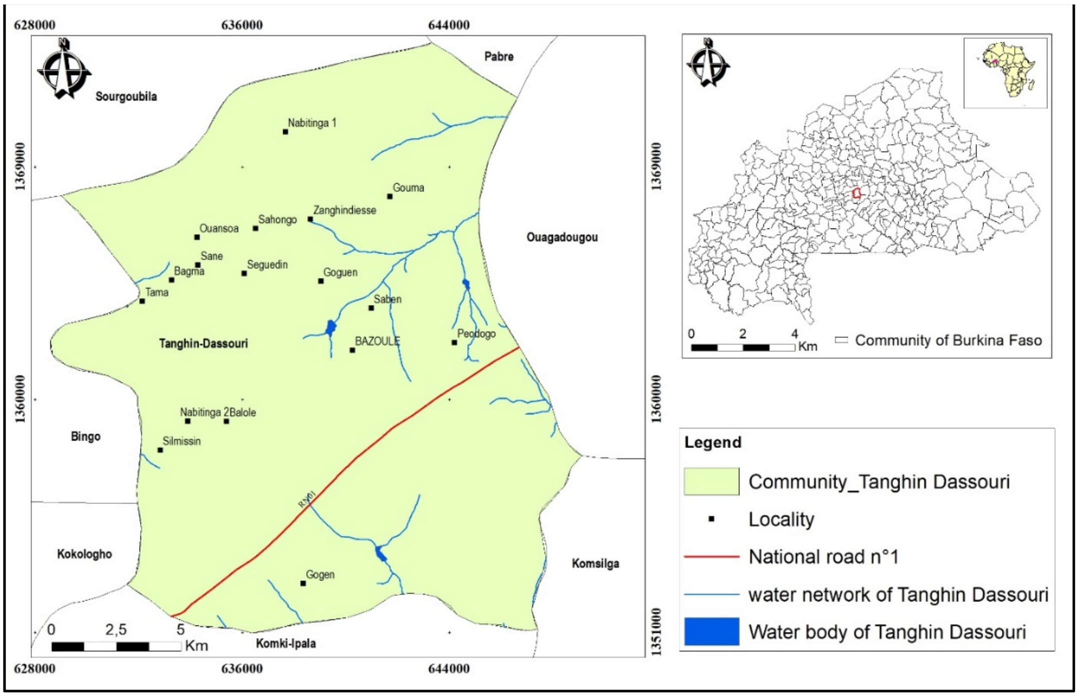

Figure 1. Location map of Tanghin-Dassouri municipality

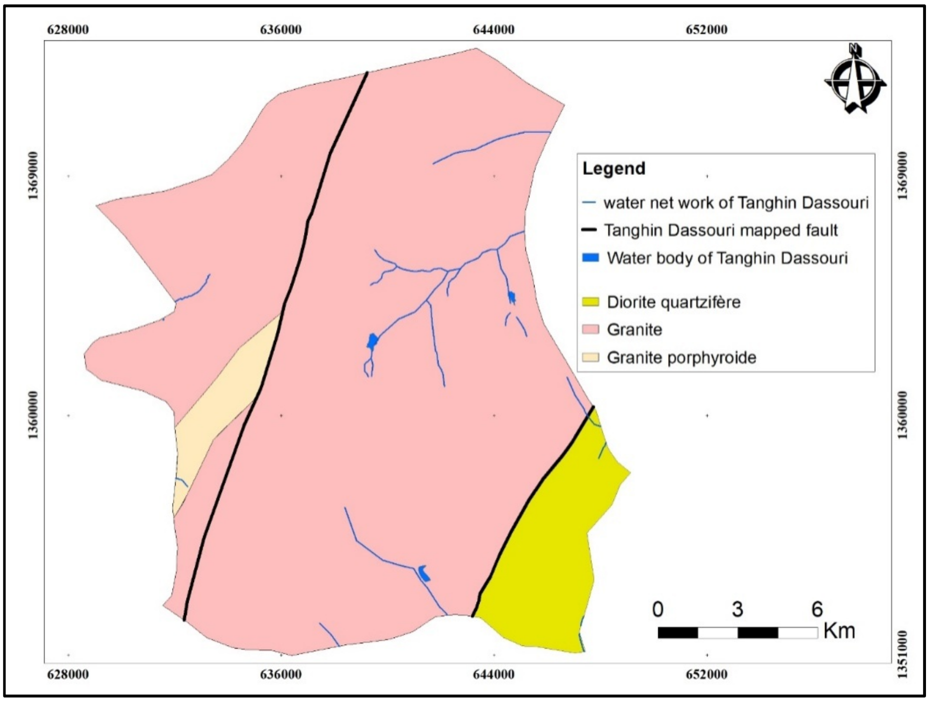

Figure 2. Geological map of Tanghin-Dassouri municipality

Table 1. Description of PCI LINE module parameters

Name	Description	Procedure
RADI	Gaussianfilter size	Specifies the size of the Gaussian filter window used for edge detection. A high value meansfewerdetailscanbedetected.
GTHR	Edge gradient threshold	Indicates the minimum gradient threshold value for an edge pixel, in order to generate a binary image.
LTHR	Lengththreshold	Specifies the minimum length in pixels for lineaments.
FTHR	Fittingthreshold	Specifies the maximum error in pixels between a polyline and a curve. A low value ensures better fitting but produces more polylines.
ATHR	Angularthreshold	Specifies the maximum angle in degrees between a segment and a polyline to differentiate a segment from a polyline.
DTHR	Spacingthreshold	Specifies the minimum distance in pixels between two endpoint points of a segment that can be linked.

RESULTS

Fracture network map of Tanghin Dassouri municipality

The lineament map was created following the structural interpretation (detection and digitization of structures) of the images processed through various techniques. Upon completing the processing phase, the extracted lineaments enabled the creation of a new and much more detailed structural map of the Tanghin Dassouri municipality, which includes a total of 427 lineaments (Figure 3). The lineament map serves as the map of the underlying fractures, devoid of superficial artifacts unrelated to geological discontinuities.

Fracture distribution by length class and angle: The minimum lineament length being 16 meters and the maximum length reaching 4814 meters. The lengths of the 427 mapped lineaments are grouped into 5 classes. The main class, comprising 63.93%, includes fractures with lengths between 1000 and 2000 meters, followed by a class of 25.29% of fractures with lengths ranging from 16 meters to 1000 meters. A smaller class, representing 9.60%, includes fractures with lengths between 2000 meters and 3000 meters, and finally, two minor classes, accounting for 0.70% and 0.47%, correspond to fractures with lengths exceeding 3 and 4 kilometers, respectively (Figure 4).

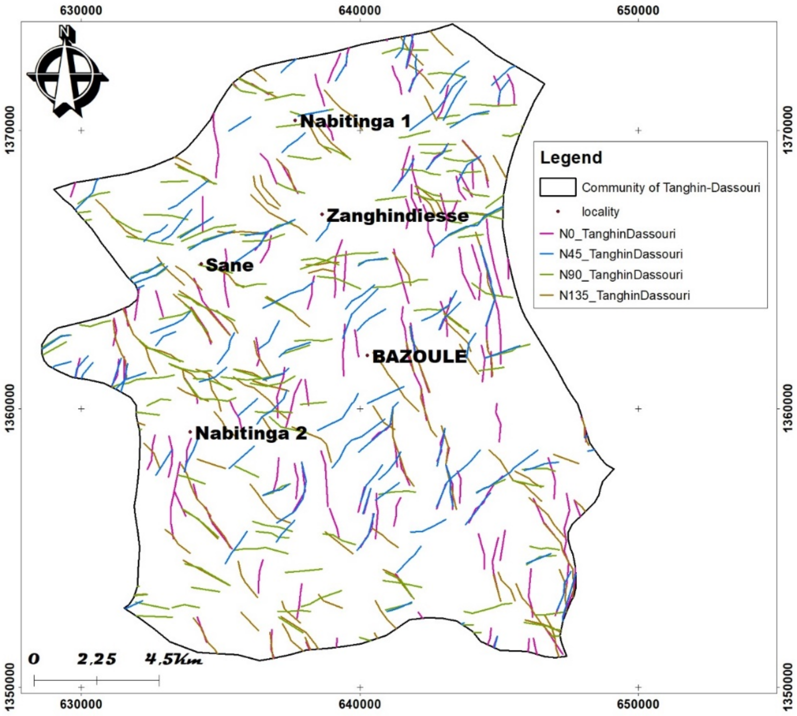

Figure 3. Lineament map of Tanghin-Dassouri municipality

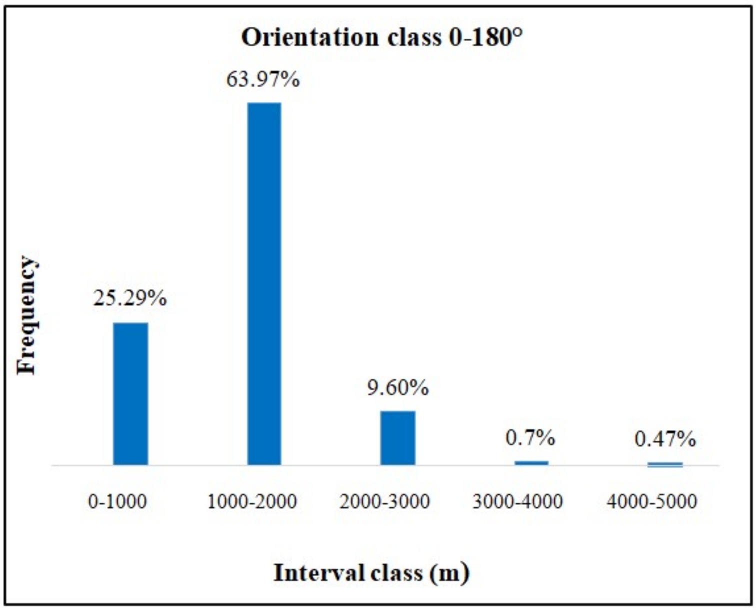

Figure 4. Distribution of lineament lengths by orientation class with 10° intervals

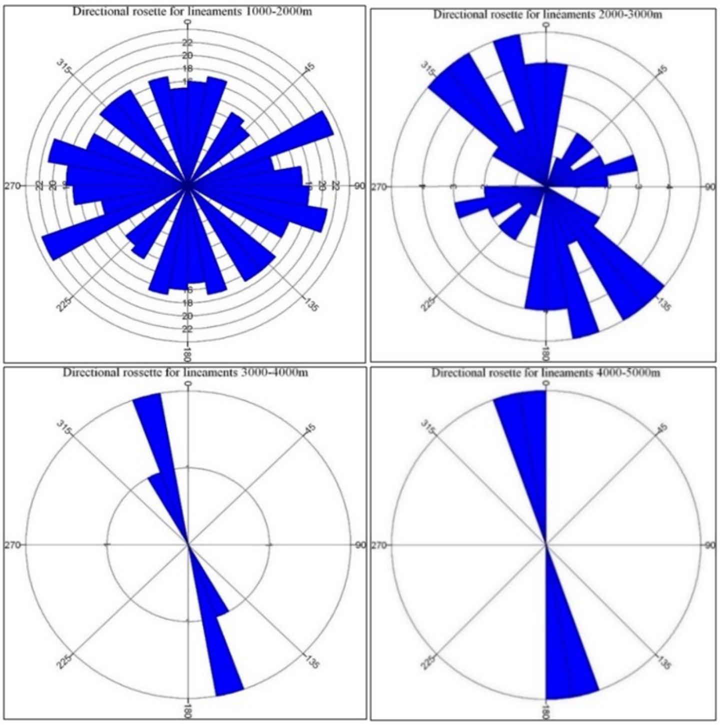

Figure 5. Distribution of lineament angles by orientation class with 10° intervals

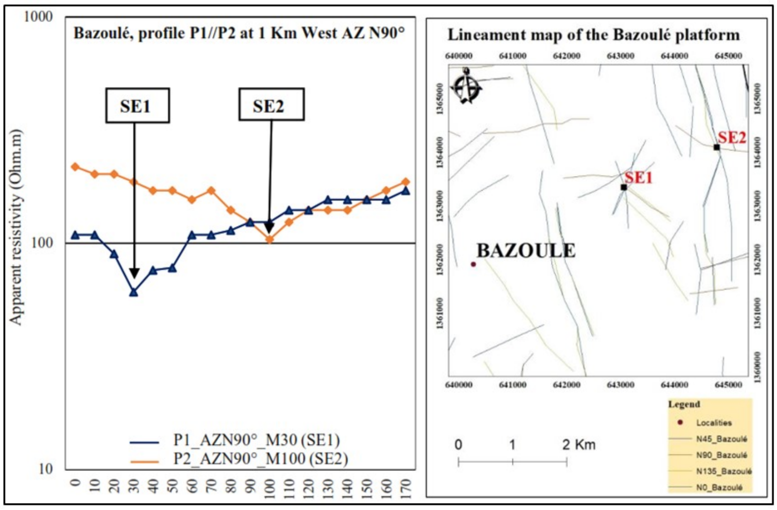

Figure 6. Electrical resistivity profiles on the Bazoulé platform

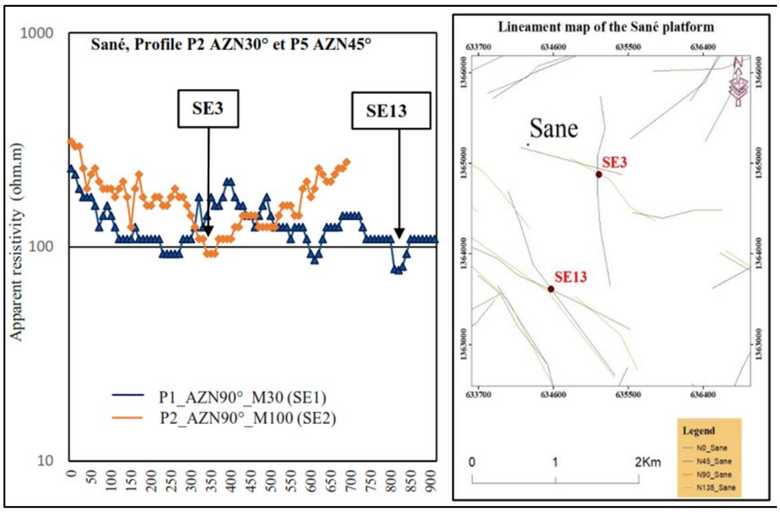

Figure 7. Electrical resistivity profiles on the Sané platform

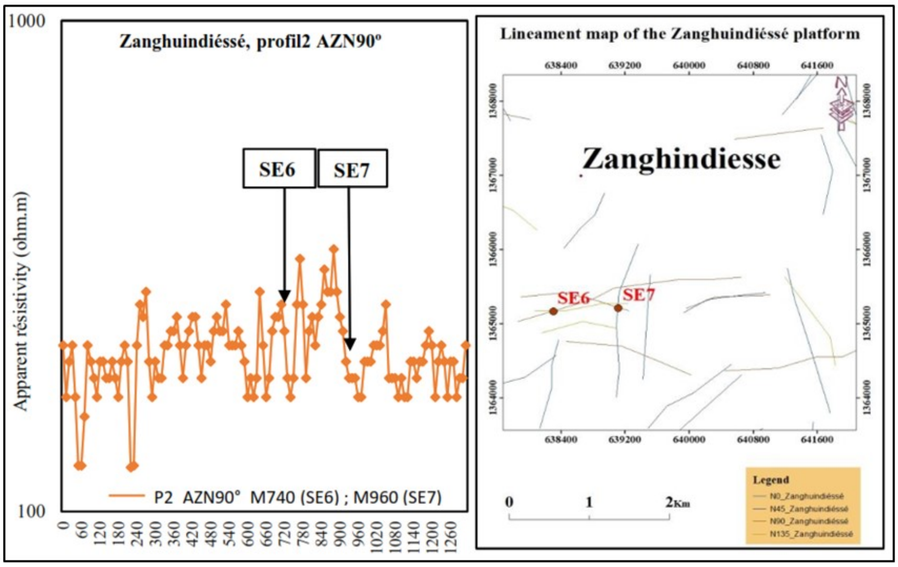

Figure 8. Electrical Resistivity Profiles on the Zanghuindiéssé Platform

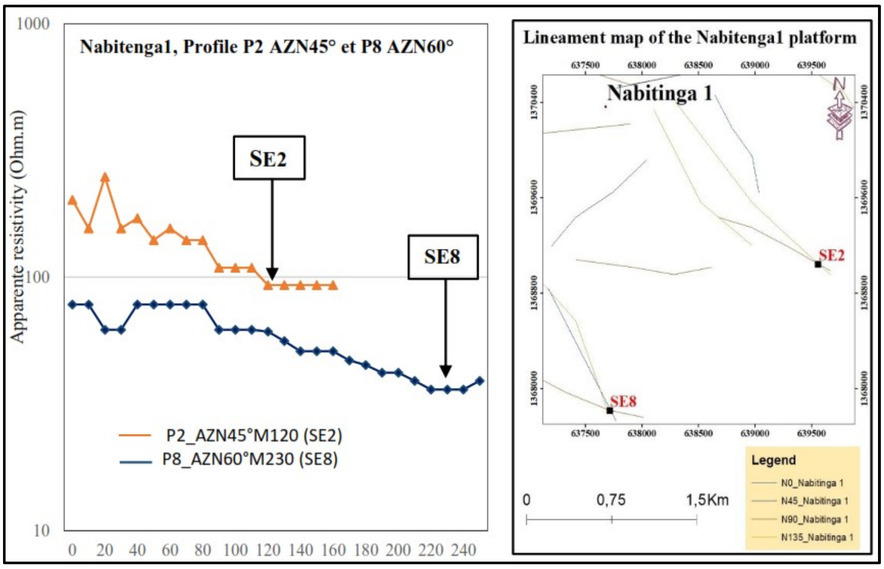

Figure 9. The electrical resistivity curves on the Nabitenga1 platform.

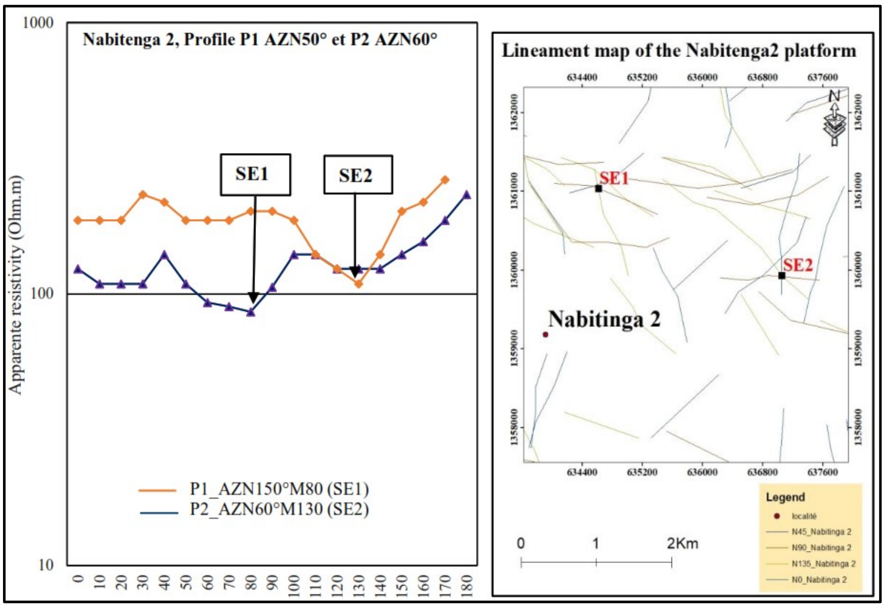

Figure 10. The electrical resistivity curves on the Nabitenga2 platform

The objective of this classification is to highlight fractures with a minimum length of 3 kilometers. One of the specific conditions for achieving a high-flow borehole in basement areas is to locate it on a mega-fracture at least 3 kilometers long (Nakolendoussé, 1991). However, it is observed that a significant number of these fractures (63.93%) fall into the 1 to 2 km class. Therefore, four fracture length classes (1 to 2 km, 2 to 3 km, 3 to 4 km, and 4 to 5 km) were selected for directional analysis. Among all the lineaments in the 1000 to 2000 meters class, the general orientation trends are NE-SW and NW-SE. The most represented orientation classes are N70-80° and N100-110°. The majority of lineaments in the 2000 to 3000 meters class are oriented at N120-150°, N160-170°, and N170-180°, with a slight tendency toward N30-40° and N50-60°. For lineaments with lengths between 3000 and 4000 meters, the orientations are predominantly in the N160-170° and N150-160° classes. For lineaments exceeding 4000 meters in length, these lineaments exhibit similar trends to those in the 3000 to 4000 meters class, but with a much stronger orientation towards N160-180°.

The analysis of these automatically extracted lineaments allowed us to identify three main directional classes: NW-SE (N120-130°; N130-140°; N140-150°; N160-170°), N-E (N0-10°; N20-30°; N30-40°; N40-50°; N50-60°), and E-W (N70-80°; N80-90°; N100-110°). Several secondary directional classes were also identified: NNE-SSW, NE-SW, WNW-ESE, and NW-SE (Figure 5). These directions are consistent with the two predominant orientations NE-SW and NNE-SSW associated with the major Eburnean orogenic phase (2150-2100 Ma) that affected all the geological formations in Burkina Faso (Castaing et al., 2003). Furthermore, field measurements carried out by (Yameogo,2008) on quartz and pegmatite vein injections at the Kanazoé outcrop (direction N150-160° and N180°) perfectly match those of the longest lineament class in Tanghin Dassouri (3000 to 5000 meters). Similarly, highlighted the N100°-N110° direction of doleritic dykes mapped in the Ouagadougou sheet, which is also confirmed in the class of lineaments between 1000 and 2000 meters (Kafando, 2020). This method ability, based on satellite image interpretation, to identify previously known fractures not only the largest ones validates our extraction technique. The lineament map of the commune shows a well-fractured region, with several lineament intersections confirmed and validated through simple electrical resistivity profiles during a field mission.

Verification of the presence of extracted lineaments via electrical resistivity profiles: This phase consisted of applying the electrical tracing method to five platforms (Bazoulé, Sané, Zanghuindiéssé, Nabitenga 1 and Nabitenga 2) in the Tanghin-Dassouri commune to confirm anomalous zones (faults, fracture nodes) identified using satellite imagery. These tracings were carried out essentially by following the three preferential directions of the lineaments extracted in the commune of Tanghin Dassouri (Figure 6,7,8,9 and 10). The electrical resistivity profiles P1M30/Bazoulé, P2M130/Silmissin, P5M820/Sané, and P8M230/Tang Longo, exhibiting U-shaped anomalies, as well as the profiles P2M350/Seguedin and P2M960/Ouasouan, which show H-shaped anomalies, highlight structures with highly variable conductivities within the Tanghin Dassouri region. A succession of resistive and conductive structures, which can be interpreted as shear zones, is observed.Within large conductive corridors (e.g., P1 AZ N150° at Nabitenga2, from 40 m to 100 m; P2 AZ N90° at Zanghuindiéssé, from 880 m to 1050 m), conductive anomalies of variable widths are found, with the largest anomalies likely corresponding to wider and potentially deeper fractures. Additionally, the shape of the resistivity curves from these electrical profiles suggests that the measurements were made within shear zones. These results are consistent with those reported by (Millogo et al.,2019), who indicated that the U-shaped anomaly provides the most reliable results across various geological contexts, followed by the H-shaped anomaly, which yields results significantly more satisfactory than those of the V-shaped anomaly. According to (Kouamé et al.,2018), the U, H, and V-shaped anomalies, from a geophysical standpoint, represent low-resistivity zones that can be attributed to fractures or fissures capable of serving as reservoirs for water in the crystalline basement. These field measurements confirm the presence of these sheared zones, identified through satellite imagery within the study area. The identified and confirmed fractures appear to be potential aquifers.

CONCLUSION

Remote sensing has proven to be an indispensable tool for mapping and characterizing lithostructural discontinuities in basement zones. The processing and analysis of satellite imagery data have enabled the detailed mapping of the fracture network, which serves as the primary pathway for groundwater circulation, and also facilitated the identification of the dominant directional classes: NW-SE, N-E, and E-W. These directions align with previous studies in the region. Through automatic lineament extraction, we were able to identify linear structures ranging from 16 m to 4814 m in length. In the field, those that intersect and form fracture nodes were detected and confirmed using simple electrical resistivity profiles. This process significantly contributes to the characterization of these potentially aquiferous fracture networks in Tanghin Dassouri and will enhance the techniques for locating high-yield wells in crystalline terrains.

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