GSC Advanced Research and Reviews

eISSN: 2582-4597 CODEN (USA): GARRC2

Cross Ref DOI: 10.30574/gscarr

Journal homepage: https://gsconlinepress.com/journals/gscarr/

(Research Article)

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Contribution of remote sensing and geophysics to optimize the location of boreholes in the basement zone: The case of the city of Abeche (CHAD)

Moustapha Dinard [1], Abderamane Hamit [2,*] and Mahamat Nour Abdallah [2]

[1] *Adam Barka University of Abeche, Faculty of Science and Technology, Department of Geology.*

[2] *University of N'Djamena, Faculty of Exact and Applied Sciences, Department of Geology.*

GSC Advanced Research and Reviews, 2021, 08(03), 146–159

Publication history: Received on 13 August; revised on 23 September 2021; accepted on 25 September 2021

Article DOI: https://doi.org/10.30574/gscarr.2021.8.3.0201

Abstract

The study area is one of the regions of Chad where the problem of access to water is still relevant. The present study, using electrical and remote sensing methods, aims to contribute to the identification of sites favorable to the implementation of hydraulic drilling by highlighting potentially aquiferous fractures. Indeed, the analysis of satellite images and geophysics have shown the potential of fractures in the search for water. The 2D imagery of the tomography allowed to reinforce the knowledge on the geological and structural structure of the basement in the region of the basement.

Keywords: Geophysics; Remote sensing; Satellite images; Aquifer; Abeche; Chad

1. Introduction

Some provinces in Chad, particularly in the basement areas, face a challenge, which is access to water. Abeche, the area studied in this study, is part of the large Ouaddaï massif, characterized by crystalline basement formations.

The main water resources in this area are rainwater and groundwater, marked by unfavorable climatic and meteorological conditions.

Part of the city of Abeche is served with drinking water by the Chadian Water Company, which has a daily production capacity of 5,000 m3. Initially planned for 20,000 inhabitants. Today, the city's population has grown and the need for water is felt in the three months (April, May and June) preceding the rainy season.

The essential of this resource is located in the cracks or fractures of the crystalline base but constitutes an unknown resource [1] and its exploitation is very difficult [2] which depends notably on these lithological, topographical, meteorological and structural characteristics.

Many hydraulic works (wells and boreholes) have been carried out in the altered basement in a traditional and sometimes risky way in the fractured basement leading to a failure of its realizations, either by drying up or by a very low flow rate inferior to 1m3.

Water prospecting in basement areas integrates several disciplines, techniques and methods and especially a good knowledge of the area to be studied. Many works in Central Africa [3], [4], [5] and West Africa [6], [7],[8], [9] have been conducted in the basement areas and have highlighted the relationships between remote sensing data, electrical

* Corresponding author: Abderamane Hamit

University of N'Djamena, Faculty of Exact and Applied Sciences, Department of Geology.

prospecting and geostatistics through well and borehole data, for a better knowledge of the productivity of fractured basement aquifers.

The objective of this study is to highlight the fractured network of the city of Abeche and to try to orient the aquifer zones and to try to understand their functioning.

1.1. Study setting and geological context

The study area is located in the Ouaddaï region, one of the country's 23 provinces. It is located in the Sahelian zone in the eastern part of Chad, on the border with Sudan, which marks the eastern limit of the Chadian basin.

It lies between 15° and 12° north latitude and between 19° and 23° east longitude. It covers an area of 29,940 square kilometers, making it the smallest of the regions in terms of area (Figure 1).

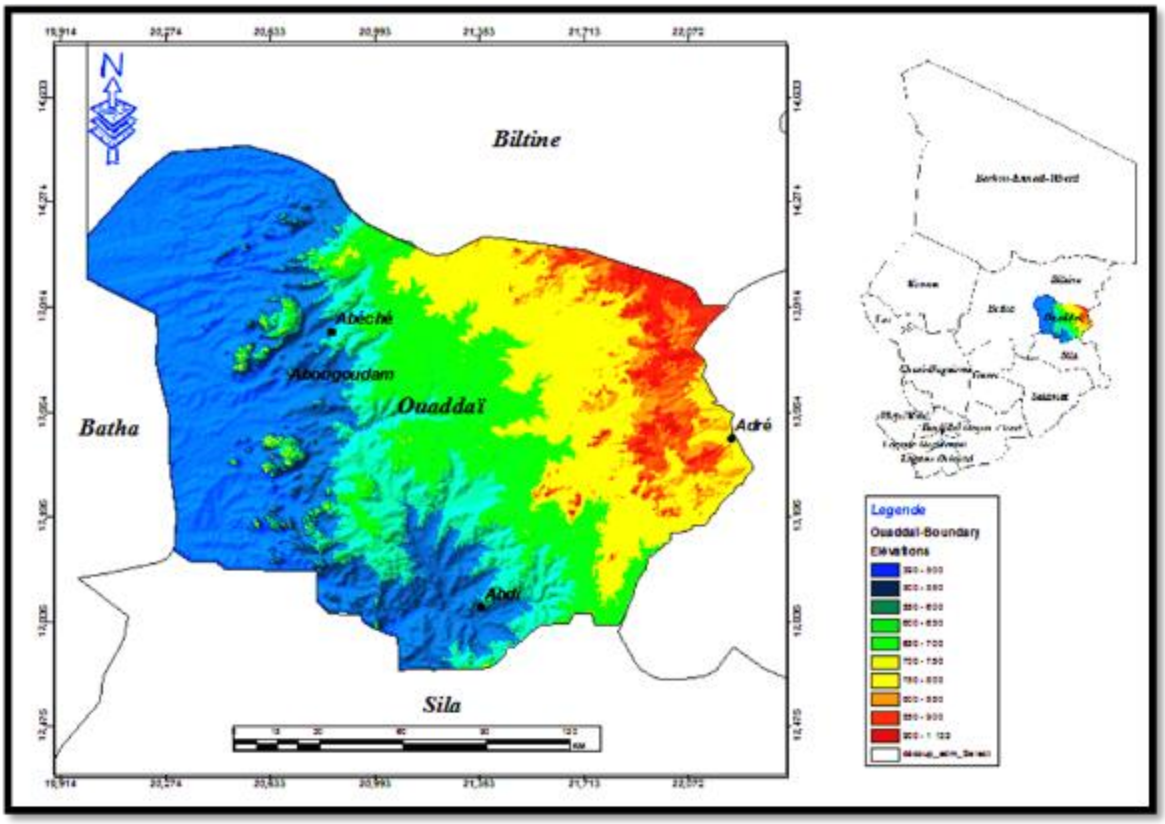

Figure 1 Representative map of Ouaddaï province

The climate is of the Sudano-Sahelian type, characterized by low rainfall, which varies between 200 and 600mm/year and the average temperature is 31°c. The aquifer formations of the region are mainly alluvial and basement, fed by rainfall, which run off through the mountains and other rugged terrain between the months of July and September.

The geological formations in the study area are part of the large granite formations of the Ouaddaï massif. Consisting, for the most part, of calc-alkaline granites [10].

The development of the vein systems corresponds to the two major tectonic phases that marked the region: the Pan-African (750 MA to 600 MA) and the Maastrichtian (70 MA to 65 MA). The structural context of the study area (Figure 2) is attributed to the Atlantic Rift (N45-65°) and the East African Rift (N115-135°).

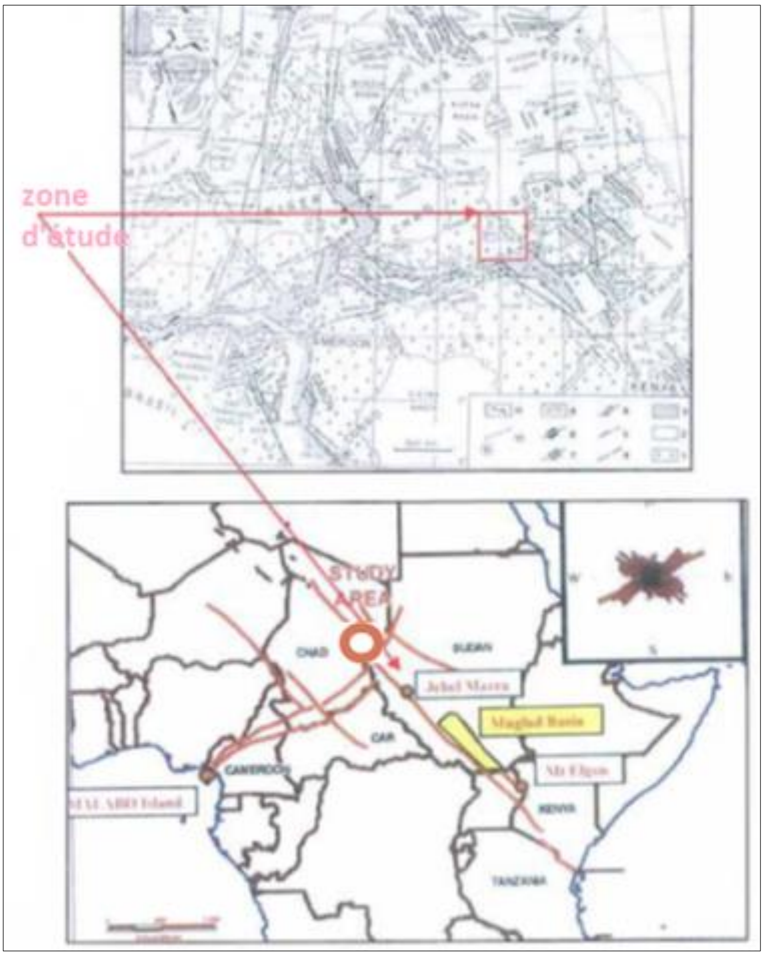

Figure 2 Map from the Final Report of the Village Water Project

2. Data And Materials Used

The approach that has been adopted in this project is that of automated and supervised processing, which consists in the use of mathematical algorithms by software ENVI, PCI Geomatia, ArcMap, Res2dinv, surfer, and ROCKWORKS in order to highlight some physical parameters likely to identify a productive aquifer in the study area which is a basement area.

This process consists in: processing satellite images and extracting lineaments, processing geophysical data and locating faults on 2D tomography images and finally compiling the different results with drilling data.

3. Characteristics of the data

Several types of data were used in this study; The remote sensing data, which are satellite images downloaded in raw form from the website: http://glovis.usgs.gov/, from the USGS (United State Geological Survey) in Geotiff form, come from the Landsat8 satellite, scene (181 - 50) and belong to the 34 North zone of the Universal Transverse Mercator map projection (UTM Zone 34) and use the WGS84 projection system.

The images are produced from the visible spectral bands (eight multi-spectral that have a resolution of 30 meters and a panchromatic band at 15m) and thermal 60m (band 10 and 11). Each spectral band, operating in a specific wavelength. The period (March 2021) of image acquisition is favored by the atmospheric conditions during the collection, which allow a good reading of different targets.

The materials used for the measurements of the geophysical data are :

- A complete geophysical apparatus of brand SYSCAL R1+ Switch 4

- A GPS
- a compass GARMIN
- Electrodes and electric cables
- A battery
- A laptop computer

Some data from boreholes drilled in the different districts of the city of Abeche and its surroundings by the ALME NADIF project and supplemented by those drilled by the HYDROTECH consultancy firm in the framework of the community project "More water for Abeche" of the Collectif Grande Source (CGS), have constituted a geostatistical database to evaluate the productivity of the aquifers.

4. Methodologies and data exploitation

The methods used call for an indirect approach where remote sensing and geophysics are addressed in this study to build a reasoning of synthesis in which the satellite image serves as a frame.

5. Mapping the fracture network using remote sensing

5.1. Correction Improvement of the visual quality of the image

The function of the pre-processing function is to improve the visual quality of the images to facilitate visual interpretation and analysis.

The pre-processing function applied to correct these data are the radiometric and geometric corrections. During the recording of the images by the sensors, they are subject to deformations caused by the curvature of the earth, the variation in altitude of the ground, atmospheric refraction, errors in the measurement systems and the movements of the platform [11]. It is therefore necessary to make a geometric correction to bring the image to a planimetric reality.

5.1.1. Analysis of the colored compositions

Each spectral band in LANDSAT images appears in shades of gray; it corresponds to a portion of the electromagnetic spectrum. To produce a colored composite image (natural color image), simply superimpose three spectral bands with red, green and blue (RGB) color filters. To obtain a colored compound contrasted and rich in information, it is also necessary to accentuate each spectral band by spreading the values on all the range of intensity of color available (gray tones), that is to say on 256 tons.

This enhancement does not modify the source data, i.e., the pixel values, it only allocates the available color palettes differently in order to facilitate the reading of certain elements in a much clearer manner. Some software (ENVI in our case) offer several types of contrast spread: linear, Gaussian, square root etc. ...

To do this we combined different bands in the basic channels (red, green and blue) to try to have a colored image that is much closer to the reality of the terrain studied. The combination of channels 654 is more or less close to this description.

5.1.2. Digital processing of Landsat 8 images

Several treatments have been applied to these images. These are mathematical operations allowing to highlight certain information. The combination obtained thanks to the ratios of the bands (6/4); (5/4) and (4/2) allowed to highlight some linear structure. The principal component analysis (PCA) performed on the images corresponding to the city of Abeche using the seven bands. It is a multispectral treatment that consists in separating the different information of these bands in order to remove all the redundant information and to group it on a new band called neo channels [12]. This reduces the number of strips to be handled later. The results of several studies [13],[14],[15],[16] have shown that generally the first three (3) bands resulting from the PCA concentrate the essential information (more than 95%) of the 7 bands.

These images thus generated, were used for the application of other types of processing in particular the high pass filter and the directional filter of Sobel of matrix dimension 7x7 in different directions N-S, E-W, NE-SW and NW-SE (table 1). These filters were used to enhance the linear structures. They were designed to highlight or mask specific features in an image based on their texture-related frequency [17]. The revealed discontinuities were automatically extracted using the PCI Geomatica software.

Table 1 Sobel 7x7 directional filter

Directional filter type Sobel N-S							Directional filter type Sobel E-W						
1	1	1	2	1	1	1	-1	-1	-1	0	1	1	1
1	1	2	3	2	1	1	-1	-1	-2	0	2	1	1
1	2	3	4	3	2	1	-1	-2	-3	0	3	2	1
0	0	0	0	0	0	0	-2	-3	-4	0	4	3	2
-1	-2	-3	-4	-3	-2	-1	-1	-2	-3	0	3	2	1
-1	-1	-2	-3	-2	-1	-1	-1	-1	-2	0	2	1	1
-1	-1	-1	-2	-1	-1	-1	-1	-1	-1	0	1	1	1
Directional filter type Sobel NE-SO							**Directional filter type Sobel NO-SE**						
0	1	1	1	1	1	2	-2	-1	-1	-1	-1	-1	0
-1	0	2	2	2	3	1	-1	-3	-2	-2	-2	0	1
-1	-2	0	3	4	2	1	-1	-2	-4	-3	0	2	1
-1	-2	-3	0	3	2	1	-1	-2	-3	0	3	2	1
-1	-2	-4	-3	0	2	1	-1	-2	0	3	4	2	1
-1	-3	-2	-2	-2	0	1	-1	0	2	2	2	3	1
-2	-1	-1	-1	-1	-1	0	0	1	1	1	1	1	2

5.2. Contribution of geophysics

In this study, we applied the electrical resistivity method, which is the most widely used in water prospecting, to determine drilling points in ten districts of the city of Abeche. We therefore carried out a series of profiles oriented perpendicular to the accidents detected by photointerpretation in order to validate and specify the anomaly. They generally show a conductive anomaly at the level of the accident, particularly in the case of a vertical or sub-vertical fracture. The study of the deformations of the anomaly can allow the determination of the dip, necessary data for the implantation of the drilling with the best chances of success.

In the case where the terrain is not very complex, we have carried out electrical soundings which have highlighted the variation in apparent resistivity of the subsoil as a function of depth, vertically from the measurement point. The interpretation leads to a good estimate of the thickness of the alteration and allows to detect the presence of the gritty arena - fissured fringe which constitutes the aquifer to be tapped. The shape of the curve is also a good indicator of the presence or not of altered or fissured rocks.

On the other hand, in the terrain considered complex by the electric trail, we applied the tomography which consists in injecting a direct current through a series of electrodes planted according to the Wenner device. The restitution by a software of the measurements acquired on the ground allows, after treatment, to determine according to a 2D section a profile of resistivity in depth. The interest of this method is to better know the distribution of the ground resistivities according to the vertical. The electrical panel thus generated gives an image of the geological layers, the passages and the dips of faults.

Two configurations are used in this study: (i) The Werner-Schlumberger which allows to set the superficial grounds (ii) The direct and reverse pole-dipole which allows to reach great depth of investigation.

6. Results

The image processing applied in this study is a set of techniques to improve an image or extract information. It is done with the help of more or less specialized software. The choice of processing techniques depends essentially on the objectives of the operator and the types of data at his disposal

- The approach used in this work, for the study of fracturing in Abeche, consists of combining remote sensing image processing techniques, geophysical techniques and a database of drillings carried out in the city. It is about :

6.1. The radiometric correction

This process aims to correct the imperfections related to the sensor. The objective was to eliminate radiometric noise to improve the reading of these images and to make it superimposable to other spatial data. We therefore applied radiometric and atmospheric corrections to the different bands to improve the contrast of the elements that constitute the 181-50 scene (Figure 3) corresponding to the area under study.

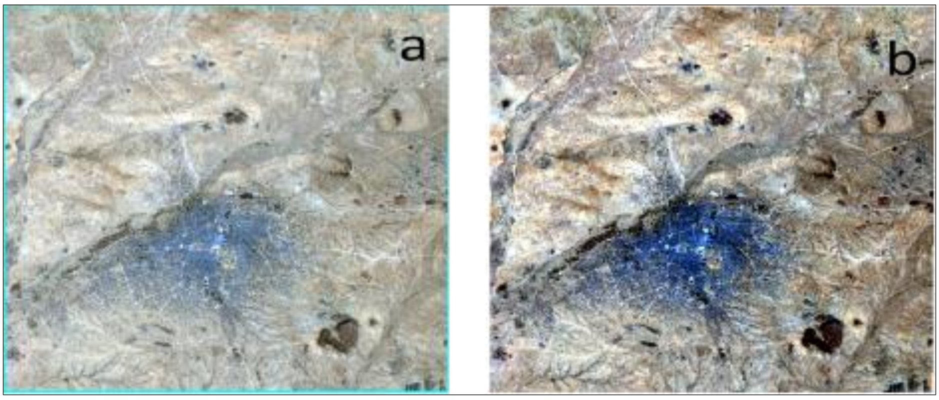

Figure 3 Landsat8 images a) raw b) corrected

6.2. Mapping the lineaments

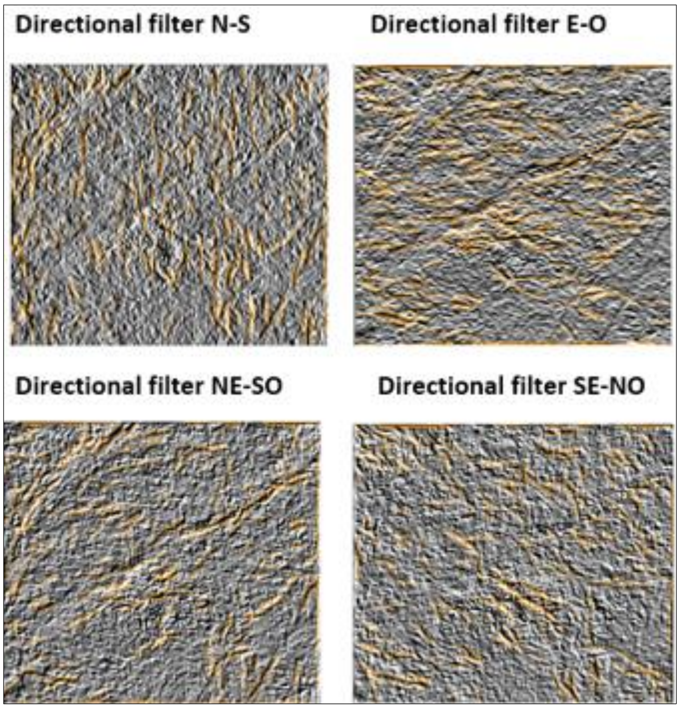

Figure 4 Lineaments superimposed on directional filters

The principal component analysis (PCA) allowed us to improve the contrast of the image corresponding to the study area, which led us to the identification of the lineaments by the directional filter of Sobel of dimension 7x7 by enhancing the lineament structures in different orientations (figure 4).

These filters were used to automatically extract the lineaments via Geomatica software and saved as a shapefile (SHP) and imported into ArcMap to overlay the different fracturing maps resulting from the directional filter. These images were then overlaid to create a thematic map of the lineaments in the city of Abeche (Figure 5).

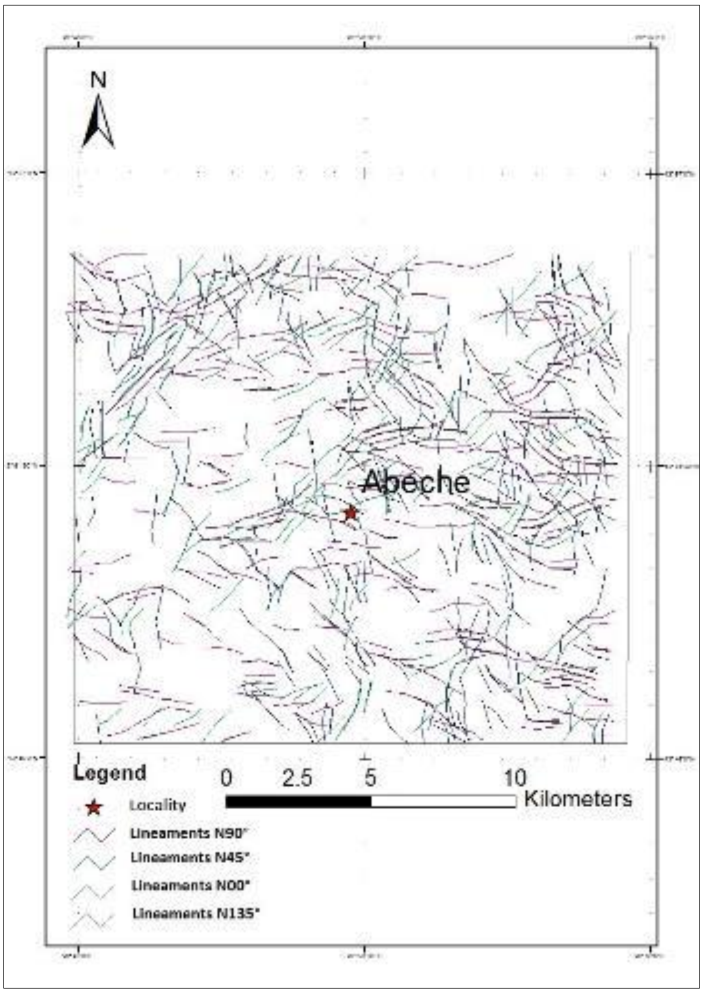

Figure 5 Linear map of the study area

6.3. Validation of the map

This is the most important phase, well done it could bring very precise information for future hydrogeological prospections. After having eliminated all the anthropic linear structures from the map, we had to scan and georeferenced a map of the RESEAU project, representing the main faults of the region, which was used to calibrate and validate the fracturing map (figure 6).

6.4. Correlation by resistivity measurements

The electrical resistivity measurements were used to determine the zone likely to contain an aquifer, i.e. the zones of alteration and/or fracturing. The electrical tracing measurements are tabulated, specifying the distance AB of the profile and the spacing between the different measurement points in one column and in another, the resistivity values of each measurement point table II.

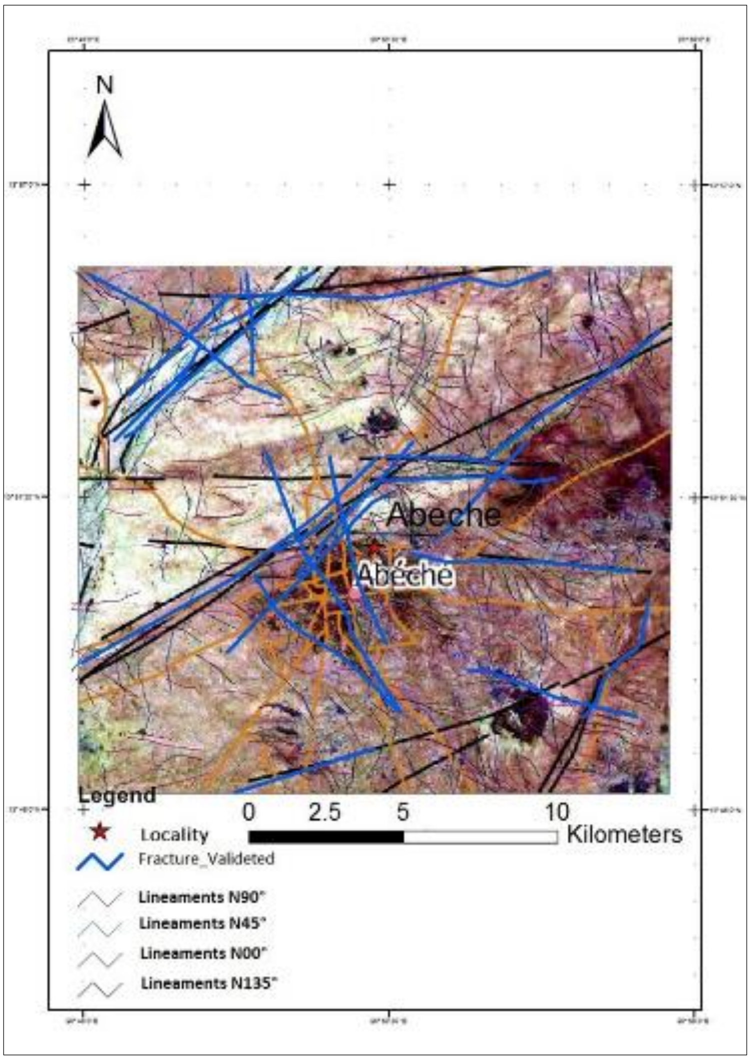

Figure 6 Map of the Abéché fracture zone

Table 2 Table of resistivity data

Horizontal axis	***Vertical axis***	***Site : 1***	***Profil : P1***	
Measuring step(m)	**Résistivité électrique (Ohm)**	**AB : 200**	**MN : 10**	**Pas : 10**
0	179			
10	239			
20	243			
30	335			
40	177			
50	247			
60	228		Panel center	
70	266			
80	338			
90	296			
100	238			
	341			

The profile is plotted on a semilogarithmic paper ρa=f(AB), on which the center of the panel could be identified (Figure 7) and in some cases, in terrains considered not very complex, the anomaly could be specified, and an electrical borehole established (Figure 8).

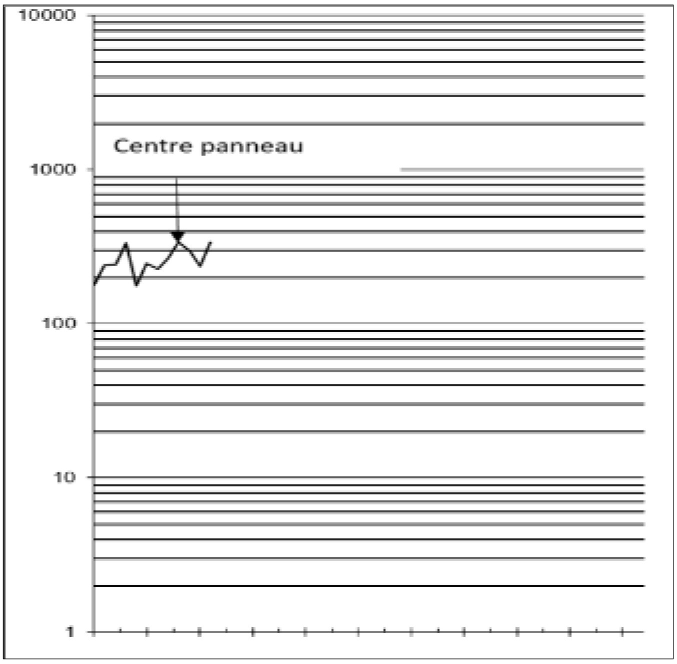

Figure 7 Example of an electrical profile in the Djatinié district of Abéché

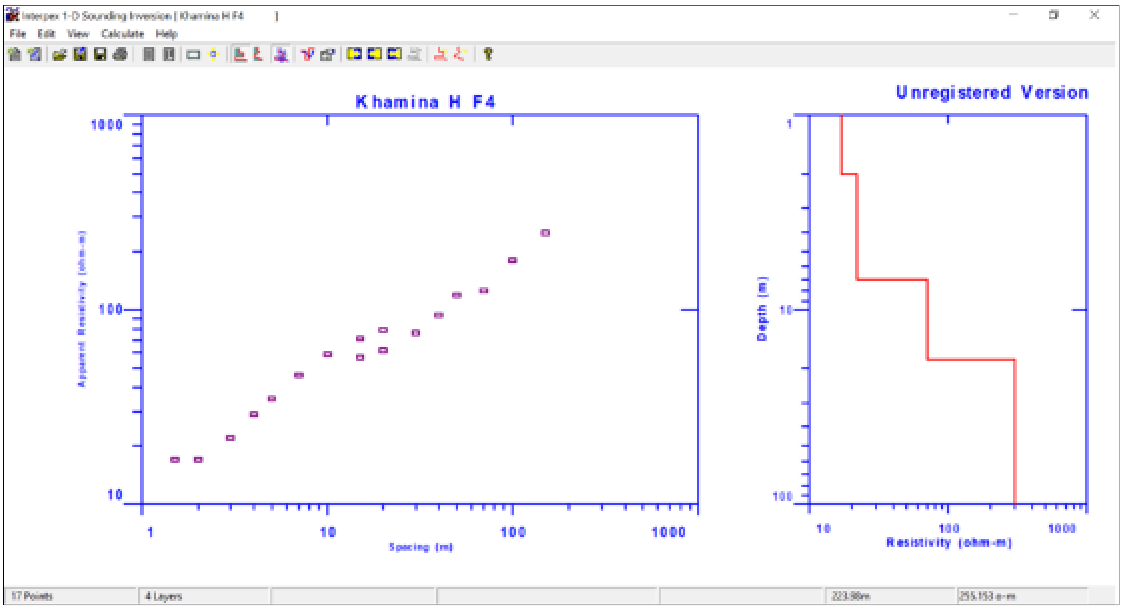

Figure 8 Example of an electrical survey

The resistivity measurements by tomographic method allowed to draw a 2D image, on which it is possible to observe different aquifer layers, the anomaly and the tectonic structures (Figure 9).

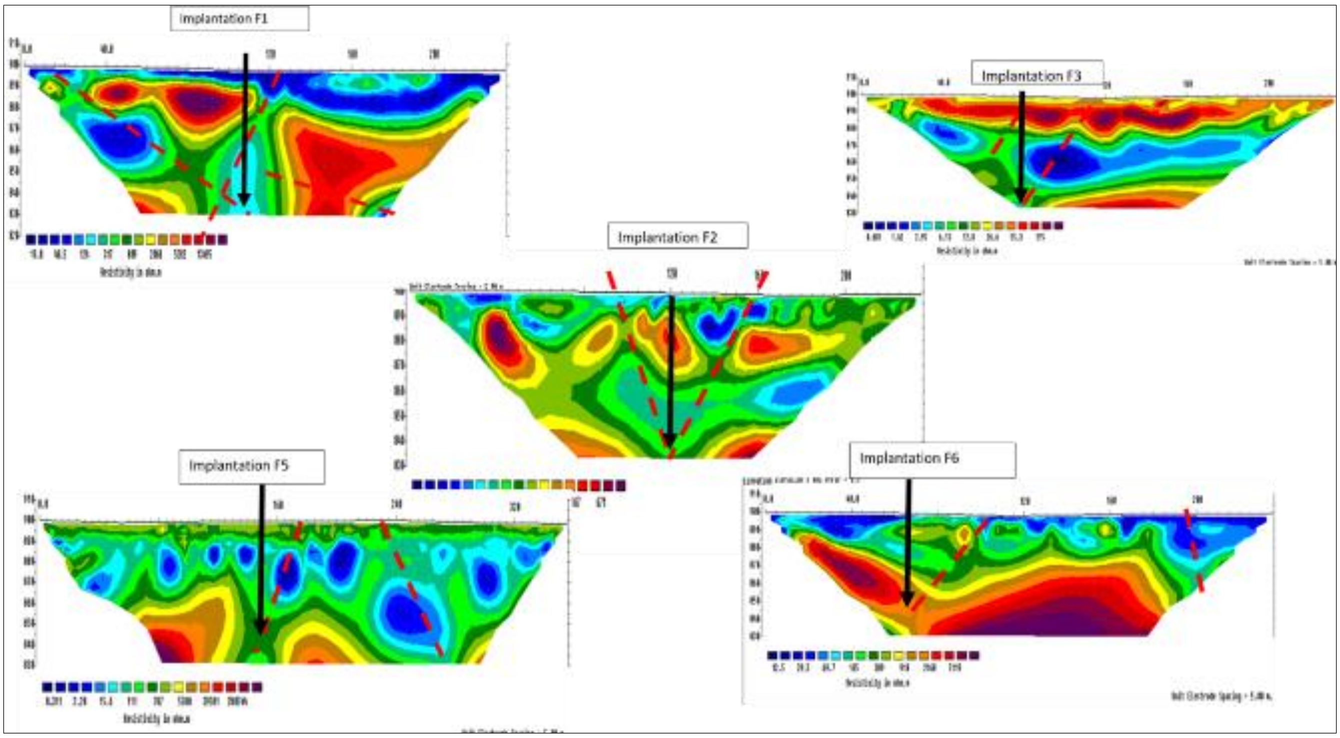

Figure 9 2D representation of the different sites studied

7. Discussion

Water resources in the basement areas are generally located in fractures. The results of the various successive treatments applied to the satellite image of the study area, allowed us to identify the main fracturing networks, validated by data from the RESEAU project, which shows a clear concordance with these data (Figure 6). Other fracturing patterns were validated by superimposing them on productive drilling data in the town of Abéché and its surroundings. Most of these boreholes are either crossed by the fracturing network or are drilled next to these fracturations (Figure 10).

Several authors have conducted their work in different contexts and have shown the necessity of lineament analysis for hydrogeological prospection in the basement zone [3],[4],[1], [18], [19].

However, the lineaments in the city are difficult or almost impossible to validate by these types of treatment, because of the urbanization and anthropic actions that could be confused with the lineaments. To do this, the application of the geophysical method by measuring the electrical resistivity has given very satisfactory results and has detected some anomalies and highlight some fractures especially by 2D imaging tomography. Figure 11 illustrates the fractures, the anomaly highlighted, the drilling location and the different conductive and resistant layers.

In addition, the measurements of resistivity carried out in the city of Abeche have made it possible to identify the drilling points in ten districts of the city. This campaign was followed by the drilling of eight (08) of these identified points and gave the results established in the table below (Table III). The tomographic method gave a good result compared to the drilling. 60% of the sites measured by the panel were productive. There may be several explanations for this. The electrical resistivity method can give satisfactory results in low complexity terrain. This method is suitable for detecting quantitative variations in resistivity perpendicular to the surface. It can therefore determine the presence or absence of an anomaly but does not specify the orientation of the fractures, and therefore the difficulty of locating the right drilling point. Plusieurs études ont été menées par le PNUD et GTZ/FD dans le cadre de projet d'hydraulique villageoise dans la région du Ouaddaï utilisant le sondage électrique. Le taux de réussite était de 40% selon le rapport final du projet Almy-Nadif.

Although the limited amount of geophysical data used in this study does not allow for an objective conclusion, electrical tomography offers a 2D overview, facilitating the determination of an aquifer potential. According to the work of Koudou et al (2012) [20], remote sensing and geophysics alone do not guarantee 100% drilling success, but they do allow us to exclude part of the territory to be prospected and to select sectors with promising aquifer potential.

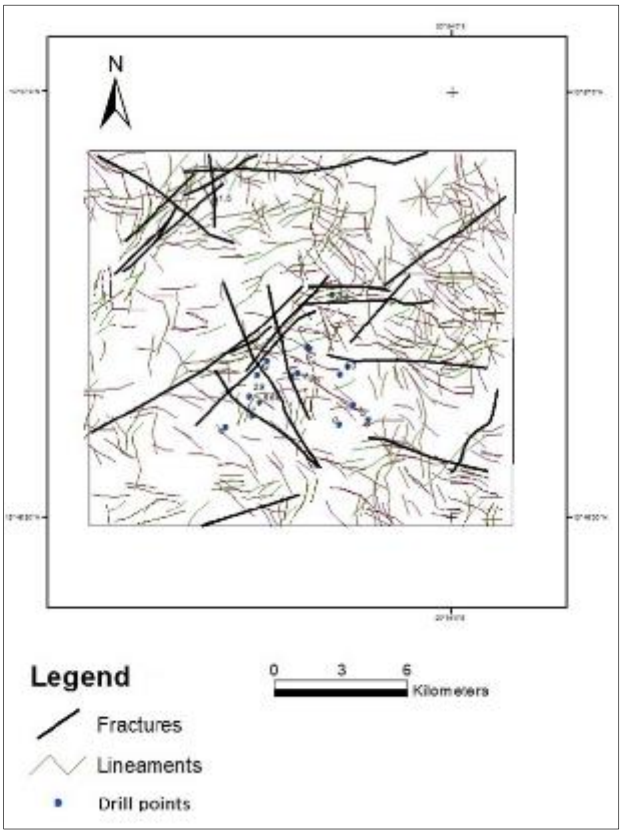

Figure 10 Drilling data overlaid on the fracturing map

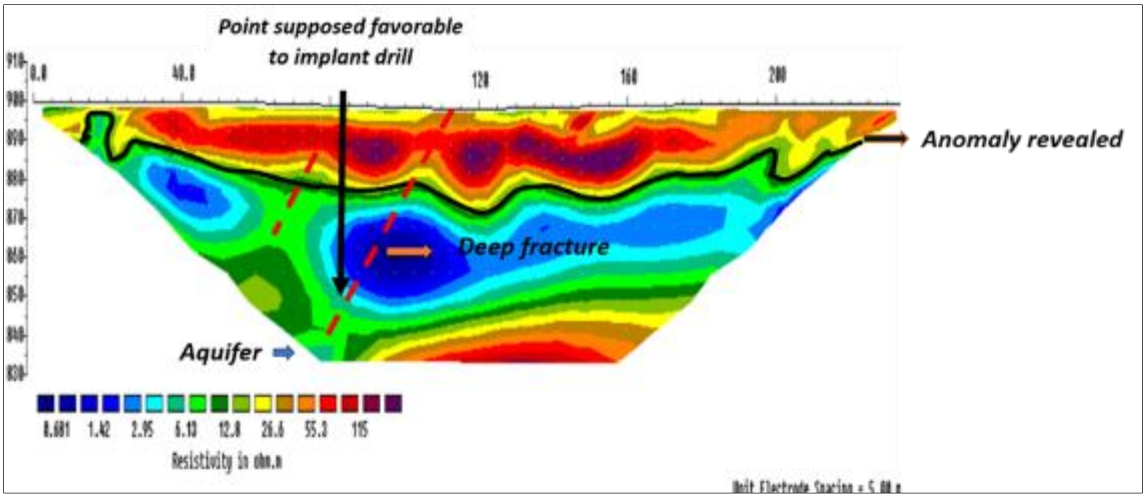

Figure 11 General view of an aquifer in the basement zone (Kamina Hayalmatar site - Abeche)

Table 3 Characteristics of borehole data in the city of Abeche

N°	Code	Districts	Total_depth in (m)	Water flow in (m)	static level in (m)	Dynamic level in (m)	Flow rate m3/h	Type of measure	Productivity	Fault orientation
1	F1	Chigal fakhara	73	16	6.4	69	2.9	Panel	Positive	N285° - N30°
2	SEV	Hayal matar III	71	30	26	41	1..3	Survey	Positive	-------
3	SEV	Dabanayir	undrilled					Survey	-------	-------
4	F2	Djatinié	47	19	3.99		8.66	Panel	Positive	N45° - N135°
5	F5	AGAD RACHID BARANI	51		-------	-------	43	Panel	Positive	N45° - N160°
6	F3	KAMINA MATAR II	-------	-------	-------	-------	-------	Panel	Negative	N30°
7	SEV	BEN DJEDID SUD	-------	-------	-------	-------	-------	Survey	Negative	-------
8	SEV	KAMINA I	undrilled					Survey	-------	-------
9	SEV	CHITIE 2	-------	Survey	-------	-------	-------	Survey	Negative	-------
10	SEV	Dabanayir 2	undrilled					Survey	-------	-------
11	F4	Ardal HABAYIB	-------	-------	-------	-------	-------	Panel	Negative	-------

8. Conclusion

At the end of this work, we defined the different steps necessary for the realization of the fracturing map integrating remote sensing and geophysical data for an identification of the potentially aquiferous zones. Indeed, the linkage between the pre-existing data allowed the validation of the map of major fractures of the city of Abeche and on the other hand the geophysics allowed the identification of potentially aquiferous zones.

Most of these fractures are oriented NE - SW and NW - SE, in correlation with the structural context defined above.

This study aims at orienting the reconnaissance campaigns by defining potentially favourable zones, the selection of punctual sites for the implantation of the future drilling. A more detailed study including several hydro-statistical parameters is necessary to determine the productive aquifers of the area of interest.

Compliance with ethical standards

Acknowledgments

we wish to acknowledge the Adam Barka University of Abeche and the University of N'Djamena for allowing us use the facilities and the enabling environment.

Disclosure of conflict of interest

Informed consent was obtained from all the individuals involved in this study

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