GSC Advanced Research and Reviews

eISSN: 2582-4597 CODEN (USA): GARRC2

Cross Ref DOI: 10.30574/gscarr

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

GSC ONLINE PRESS

(Research Article)

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Lineaments as a tool for decision-making in the optimal location of boreholes in the base zone: Case of the department of Abtouyour (republic of Chad)

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GSC Advanced Research and Reviews, 2023, 15(03), 157–170

Publication history: Received on 30 April 2023; revised on 12 June 2023; accepted on 15 June 2023

Article DOI: https://doi.org/10.30574/gscarr.2023.15.3.0191

Abstract

This study has made it possible to highlight that the extraction of structural lineaments helps in the optimal decision-making in the implantation of boreholes in the basement zone.

For this purpose, we used remote sensing, as a complementary tool in the extraction of structural lineaments and validated our results with the drillings carried out using electrical tomography carried out in the area.

This semi-automatic method allowed us to understand the importance that remote sensing can play in the establishment of successful drilling in the basement zone.

For this study we used software such as Excel for drilling data ARMAP 10.8 for GIS, PCI Geomatica software for the extraction of lineaments. The orientation of the lineaments was obtained using the rose diagram of the ROCKWORKS software. In addition, for our study we used images from Landsat 9+, ASTER, DEM, and STRM of 30m resolution which allowed us to develop thematic maps.

Thus we were able to validate our Works with the representation by the profiles of electrical resistivity especially the electrical tomography made in the study area and the drillings carried out according to the lineaments extracted.

The combination of different parameters in the middle of the basement in a GIS facilitated the spatial analysis, the results was good for the decision making to drill water well in basement area.

This approach allowed us to understand that more than 53% of positive drilling intercepts lineaments while only 13% of negative drilling intercepts lineaments.

Keywords: Lineaments; remote sensing; Satellite images; Abtouyour; Electrical resistivity

1. Introduction

Introduced in 19012 [1], the term lineament has been used in several disciplines (in petrology, geology and hydrogeology) as an indicator in the interpretation of structures at a distance in several disciplines [2].

They were considered and characterized appearing in various forms, linear structures and sometimes in geomorphological forms different from faults or fractures.

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Lineaments were defined as fine lineaments of structures that can be linear and map able from a simple or compound surface. Their components can be either aligned, rectilinear, or curvilinear which sometimes reflect subsurface phenomena [3].

It is in this perspective that we used GIS coupled with remote sensing to delineate areas of fracture networks using lineament densities and drilled boreholes.

The satellite images were chosen in order to achieve the objective which is the search for fractures or faults (structural and geomorphological lineaments) and the choice of an implantation of the successful drillings in the study area [4].

In this approach we applied different treatments on the satellite images which are the coloured composition, the main component analysis PCA the ratios and the different directional filters (Sobel filter)[5].

This allowed us to make atmospheric and radiometric corrections to improve the images, thus facilitating the visualization and extraction of these lineaments and also projected the coordinates of the boreholes drilled under ARC GIS [5].

This study relates to part of the Province of Guéra more precisely in the department of Abtouyour.

In this area, drilling which must prove positive is a very complex exercise. Figure number 1 below gives us an idea of all the negative drilling carried out in the area.

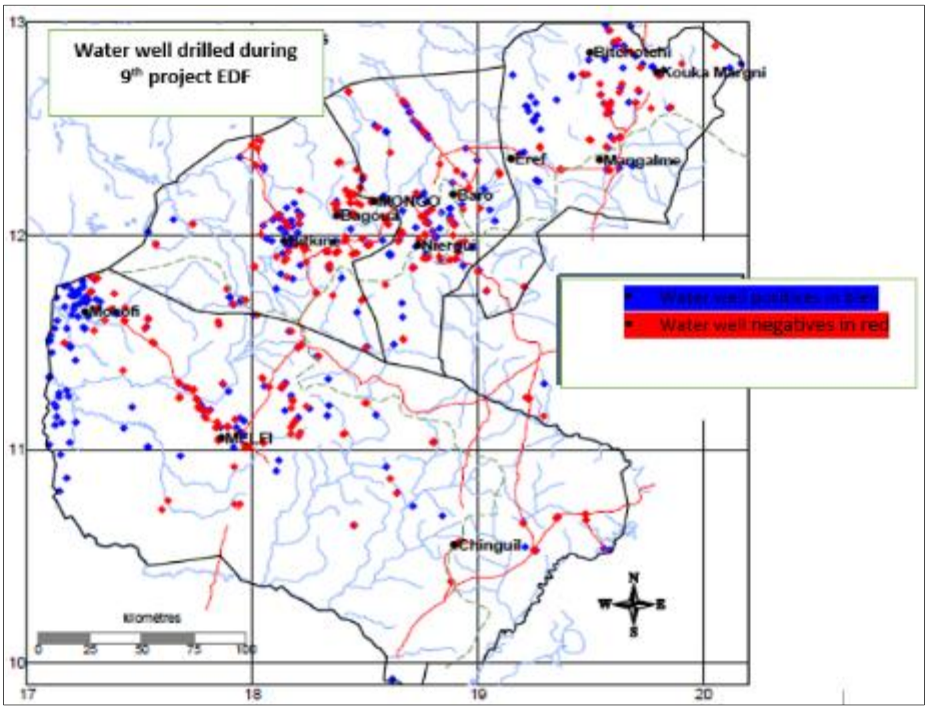


Figure 1 Positive boreholes in blue and negative boreholes in red

The mapping of groundwater potential in the province of Guéra will have a significant effect in the province and the contributions will be useful and can be used in other areas with the same geological and geomorphological characteristics.

This is why groundwater mapping in this part of the country will improve the sustainable management of groundwater. It can be used to identify potential groundwater zones in a complex geological context through the extraction of lineaments.

This study could be used as a tool for decision-makers, NGOs, politicians and planners for an efficient orientation of boreholes towards areas of high lineament densities.

1.1. Location of the study area

The department of Abtouyour is located between 11º 58' 52" longitude North and 18º 12' 45" latitude East. It is one of the four departments that make up the Province of Guéra in Chad. Its capital is Bitkine, the population of this area is estimated at 171,999 inhabitants in 2009 (RGPH).

The department of Abtouyour is divided into two sub-prefectures:

- Bitkine
- Bang-Bang (capital Bagoua)

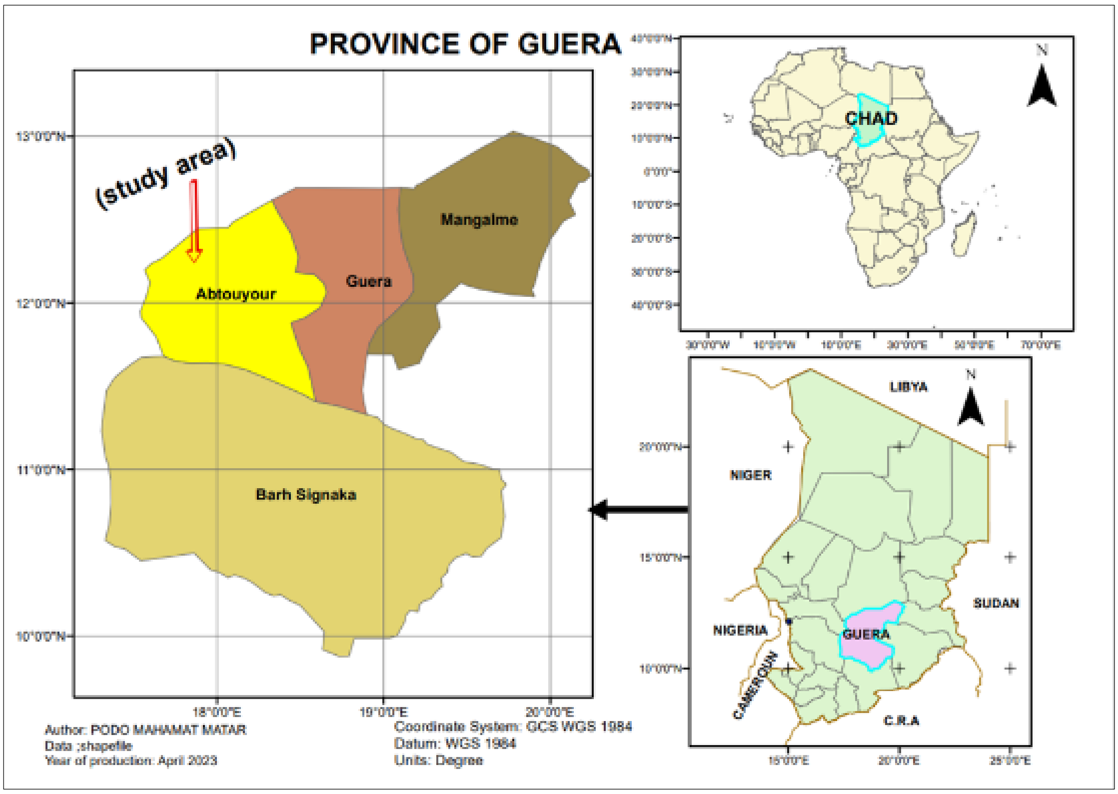


Figure 2 Location of the study area

2. Material and methods

2.1. Materials

The cartographic databases used in this study include

- Digitized 1:2,000,000 scale geological maps of the Guéra Province.
- Digitized and geo-referenced topographic maps using Arcmap.
- The satellite images used in this study which are LANDSAT 9 (ETM+) images.

These were downloaded from the USGS "Earth explorer" web application (https://earthexplorer.usgs.gov) in the UTM Zone 34 projection system. Images Scenes (Path: 182/Row: 51 and 52. These images were acquired on January 23, 2023.

The software used are:

- ARCMAP 10.8 software.
- The ROCKWORK software.
- PCI Geomatica software.
- ROCKWORKS software

- Rose diagram
- Google Earth.
- ASTER data (DEM, DEM)
- Garmin GPS.
- Excel software.

So as we can see in the image of figure: 3 scenes 51, and 52 in the map of Chad.

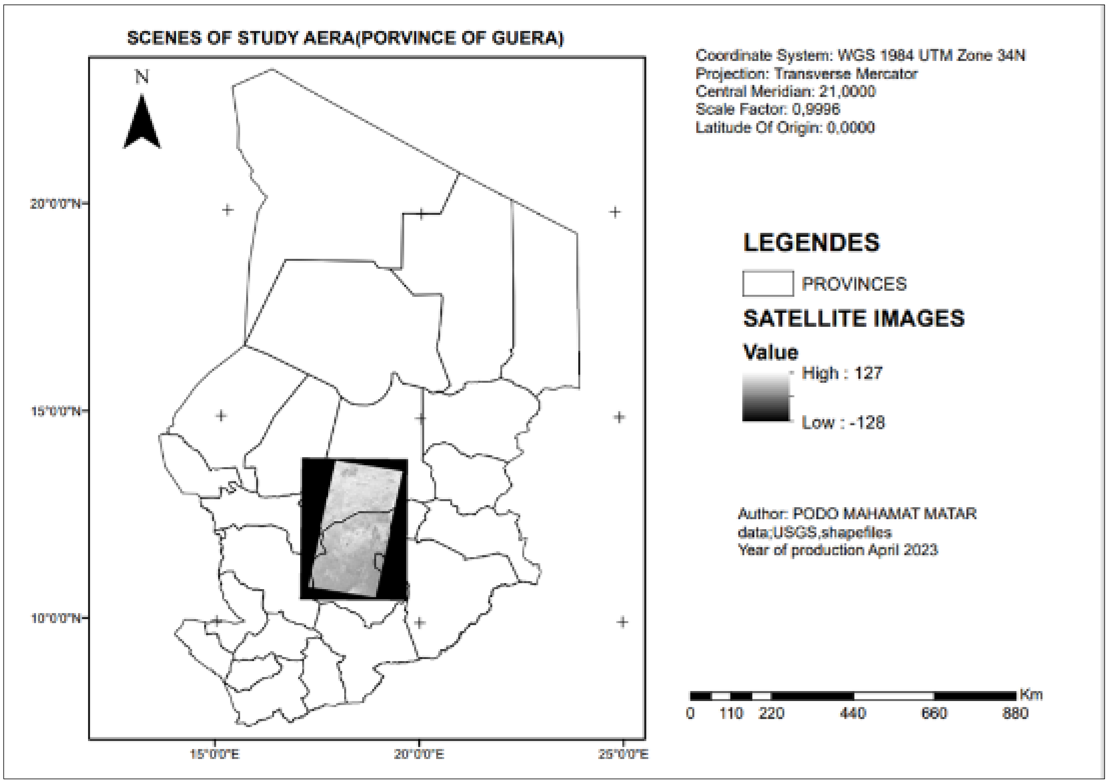


Figure 3 Scenes 51 and 52 that served as a working basis.

2.2. Cartographic, geophysical and Landsat data.

2.2.1. Map data

The cartographic data used in this study come from the CDIG database (Centre for Documentation and Geographic Information of the Ministry of Urban and Rural Hydraulics of Chad), another part of the data was obtained from the C.N.D.R (National Research Center for Development).

These are made up of vector data (vector data, Shape files of Chad) and some data have been downloaded from the internet on specialized GIS sites such as DIVA SIG etc.

From the satellite image that we downloaded from the USGS site, this image has undergone several treatments, in particular atmospheric and radiometric, to make it better improved for the visibility of the terrain, the resolution being 30 m.

So we used the mosaic function to combine several scenes from the satellite images in order to merge them to make a single more elaborate one and allow the extraction of our study area under ARCGIS.

The data of the drillings carried out in the province were also obtained in this Center (CDIG), the latter constitutes a significant database for data relating to geology, geophysics and hydrogeology.

2.2.2. Geophysical data.

The data relating to geophysics and those of the drillings carried out within the framework of the 9th EDF program in the area, in particular the electrical resistivity and ERT (Tomography, Electromagnetic, resistivity) data, were also obtained and analysed.

2.2.3. Landsat data.

To obtain the multispectral satellite image of the department we mosaicked scenes 51 and 52 to have made a raster copy.

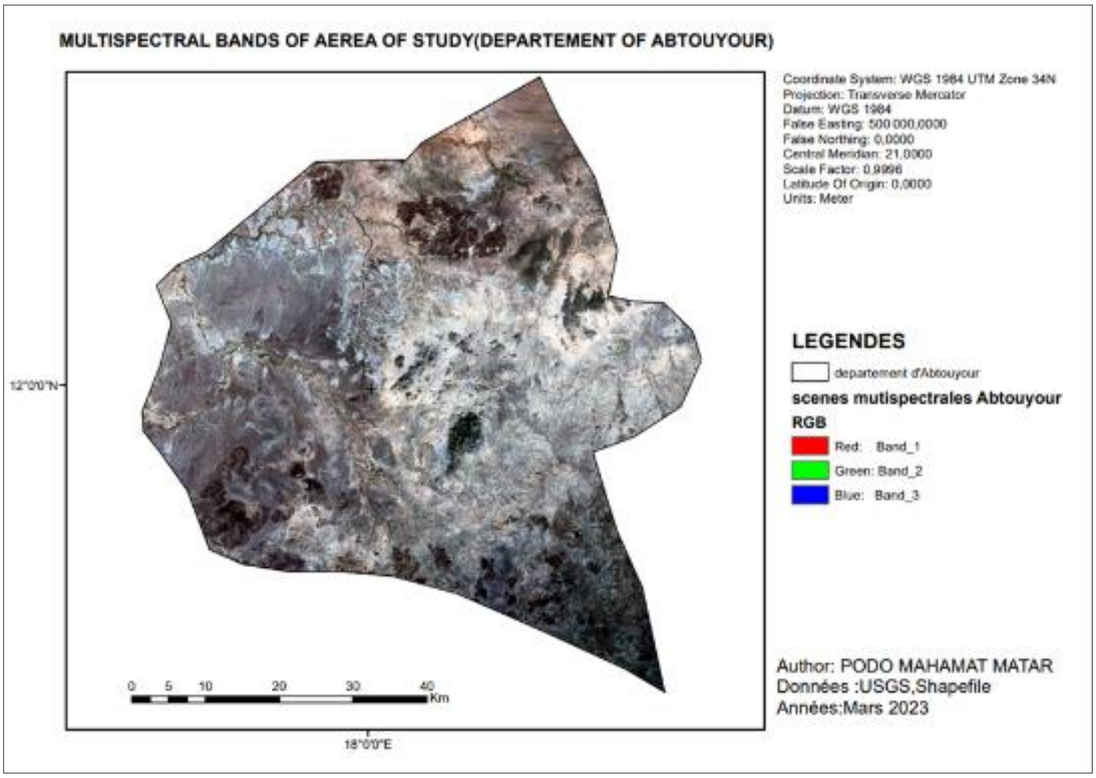


Figure 4 Mosaic satellite image of the study area (the department of Abtouyour)

2.2.4. Principal Component analysis (PCA)

The correlation matrix table 1 in different bands makes it possible to note the levels of redundancy of information existing in the original bands, its use in remote sensing is very important for the reduction of the dimensions of data and image correlations [6].

Table 1 Correlation matrix of the 6 original Landsat 9 ETM + scene tapes of the department of Abtouyour

	Band1	**Band2**	**Band3**	**Band4**	**Band5**	**Band6**
Band1	**1.000000**	0.999145	0.989792	0.998800	0.958262	0.986371
Band2	0.999145	**1.000000**	0.994628	0.998778	0.967908	0.990812
Band3	0.989792	0.999145	**1.000000**	0.990996	0.986500	0.994913
Band4	0.998800	0.998778	0.990996	**1.000000**	0.962097	0.985743
Band5	0.958262	0.967908	0.986500	0.962097	**1.000000**	0.984926
Band6	0.986371	0.990812	0.994913	0.985743	0.984926	**1.000000**

By carrying out the PCA we obtained new resized channels called principal components.

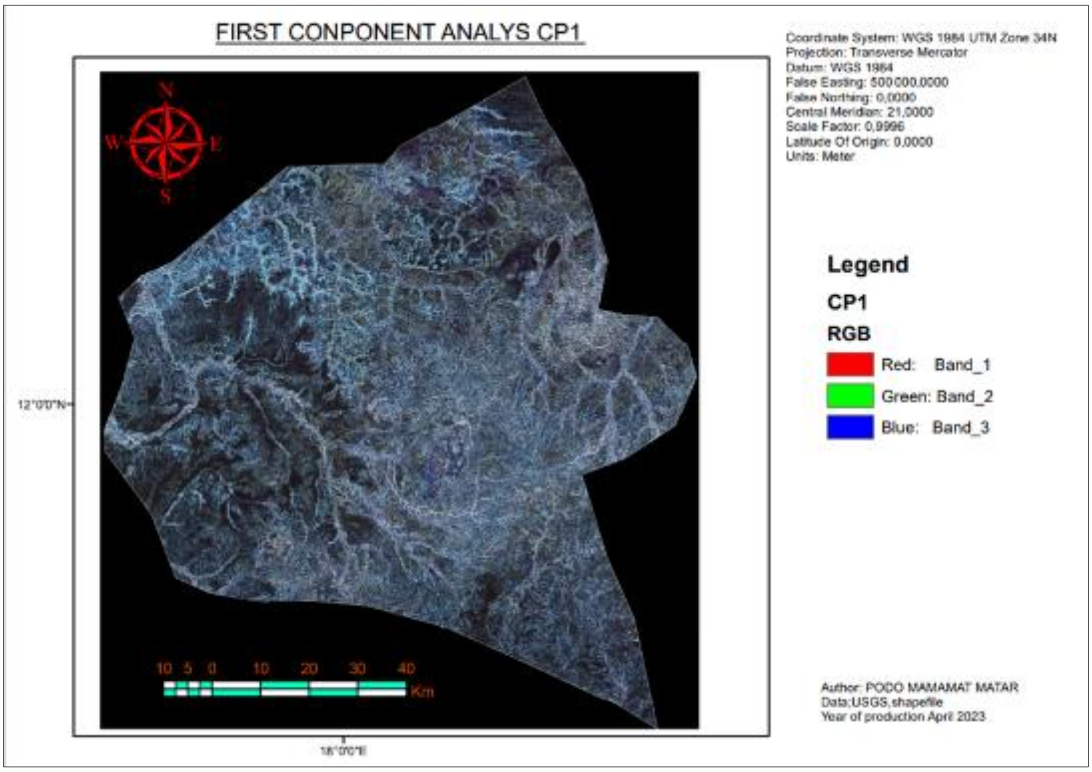


Figure 5 First principal component (CP1)

2.3. Methods of producing thematic maps

For the creation of the thematic maps, the Shape files data were extracted on the basis of the limits of the catchment area, followed by an automatic layout on Arc GIS 10.8.

The altimetry map and the slope map were produced from the DEM (from images uploaded to USGS).

We also extracted the study area using the basin boundaries. The same extracted product was used to produce the lineament density map and the drainage density map. The Spatial Analyst extension of Arc Gis made it possible to perform all the cartographic processing.

The LANDSAT 9 (ETM+) satellite images have undergone a number of processing operations using the ENVI software.

The different bands were first mosaicked. We then carried out the classification using the unsupervised nesting method [7].

It is a method that has the advantage of grouping the pixels of an image into homogeneous spectral classes according to their signatures and assigning them a thematic meaning [8].

The validation of the results was done by a descent on the ground thanks to the points raised by GPS, according to the thematic maps elaborated, the drillings carried out and the electrical resistivity in the zone.

2.4. Geomorphology

The massifs are surrounded by a halo of glacis detrital products separated from each other by basins and depressions filled with alluvium where numerous outcrops recall the presence of the basement at shallow depth [9].

Around the rocky outcrop, the glacis begins with a shallow arena zone, gently sloping, more or less hilly, and mixed with numerous rock debris.

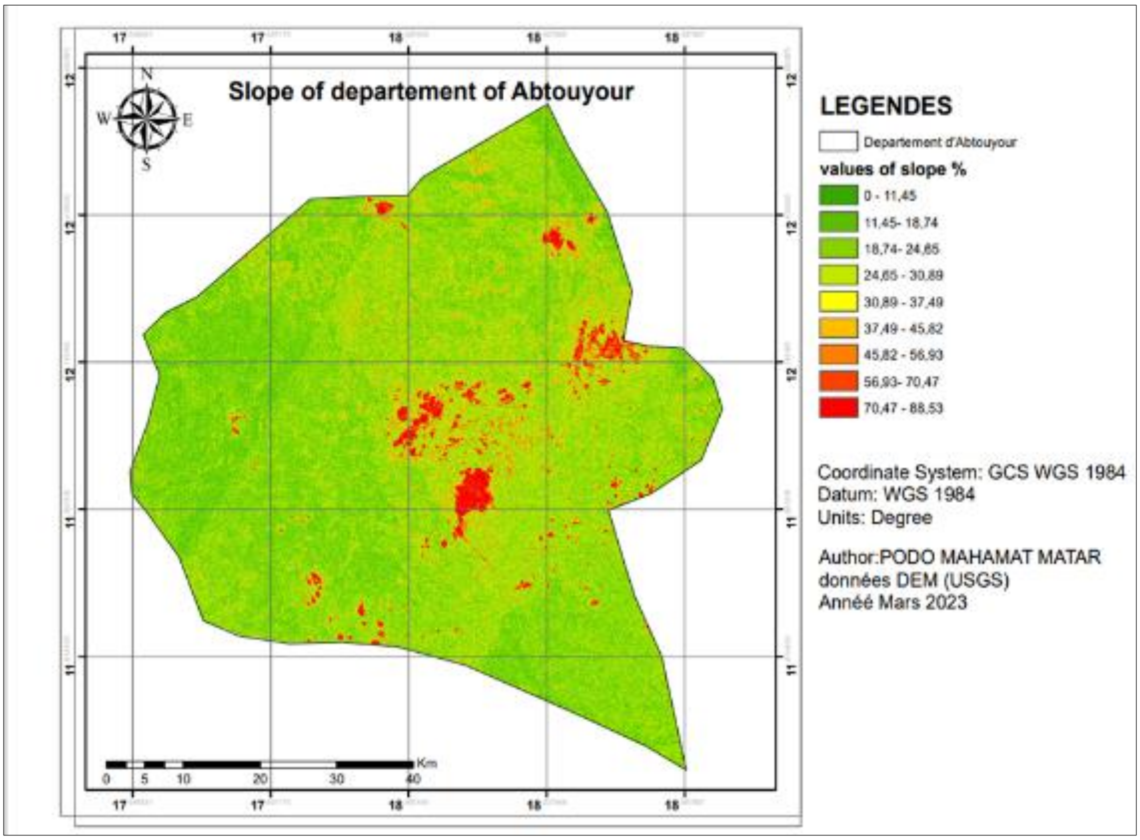


Figure 6 illustrating Mountain and plains areas

The map below in figure 7 shows us the geological map of the study area.

2.5. VI. Geology

Located in the heart of the Chadian basin, the department of Abtouyour is an integral part of the Chadian central massif which, with all the formations in this area, constitutes an orographic unit grouping three main massifs[10]:

- Those of Abu Telfan, Kenga and Melfi,
- As well as many small secondary massifs and inselbergs separated by arena areas.

Of vigorous relief, which culminates at 1613 m at the Pic du Guéra while the average level of the surrounding plain oscillates between 400 and 500 m.

Generally the massif quickly drowns under the recent formations of the basin from which emerge, sporadically, a few isolated inselbergs.

The rest of the presentation will be based essentially on the work of [9] whose conclusions are applicable to the entire massif.

According to this geologist, we will distinguish: varied metamorphic rocks, in much localized outcrops and often not map able (at this time 1953), intrusive rocks which represent almost all the outcrops of the Precambrian basement, These are essentially granitic rocks but also meets metamorphic rocks. The elaborate geological map of the department shows us these geological formations.

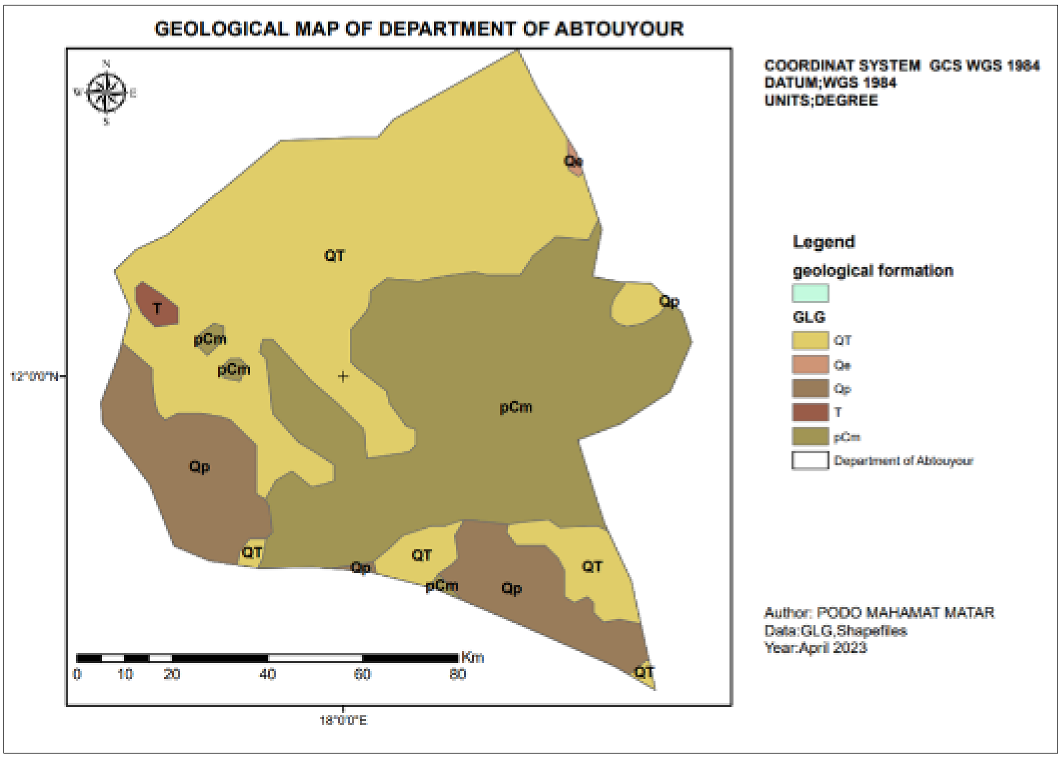


Figure 7 Geological map of the department dominated by Quaternary formations

2.6. The method of automatic extraction of lineaments.

The lineament extraction method responds to our logic in the search for groundwater contained in cracks and faults to visualize faults and fractures in this context satellite images become an absolute necessity because without them we cannot locate fractures and faults on a local scale over several kilometres.

For this reason we were forced to look for an easier accessible site that will provide us with the necessary data for this study. We chose the USGS explorer site, which allowed us to download the desired satellite images ranging from SRTM, ASTER and DEM.

Thus we used the Arcmap 10.8 mapping software to carry out a series of works which enabled us to produce a set of thematic maps necessary for our study.

So we thought it useful to do it automatically by adjusting the radius and length parameters using the GEOMATICA PCI software.

To carry out the map of the lineaments to do this it would be necessary to make an atmospheric and radiometric correction in order to clear the zones likely to deceive us on the lineaments, tracks and roads.

To do this, the raster’s would have to be transferred to the Geomatica software to perform the extractions.

Table 2 Algorithm parameters used to extract lineaments

RADI	**FILTER RADUIS (le rayon du filtrage)**	**10**
GTHR	Edge Gradient Treshold	100
LTHR	Curve Length Treshold	30
FTHR	Line Fitting Error Treshold	3
ATHR	Angular Difference Treshold	30
DTHR	Linking distance treshold	20

Figure 8 below gives us the automatic extraction of lineaments.

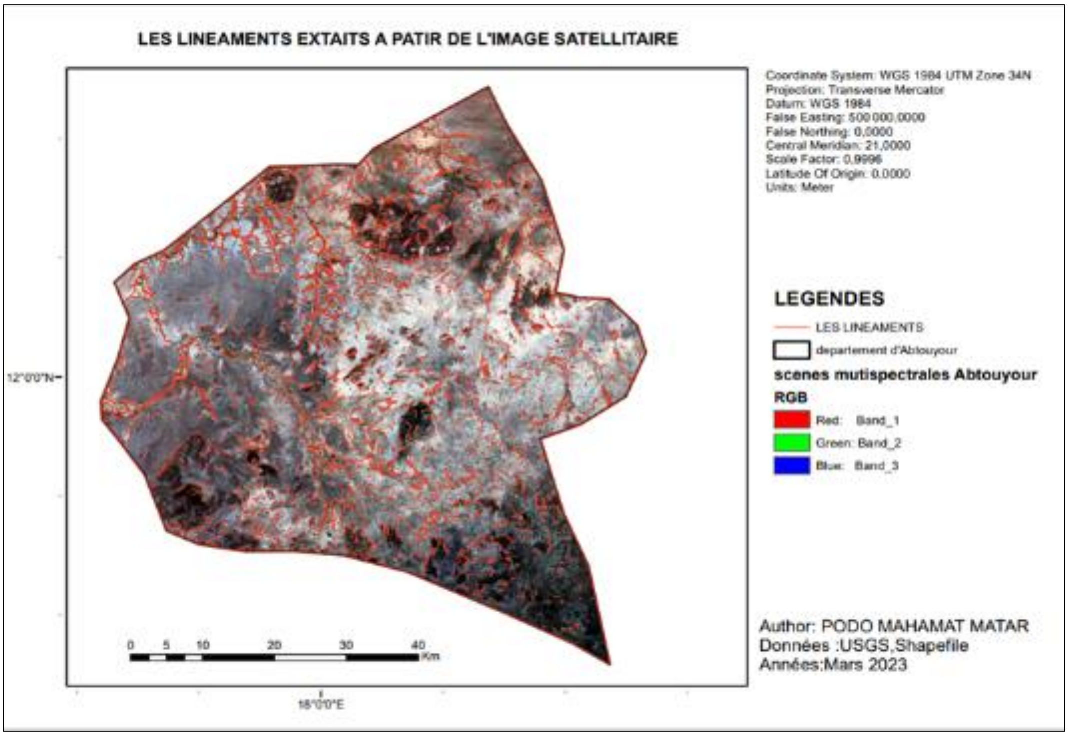


Figure 8 Automatically extracted lineaments with parameter adjustment in red

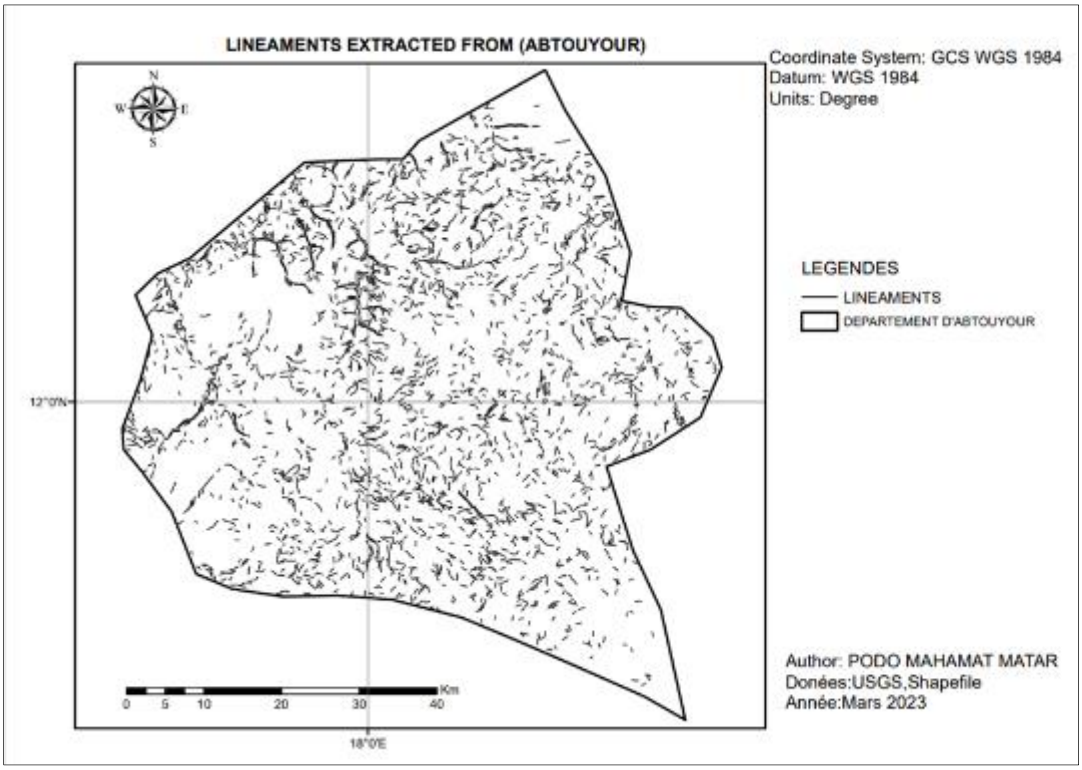


Figure 9 Automatically extracted lineaments

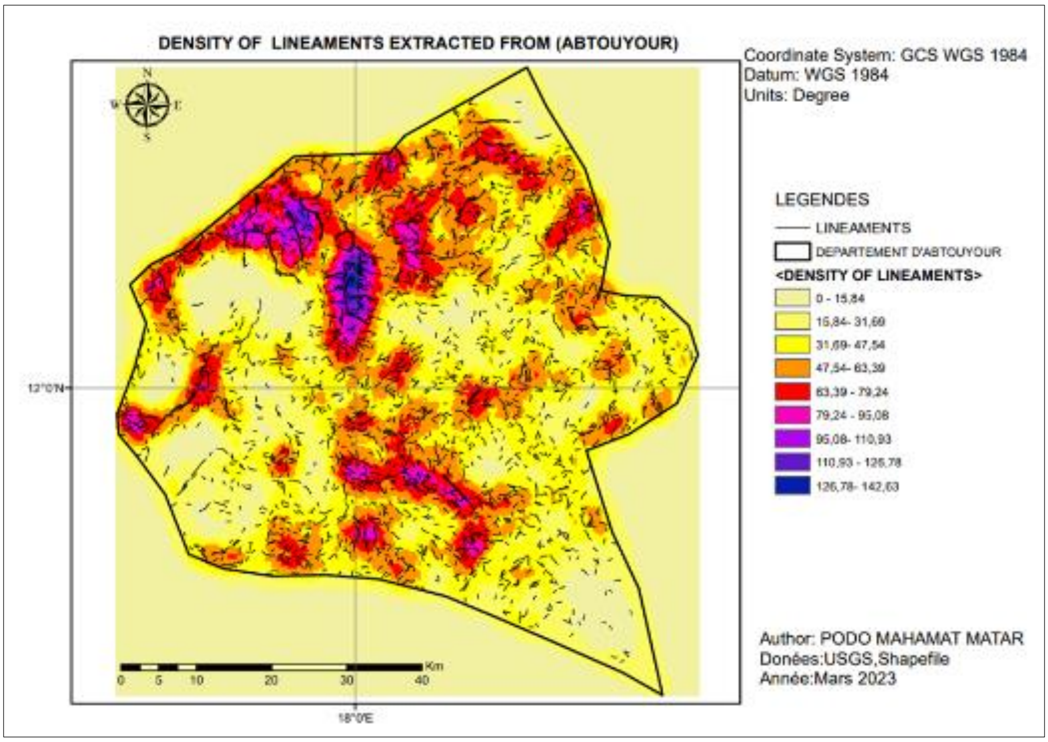


Figure 10 Density of lineaments extracted

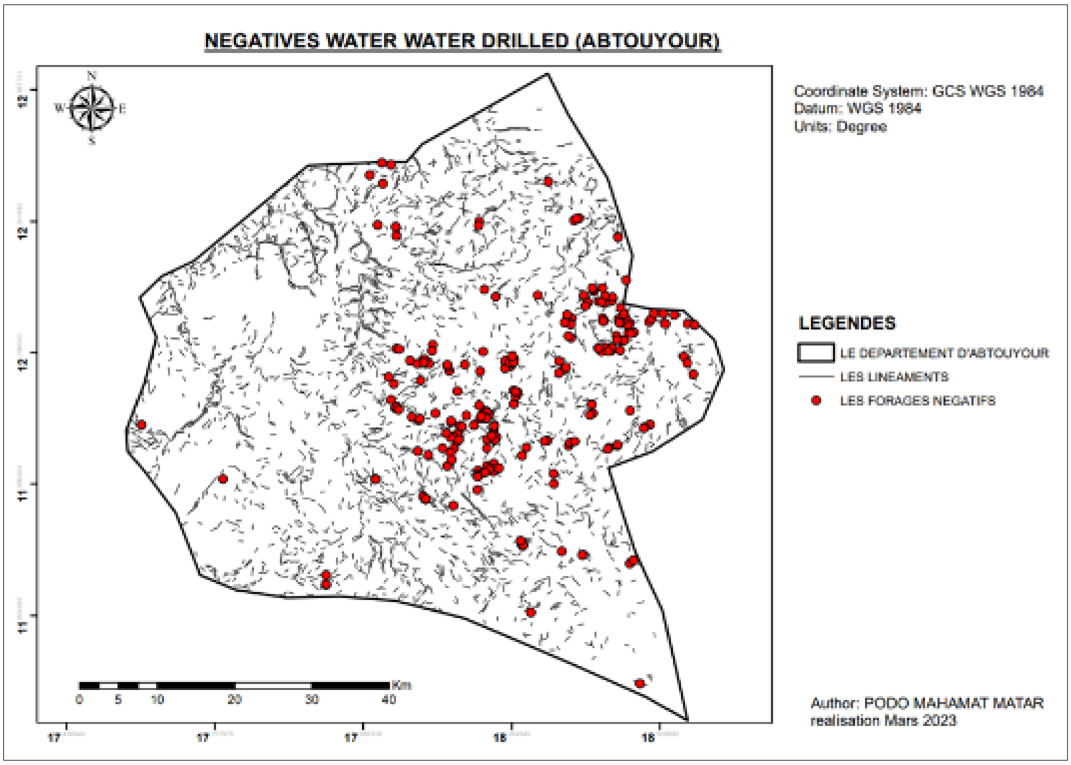


Figure 11 Negatives water well drilled their positions with extracted lineaments

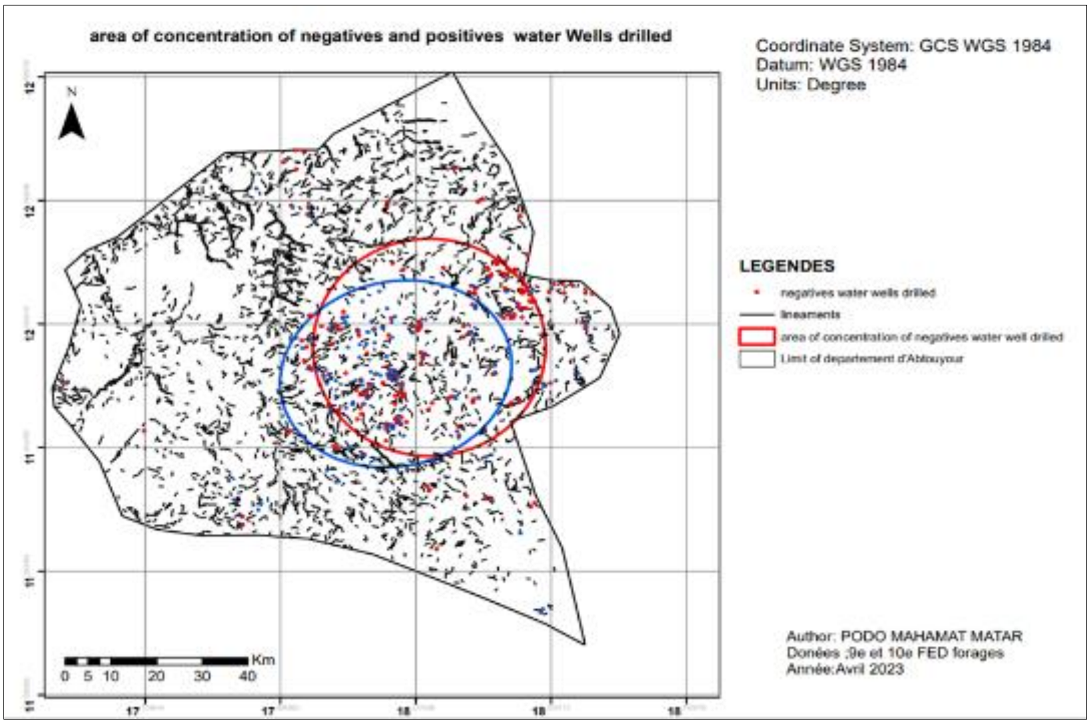


Figure 12 The concentration of negative and positive boreholes according to the lineaments extracted

Table 3 Summary of vertical electrical soundings (implantations) and estimated depths to be drilled in the Bitkine area

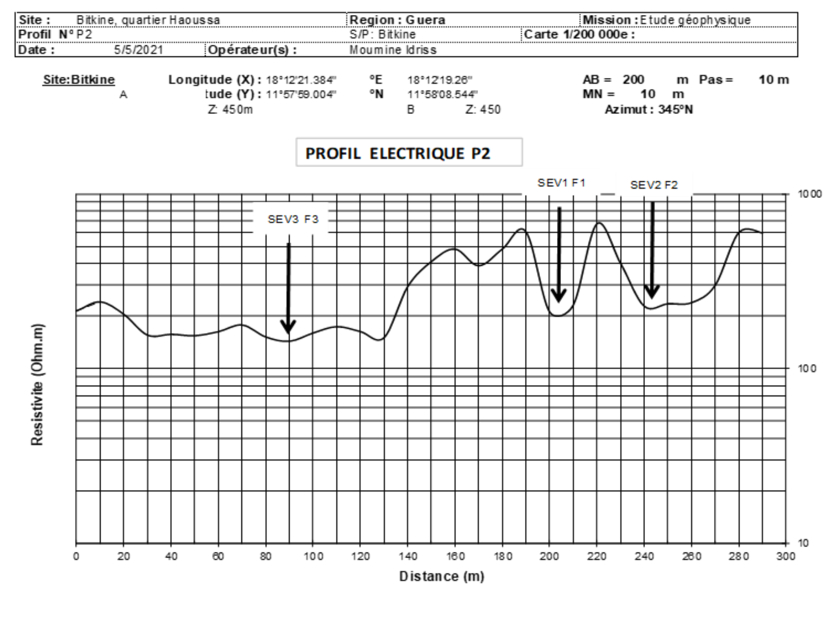
Town/Village	Borehole No	X Coordinate	Y Coordinate	Altitude
1	F1	18°12'20.664"	11°58'02.28"	450
2	F2	18°12'19.836"	11°58'05.52"	450
3	F3	18°12'19.512"	11°58'07.464"	450
4	F4	18°12'26.064"	11°58'06.924"	450
5	F5	18°12'27.612"	11°58'05.016"	450
6	F6	18°12'28.764"	11°58'03.36"	450

3. Results and discussion

The results of this study allowed us to understand how we can extract structural lineaments from satellite images and make correlations with the realities on the ground.

We can see the survey carried out in the area with the positions of the drillings executed for this it was necessary that the drilling be positioned by the intersection of the fractures (lineament) to have the chance to drill a positive water drilling. This shows the limit of electrical resistance conducted alone to install a water borehole in the sole area

Electrical resistivity leads us to electrical resistivity tomography which involves the knowledge of sub-adjacent formations to properly position the drilling of water wells because the tomography allows us to confirm the lineaments for the validation of work.



X (m)	Δv (mv)	I (mA)	ρ (Ωm)	X (m)	ρ (1) (Ω m)
0			214	380	
10			241	390	
20			205	400	
30			156	410	
40			157	420	
50			155	430	
60			163	440	
70			178	450	
80			152	460	
90			144	470	
100			160	480	
110			174	490	
120			163		
130			150		
140			295		
150			411		
160			484		
170			389		
180			484		
190			610		
200			212		
210			231		
220			676		
230			401		
240			228		
250			235		
260			239		
270			300		
280			602		
290			599		
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340					
350					
360					
370					

Figure 13 Electrical profile sounding

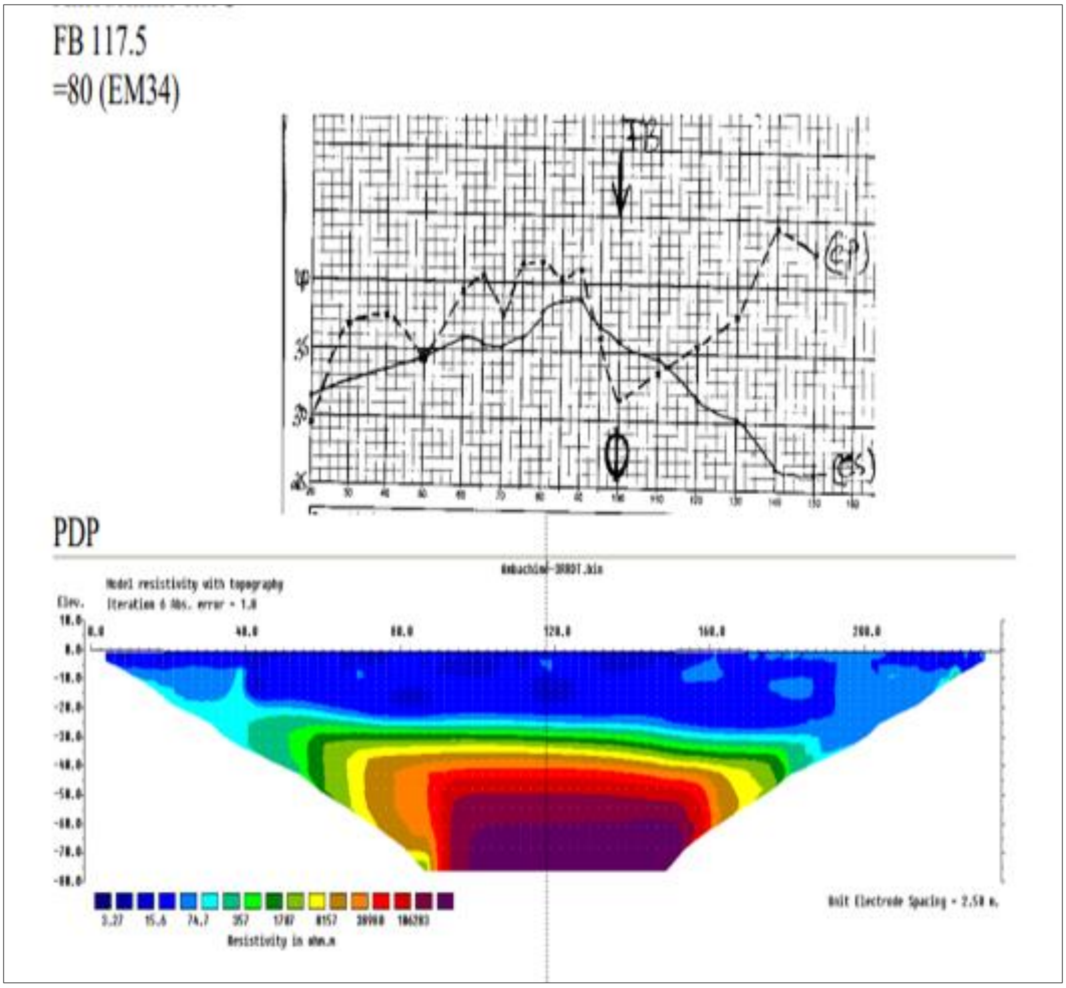

Figure 14 No visualized fracture, abandoned site

However, to carry out this analysis, it was appropriate for us to take the coordinates of the boreholes drilled in the area.

The drillings being divided by two categories those positive and negative for the dispatched on the lineaments in order to see their correlation.

It is in this perspective that the positive boreholes are positioned in relation to the lineaments extracted in the order of 58% out of 172 projected boreholes 100 forges intersect the lineaments.

On the other hand for the negative forges more than 13% do not meet our lineaments on the total number of 150 only 20 boreholes intersect the lineaments this shows that the lineaments and the positive boreholes have a correlation.

Table 3 Correlations of lineament intersections according to boreholes

Number Positive boreholes	Position in relation to lineaments	percentages
172	100	58 %
Number Positive boreholes	Position in relation to lineaments	percentages
150	20	13%

From this results we can affirm that in zone of the bases the exploitation of the lineaments can be a tool for a good orientation of the drillings water well.

However, we were able to note some imperfections also due to the position of certain negative boreholes which intersect the lineaments, which show us that the lineaments cannot indicate the presence of groundwater in the basement areas at 100%.

Some lineaments are not visible to the eye even being on the ground we could not see them we had to use tomography (electrical resistivity) for confirmation.

The following conclusions can be drawn:

- Lineaments can be divided into two structural and geomorphological categories.
- Their orientations are along the North East axis.
- Some areas are devoid of lineaments.
- Certain high concentration of lineaments is found in uninhabited areas and therefore not exploitable.
- The lineaments on the sides of the mountains are not exploitable.
- Lineaments do not necessarily indicate the presence of groundwater.

The concentration of lineaments is a good indicator for the search for groundwater for the establishment of boreholes in the basement zones.

It is also necessary to qualify because certain lineaments would not contain groundwater because groundwater is governed by a set of processes which goes from material which constitutes the aquifers which must be porous and permeable.

4. Conclusion

With the evolution of technology and computing, remote sensing has evolved with the appearance of many software programs that are capable of performing many more elaborate tasks in record time.

For the materialization of this study we used the satellite images, the Shape files data, the data of drillings carried out in the zone and software in order to finalize this study on the extraction of the lineaments and the drillings which become necessary if one wants to understand the functioning of a certain number of geological and hydrogeological structures.

Compliance with ethical standards

Acknowledgments

Our tanks for CDIG (Center for Documentation and Geographic Information)) and the National Center of support research (CNRD) for the data they have provided to us and the documentation and also to Mr Djamaldine Ahmat the Director General of Urban and Rural Hydraulics for his support.

Disclosure of conflict of interest

We affirm on honor that all the authors who contributed to the writing of this article have no conflict of interest.

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