Lineamentary and Structural Cartography of Iullemmeden Basin in the Dosso Region (South-West of Niger)

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Abstract: Located in the southwestern part of the Niger and the Iullemmeden basin, the Dosso region is full of enormous potential in groundwater used for feeding populations and livestock. In the region of Dosso, given the rapid population growth, the population is facing problems of drinking water supply. To meet the needs of the population, the implementation of village water programs has led to an ever increasing demand for groundwater, causing a problem of management of these resources. Therefore, for judicious management of these water resources it is important to improve knowledge of the geological and hydrogeological characteristics of aquifers in the Iullemmeden basin. Many other studies carried out in the Iullemmeden basin have determined the hydrogeological, hydrochemical and hydrodynamic characteristics of these aquifers and their recharge conditions. The main objective of this contribution is to highlight the lineament networks and then analyze the different directions to validate the fracturing map of the Dosso region. The implemented methodology integrates remote sensing techniques and GIS tools to process and analyze satellite images. This approach has led to the identification, in the study area, of two main directions of NE-SW and NW-SE fractures.

Key words: Iullemmeden Basin, Remote Sensing Techniques, GIS, Fractures, Lineaments

1. Introduction

In Niger in general and in the Dosso region in particular (Fig. 1), the drinking water supply for populations is dependent on more than 80% of the groundwater of the Iullemmeden basin [30].

With increasing population pressure, the available water supply points are insufficient to cover the ever-increasing water needs of the population. In addition, the programs implemented to meet these needs lead to a strong demand for groundwater resources, which impacts on the efficient management of these resources.

It is therefore important to improve the knowledge and understanding of the geological and hydrogeological characteristics of aquifers in the Iullemmeden basin.

For better management of water resources in the requested aquifers, it is important to improve the knowledge and understanding of the geological and hydrogeological characteristics of these aquifers leading to the realization of several studies on Iullemmeden basin [7], [8], [11], [12], [14], [16], [20], [27], [35].

The main objective of this study is to highlight the existence of a fracturing system whose hydrogeological role has been demonstrated by several authors [1], [18], [26]. Specifically, the aim is to map the lineaments and to validate the fracture network of the southwestern part of the Iullemmeden basin by using remote sensing and GIS techniques.

2. Geological Context

The Iullemmeden Basin is an intracratonic basin that has been established in the pan-African mobile zone east of the West African Craton (Fig. 2). It contains Paleozoic and Meso-Cenozoic sediments. During geological times, this basin has been the site of intracratonic sedimentation resulting in a displacement of the deposit zones from north-east to south-west. Paleozoic sediments occupy the northern part of the basin, while Mesozoic and Cenozoic deposits occupy the most southwestern part of the basin.
The Iullemmeden basin contains sedimentary series ranging in age from Cambrian to Quaternary. Table 1 below gives a general overview of the sedimentary series of the Iullemmeden basin.

Table 1: Post-Precambrian Sedimentary Formations of the Iullemmeden Basin [34].

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<tr>
<th>Formation</th>
<th>( \text{Cambrian} )</th>
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<td>Ablation</td>
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3. Methodological Approach and Materials

There are two methods of extracting lineaments, one of which is done manually and the other is done automatically.

The manual extraction consists of digitizing any linear structure observed on the image ignoring the human linearities (roads, high-voltage wires, etc.) by superposing the vector layers on the images and then manually extracting the lineaments contained in the satellite image to form the lineaments network. The extraction of lineaments is done on previously processed images (transformation, enhancement and filtering).

Automatic extraction consists of a linear processing oriented to the lineaments in two categories:

The first category includes enhancements that facilitate human interpretation. The digital filters are a typical example. We can mention the Laplacian filters and the Sobel filters whose advantages and disadvantages have been explained in detail by several authors [2], [23], [32].

The second category of treatments consists of extracting and automatically drawing the lineaments from the image directly or in an image of the gradients or in a binarized image. The operation is more complex, and the programs capable of successfully performing it are few.

In the case of our study, the methodological approach used is shown in the flowchart below (Fig. 3). It includes several stages, the main ones being:

- Pretreatment and processing of satellite images;
- The extraction of lineaments from processed images;
- The validation of the map of the lineaments obtained.

To carry out this study, various softwares were used including:

- Envi 5.1 Classic for image processing;
- ArcGis 10.3, for the establishment and crossing of the different maps, as well as the geo-referencing;

**Figure 2:** Location of the Synéclise of Iullemmeden [37], [38] modified.

**Figure 3:** Flow chart of treatment and lineament mapping.
- LINWIN, for the statistical analysis of lineaments;
- Excel, Word: for processing other datas.

Dosso region is covered by six images Landsat series 8 OLI (Operational Land Imager) images in Imagine format, each consisting of 7 bands. These images are thus multi-spectral (multi-band) ones, georeferenced in the WGS 84 geographic coordinate system with a resolution of 30 meters.
- P191R050 - P191R051
- P191R051 - P192R050
- P192R051 - P192R052

These images date from December 04, 2011 for the 191 and December 11, 2011 for the 192. They appear generally very clear. Indeed, this period of the year corresponds to the dry season from where there is absence of clouds and humidity in the air. As a result, these images did not require any radiometric correction. These images were made available to us by the Agrhymet Regional Center of Niamey/Niger and have very good spatial and spectral characteristics which are perfectly suitable for our study.

4. Results and Discussion

4.1 Mosaicing and extraction of the study area

The study area is covered by several images that we have juxtaposed by the image mosaic technique to obtain a complete image of Dosso (Fig. 4) and extract our study area (Fig. 5).

4.2 Image processing and lineament mapping

The different treatments of satellite images using several techniques (PCA, color compositions, contrast enhancement, linear spreading, histogram equalization) have resulted in the radiometric enhancement of the images, making them more expressive and clearer.

To these processed images, Sobel directional filters (7x7 matrix) high frequency have been applied to enhance the discontinuities.

By combining, on the one hand, the images resulting from the various treatments carried out, notably contrast enhancement and filtering techniques and, on the other hand, the criteria defining the discontinuities-images, we were able to manually perform the mapping of all the Linear structures visible on the computer screen.

The linear structures were extracted, manually, from the images. A total of approximately 2347 lineaments of all directions were identified. They correspond to the hydrographic network, the topographic lines and the geological structures (Fig. 6).
4.3 Validation of the linear map

The lineament map this obtained is the result of a process of digital Landsat image processing by ENVI software (Fig. 6), combined with the use of the Geographic Information System (GIS) and field observations. The lineaments are numerous but are not exhaustive because the complexity of the fracturing and the image acquisition system make that all the fractures could not be detected.

To specify the structural significance of linear structures extracted from satellite images, the phase of control and validation of the lineaments is a necessary step [31].

4.3.1 Analysis of directional distributions of lineaments from Landsat images

The density of lineaments can be expressed either in number or cumulative length according to the distribution of the principal directions of these lineaments. Its representation can be in the form of directional rose window or histograms (Figs 7 and 8). This distribution of the main directions has been the subject of a statistical analysis as follows:

The analysis of these results leads to the following observations concerning the global fracturing field:

- According to the frequencies in number of lineaments (Figs 7b and 8b), three directional peaks of the fractures were highlighted. The most remarkable are observed in the directions N0° to N10°, N10° to N 20°, N20° to N30° with the respective proportions of 12%, 8% and 11% which represent the major directions. They correspond to the directions observed in the Ader Doutchi Block by [13], in the North-East of the study area. These authors have highlighted open kilometric lineaments of directions NE-SW (N8°) and NW-SE (N98°).

Other secondary directions also appear and are in less important compared to the first one. These are the directions N30° to N40°, N30° to N40°, N50° to N60°, N60° to N70°, N90° to N100° and N150° to N160° with proportion ranging from 6 to 7 % in number. A third family of lineaments emerges with the directions N70° to N80°, N80° to N90°, N100° to N110°, N110° to N120°, N120° to N130°, N130° to N140°, N140° to N150°, N160° to N170° and N170° to N180°. These directions are those of minor
lineaments with a percentage in number ranging from 2 to 5%.

- Depending on the orientation of the fractures in cumulative lengths (Figs 7a and 8a), the same trend appears with three families. The principal directions with a percentage of 7 to 11%, secondary directions with 6 to 9% and minor directions with a percentage ranging from 2 to 5%.

These directions are in good accordance with those resulting from the replay of deep Tertiary and Quaternary structures in the Gao Ditch [3]. These deep structures induced soft and brittle deformations in the Iullemmeden basin, particularly in the northern part (Tin Sérifin and Irhazer basins), where [3] defined four accident families of unequal importance, suborthogonal and conjugate two by two. These are the following directions: N60° E to E-W, N110° to N140° E, N170° E to N-S and N10° to N30°E.

After analysis and comparison of the principal directions of lineaments identified with those described by [13], we found a deep similarity. In fact, the orientations of the lineaments in general and the main orientation classes in particular are concordant at the level of the two zones. This observed concordance confirms and validates this detailed map of the lineaments of the Dosso region established from the Landsat images.

The structural scheme thus obtained may also add to the inventory of faults in the region. Lineaments mapped by satellite imagery and retained in this study after validation will be considered fractures or tectonic discontinuities.

4.3.2 Correlation between cumulative lengths and number of lineaments
Fracturing can be investigated by using the two parameters, namely the number of lineaments and the cumulative lengths. These two parameters express the density or the intensity of the fracturing. According to [31], to do this structural study well, it is necessary that these two parameters are correlated. This is the case of data from the processing of satellite images used in this study. Fig. 9 illustrates this correlation which exists between the number and the cumulative lengths of the lineaments whose characteristic equation is \( Y = 0.757x + 1.1966 \) and the correlation coefficient is \( R^2 = 0.6779 \). This value is well justified by the grouping of points along the regression line, as can be seen in the graph below (Fig. 9).

4.3.3 Validation of lineaments from field observations
The first validation tests carried out was to compare the main directions of the linear structures from the satellite images to those of the micro tectonic measurements made during the field trip. In the field, the measurements made directly on the outcrops were those of fracture directions and dips. From these field measurements we observed the same directions as the lineaments identified by the treatment of Landsat images of the study area.

Photo 1: Medium coarse sandstone of the Continental of Haiti with occasional presence of hardened level (yellowish-white). The deposits are massive and subhorizontal, more or less altered. Normal faults N60° to N90° with sinistral component were observed. (Sector of Bana)

Figure 10: Field Observations in Bana area (Department of Gaya)
Figure 1: Field Observations in the area of Tondika (Department of Gaya)

Figure 2: Field Observations south of Gaya (Department of Gaya)

Figure 3: Continental Hamadian formation comprising at the base the solid clay sandstones, passing vertically to conglomeratic sandstones yellowish to reddish colour. The deposits of the continental hamadian are affected by deformational low-angle faults or fractures (dip angle N120° and N180°, having an average dip of 20°). The settlement of faults between sandstones reduces a structure in microlithic and microcrystalline (Gaya area)

Figure 4: Continental Hamadian formation comprising massive clay sandstones, and conglomeratic sandstones yellowish to reddish in colour. Normal faults or fractures affect these deposits. The mean orientation of the deformations is between N120° and N180°. (Gaya area)

Figure 5: Outcrop of variated arkosites affected by large metric fractures (1 to 2 m) oriented N35°, on which are connected parallel small secondary fractures associated to a fault zone or deformation corridor. This corridor evolves and becomes a permanent stream or not contributing to the recharge of groundwater. (Bagagi, Dogondoutchi)

Figure 6: Medium size sandstones with NS0° fractures filled in by sandy ferruginous sandstone levels. (Bagagi, Dogondoutchi)

Figure 7: Field Observations in Bagagi’s area (Department of Dogondoutchi)

Figure 8: Massive medium sandstones with concentric structures of varying sizes of reddish colour. The thickness at the outcrop varies from 2 to 3 m. A network of fractures and cracks N40° and N50° affects this level of massive medium sandstones. (Mound of Dogondoutchi)
The fracture directions measured (Figs 10 to 14) are mainly N10° to N30°, followed by the directions N60° to N160° recalling the directions of lineaments highlighted from the satellite images.

These directions are also in accordance with those observed in the basins of Tin Sérrin and Ihazer. They result from the replay of deep Tertiary and Quaternary structures in the Gao Ditch [3].

These field observations enable us to validate the fracturing map thus generated from the satellite imagery of the Dosso region.

4.3.4 Relationship between the hydrographic network and major accidents

For the second validation test, the hydrographic network generated from SRTM image was superimposed on that of the lineaments resulting from the Landsat images processed in this study. Most of the lineaments are lined up on the hydrographic network (Fig. 15) in the major directions NE-SW and NW-SE, thus showing a correspondence between the flow of surface water and the main accidents in the dallols. We can then conclude that there is a concordance between the behavior of the hydrographic network and the major accidents observed on satellite images as described by [5] on the state of knowledge acquired in general in Africa. This relationship has also been demonstrated by other authors in the Niger Liptako and in the basement of Zinder region [21], [26].

This similarity between the lineaments and the hydrographic network also validates the fracturing map obtained in this study.

These linear structures evolve for the most part to become a permanent or temporary streams from which the groundwater recharge is made.

Figure 14: Field Observations in Matankari’s area (Department of Dogondoutchi)

Figure 15: Relationship between hydrographic network and lineaments

5. Conclusion

The methodological approach adopted in this work shows that remote sensing image processing methods allow the cartography of lineaments and that of some geological structures of the Dosso region. These results from this study are consistent with those obtained in previous work done in the north-east of the study area. These methods allowed not only the highlighting of the linear structures but also to give the different directions mainly NE-SW and NW-SE which are the directions of major faults, observed in the Ader Doutchi in the North-East and in the Kandi basin (Kandi fault) in the South.

It is also clear that the lineament directions fit well with that of the major fractures affecting the Iullemmeden basin. The main directions of lineaments highlighted in this study would be of the same origin as that of Ader Doutchi.

According to the observations of [13], the 4°50’ accident would have just crossed the Iullemmeden basin without marking the tertiary and would have continued further south by the Kandi Fault in Benin. In contrast to these last observations, the combination of the techniques of remote sensing and GIS with the field observations rather highlights the replay in the tertiary bases of major fault satellite accidents such as the Kandi fault.

The results of this study confirm the reliability of this approach combining the use of remote sensing, GIS and field observations. For the study area, this technique can be used as a new effective tool for hydrogeological prospecting.
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References


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