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# 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.

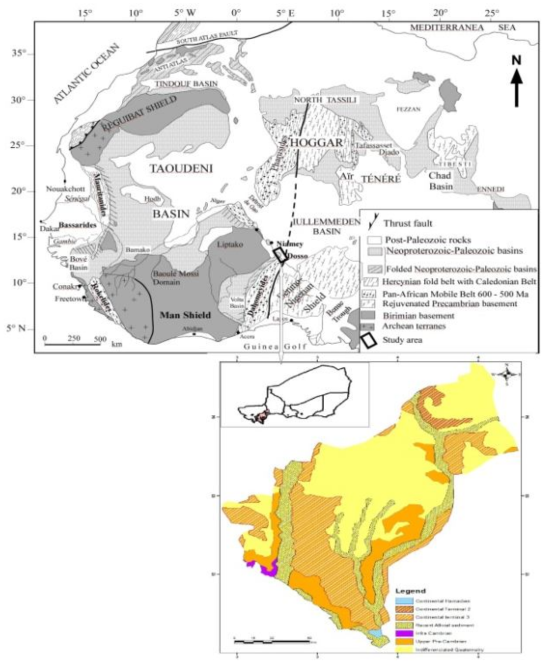


**Figure 1**: Iullemmeden basin structural schematic map after [36], modified and localization of study area within Iullemmeden basin

## 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.

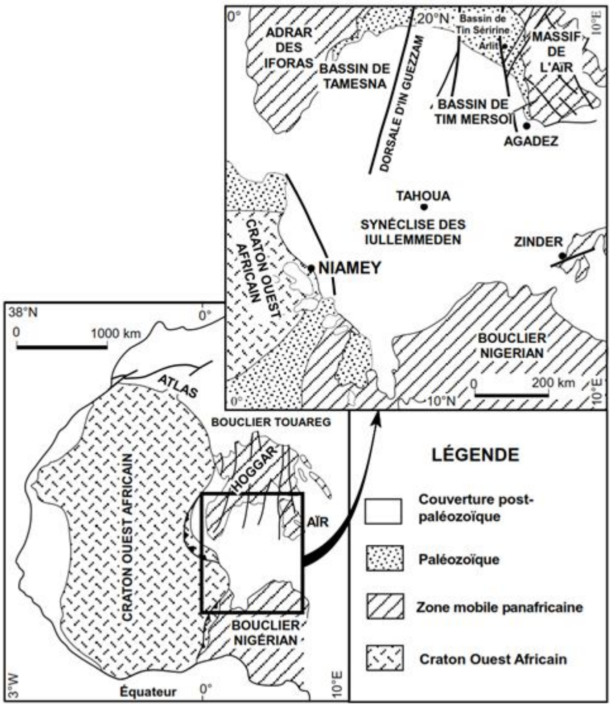


**Figure 2:** Location of the Synéclise of Iullemmeden [37], [38] modified.

The Iullemmeden basin contains sedimentary series ranging in age from Cambrian to Quaternary. **Table 1** below [34] gives a general overview of the sedimentary series of the Iullemmeden basin.

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

| Era | Age | Formations | | Group | Environment |
|---|---|---|---|---|---|
| **Quaternary** | | Alluvial deposits, wind, glacis, Terrace, Ironstone breastplate | | | |
| CENOZOIC | Mio-Pliocène or ''Continental Terminal'' | Clay sandstone of the Middle Niger (CT3)<br>Red sandstone and Clay sandstone<br>Lignite clay sandy series (CT2) | | | (*continental*) |
| CENOZOIC | Middle Eocene to Lower Paleocene Inférieur | Sidérolithique series of Adrar Doutchi (CT1)<br>Clay to Attapulgites<br>Limestone of *Ranikothalis bermudezi* and *Lokhartia haimei*<br>Papery and limestones clays to *Elphidiella* sand | | Continental hamadien | (*continental*)<br>(*coaline marin*)<br>(*neritic marin*)<br>(*coastal marin*) |
| MESOZOIC | Maastrichtian terminal | limestones in *Libycoceras and Laffiteine* | | Continental hamadien | (*neritic marin*) |
| MESOZOIC | Maastrichtian to Campanian | Upper Sandstones and Mudstones<br>Mosasaurus Shales (*Libycocaras*)<br>Lower Sandstones and Mudstones | | Continental hamadien | (*coastal lagoon*)<br>(*coastal marin*)<br>(*coastal lagoon*) |
| MESOZOIC | Senomanian (lower) | Clays and limestones | | Continental hamadien | |
| MESOZOIC | Turonien (upper)<br>Turonien (lower)<br>Cenomanian (upper) | White limestones series<br>Limestones to *Nigericeras*<br>Calcaires à *Neolobites vibrayoanus* | | Continental hamadien | (*marin*) |
| MESOZOIC | Cenomanian lower | Farak Formation | | Continental Intercalary | (*continental*) |
| MESOZOIC | Albien to Neocomien | Tégama series | Echkar's formations<br>Elrhaz's formation<br>Tazolé's formation | Continental Intercalary | (*continental*) |
| MESOZOIC | Berriasian à Upper Jurassic | Dabla Series | Irahzer Clay<br>Assouas Sandstones<br>Tchirézrine 2 Sandstones | Continental Intercalary | (*continental*) |
| MESOZOIC | Middle Jurassic to Trias | Agadès Sandstones | Wagadi: Abinky Analcimolites, Tchirézrine 1 Sandstones<br>Goufat: Mousseden Analcimolites, Téloua 2 Sandstone<br>Aguélal: Téloua 1 Sandstone | Continental Intercalary | (*continental*) |
| PALEOZOIC | Permien | Izéguandane series | Moradi Clay-stone<br>Tamamait Sandstone<br>Téjia Clay<br>Arkoses of Izéguande | Continental Intercalary | (*continental*) |
| PALEOZOIC | Carbonifère lower (Viseen upper ?) | Upper Tagora series | Argilites and fine stone of Madaouéla<br>Tarat sandstone | | (*epicontinental marin*) |
| PALEOZOIC | Carbonifère lower (Viseen upper ?) | Lower Tagora series | Argilites and fine stone of Tchinézogue<br>Guézouman sandstone | | (*epicontinental marin*) |
| PALEOZOIC | Carbonifère lower (Viséen lower) | Térada series | Argilites to gypsum, silts and Talach sandstone<br>Arkoses, Téragh-Farazekat conglomerat | | (*marin*)<br>(*continental*) |
| PALEOZOIC | Devonian upper | Amesguer sandstone and gypsum pasmite | | | (lagoon) |
| PALEOZOIC | Devonian middle | 'Akara shistes'<br>Touaret fine sandstone to iron oolites | | | (*marin*)<br>(*neritic marin*) |
| PALEOZOIC | Devonian lower | Idekel sandstone | | | (*continental*) |
| PALEOZOIC | Silurien<br>Ordovician upper | 'Schistes to Graptolites'<br>Fine clay sandstone, limestone | | | (*marin*) |
| PALEOZOIC | Cambro-ordovician | In Azaoua Sandstone<br>Sandstone to Tigillites, and clays<br>Timesguar sandstone | | | (*marin*) |
| **PRECAMBRIEN BASE** | | | | | |

## 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 are being:

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

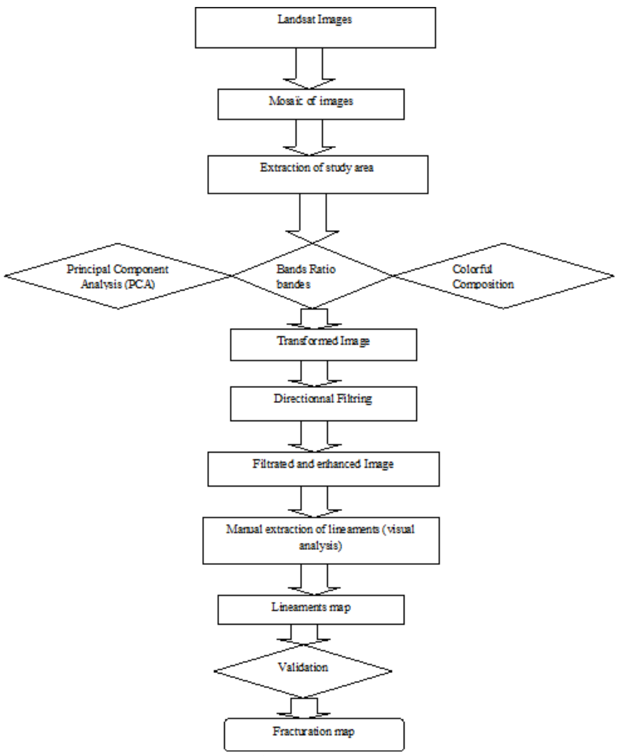


**Figure 3:** Flow chart of treatment and lineament mapping.

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;

- 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)**.

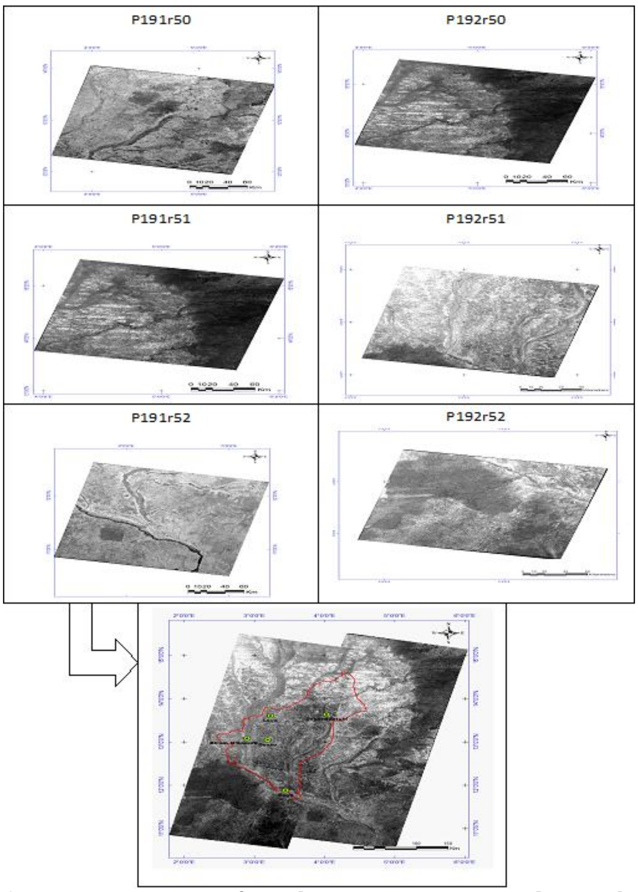


**Figure 4:** Six scenes of Landsat images corresponding to the study area. The last image that comes from mosaicing covers the study area.

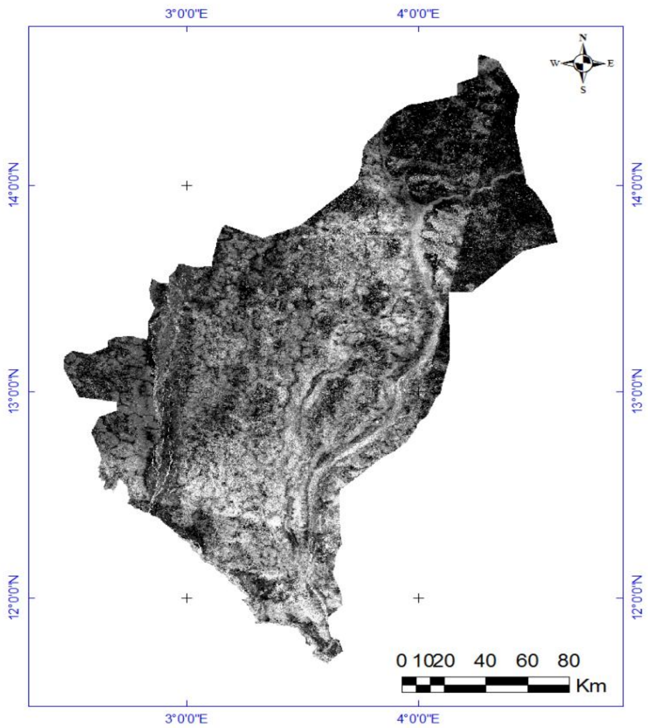


**Figure 5:** Image of the study area, extracted from the mosaic image

### 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)**.

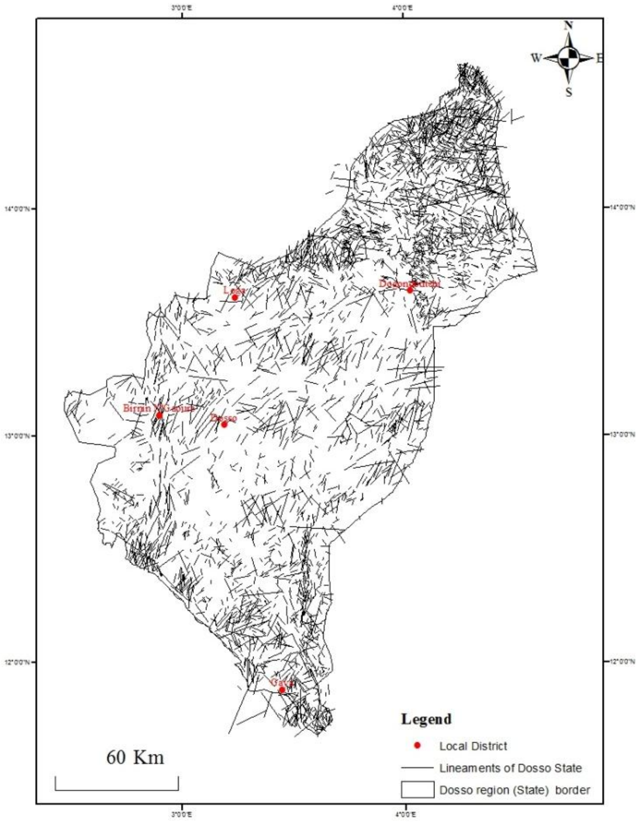


**Figure 6:** Map of lineaments from Landsat image processing

### 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:

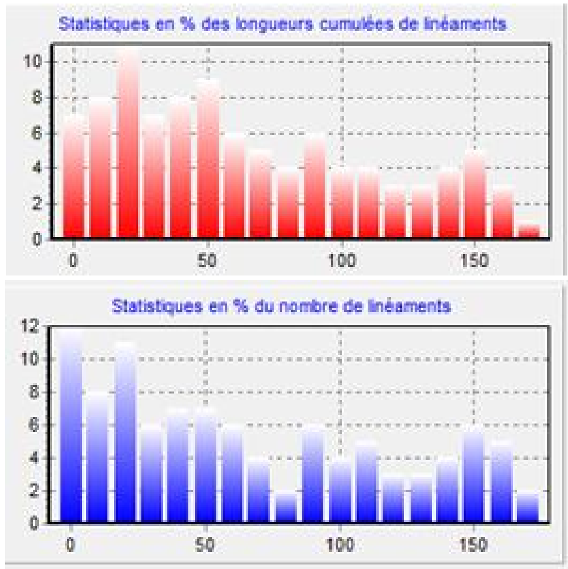


**Figure 7:** Directional histogram of the lineaments of the study area: a) according to the cumulative lengths and b) according to the number.

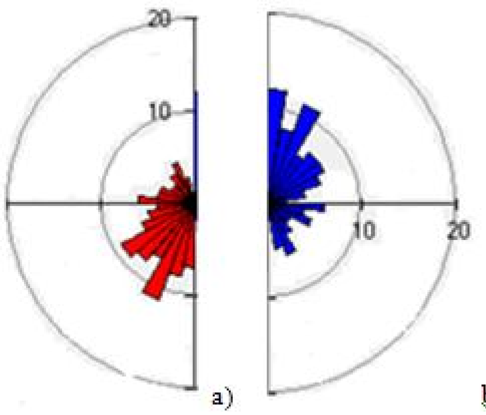


**Figure 8:** Directional rose window of the lineaments of the study area: a) according to the cumulative lengths and b) according to the number

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).**

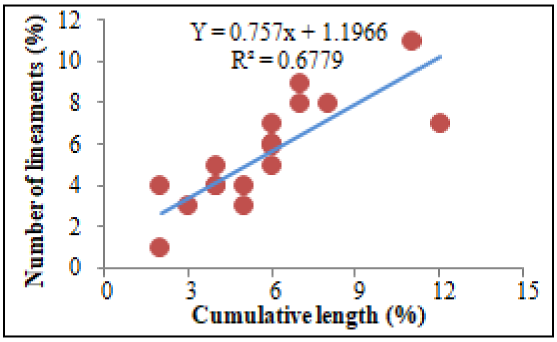


**Figure 9**: Relationship between the number and the cumulative lengths of the lineaments

**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.

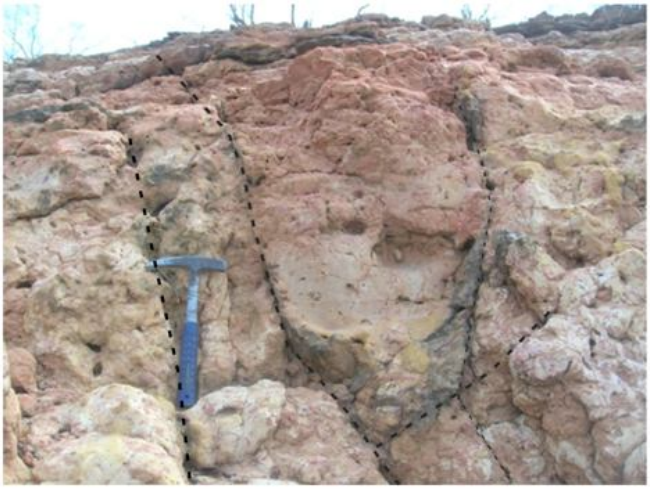

**Photo 1:** Medium coarse sandstone of the Continental of Haiti with occasional presence of hardened level (yellowish-white). The deposits are massive and subhorizontal, more or less altered. Normal faults N60 ° to N90 ° with sinistral component were observed. (Sector of Bana)

**Figure 10**: Field Observations in Bana area (Department of Gaya)

**Photo 2:** Cataclasis area, in the pan-African quartzitic base, linked to Kandi's N 10 ° to N 30° fault. The outcrop width of the noncohesive cataclasite varies from 1 to 2 m. (Tondika, South Gaya)

**Photo 3**: Cataclasis Ordovician Sandstone in the crossing zone of the N10° to N30° Kand's fault. The Cataclasis area with a width of 30 to 50 m is associated with several Micro-fracture plans with silica filling. The deformed rock corresponds to a cohesive cataclasite. The sandstone benches are generally north-south and have an average dip of 40° E. (South Gaya)

**Figure 11:** Field Observations in the area of Tondika (Department of Gaya)

**Photo 4**: 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 deformations like faults or fractures (Orientation N120° and N160°, having an average dip of 50°). The settlements of faults sometimes induce a structure in microhorse and micrograben (Gaya area)

**Photo 5**: Continental hamadien 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 N160 °. (Gaya area)

**Figure 12:** Field Observations south of Gaya (Department of Gaya)

**Photo 6**: Medium size sandstones with N80° fractures filled in by sandy ferruginous sandstone levels. (Bagagi/Dogondoutchi)

**Photo 7**: Outcrop of variegate argillite affected by large metric fractures (1 to 2 m) oriented N15°, on which are connected parallel small secondary fractures associated to a fault zone or deformation corridor. This corridor evolves and become a permanent stream or not contributing to the recharge of groundwater. (Bagagi/Dogondoutchi)

**Figure 13:** Field Observations in Bagagi's area (Department of Dogondoutchi)

**Photo 8**: Moltey medium sandstone 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 N140 ° and N50 ° affects this level of moltey medium sandstone. (Matankari/Dogondoutchi)



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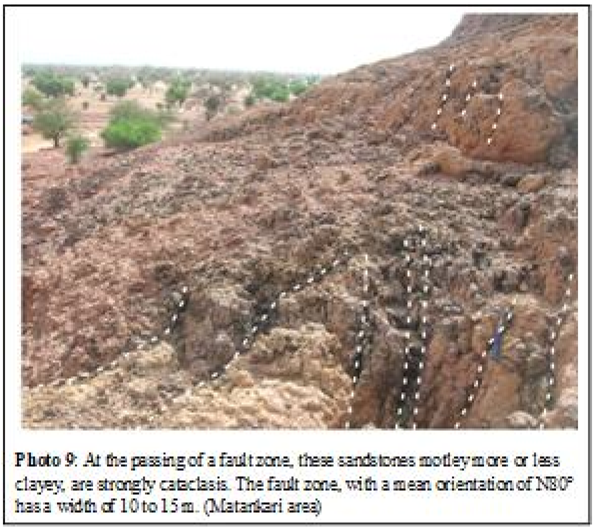


**Figure 14:** Field Observations in Matankari's area (Department of Dogondoutchi)

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 Irhazer. 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.

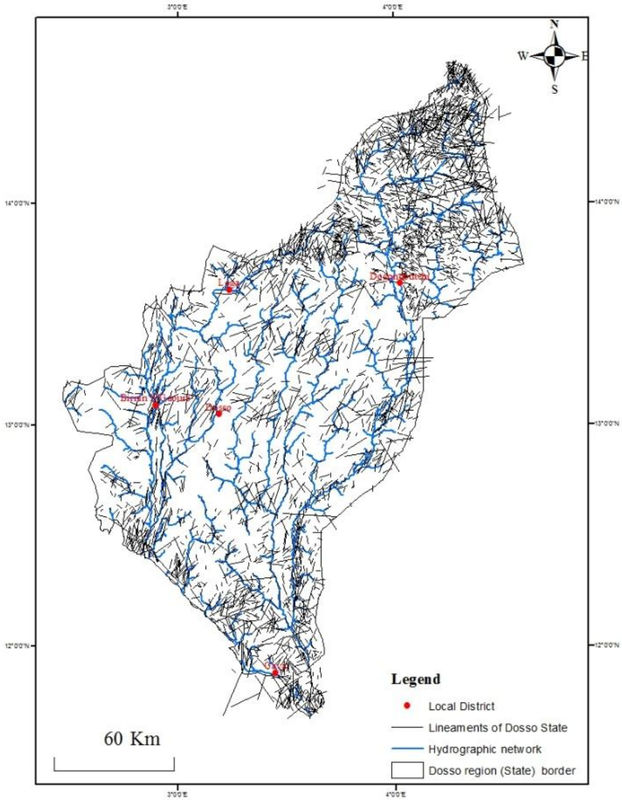


**Figure 15:** Relationship between hydrographic network and lineaments

## 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.

## 6. Acknowledgement

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## References

[1] **A. M. S. BABAYE. (2012).** Evaluation des ressources en eau souterraine dans le bassin de Dargol (Liptako-Niger). Thèse de Doct., Univ. Liège, 244 p.

[2] **ASSOMA T.V. (2005).** Combinaison d'images ROS de RADARSAT 1 et D'ERS-2, et TM+de Landsat-7 pour la cartographie des potentialités hydrogéologiques des aquifères de socle fracturé : cas du bassin versant du Koué à l'ouest de la Côte d'ivoire. Mém. de DEA hydrogéologie, Univ. Cocody, 104p.

[3] **BELLION YJ C. (1987)**. Histoire Géodynamique post-paléozoïque de l'Afrique de l'Ouest d'après l'étude de quelques bassins sédimentaires (Sénégal, Taoudéni, Iullemmeden, Tchad).Thèse d'état Es Science Univ. Avignon et des Pays de Vaucluse 296p

[4] **BELLION Y. (1989)**. Histoire géodynamique post-paléozoïque de l'Afrique de l'Ouest d'après l'étude de quelques bassins sédimentaires (Sénégal, Taoudeni, Iullemmeden, Tchad). Publ. CIFEG, 1989/17.

[5] **BIEMI J. (1992):** Contribution à l'étude géologique, hydrogéologique par télédétection des bassins Versants subsahéliens du socle précambrien d'Afrique de l'Ouest: Hydrostructurale, hydrodynamique, hydrochimie et isotopie des aquifères discontinus de sillons et aire granitique de la haute Marahoué (Côte d'Ivoire). *Thèse Doct. ès Sc. Nat. Univ. Abidjan, 479p.*

[6] **BODIN R. ET RAZACK M. (1999).** L'analyse d'images appliqué au traitement automatique de champ de fractures. Propriétés géométriques et los d'échelles. Bul. de la société géologique de France, tome 170, n°4, pp. 579-593.

[7] **BOECKH E. (1965)**. Contribution à l'étude hydrogéologique de la zone sédentaire de la république du Niger. Rapport technique BRGM/BFBH, DAK 65-A 20. Dakar, Sénégal

[8] **DADDY GAOH A. (1993).** Etude des nappes aquifères du continental terminal entre les Dallols Bosso et Maouri (République du Niger)*.Thèse,Université de Liége, Belgique.*

[9] **DUBOIS, D., LANG, J.(1981)**. Etude litho-stratigraphique et géomorphologique du Continental Terminal et du Cénozoïque Inférieur dans le bassin des Iullemmeden (Niger). *Bull.I. F. d'Áfrique Noire, t.43,sér.A, nos 1-2, 1984.*

[10] **DUBOIS, D., LANG J., IFAN. (1984).** Etude lithostratigraphique et géomorphologique du continent terminal et du cénozoïque inférieur dans le bassin des lullemmeden, Dakar- IFAN.

[11] **FAVREAU G. (2000)**. Caractérisation et Modélisation d'une nappe phréatique en hausse au Sahel dynamique et géochimie de la dépression piézométrique naturelle du kori de Dantiandou (sud-ouest du Niger. Thèse de doctorat Univ. Paris XI, Orsay, France.

[12] **GUERO A. (2003)**. Étude des relations hydrauliques entre les différentes nappes du complexe sédimentaire de la bordure Sud-Ouest du bassin des Iullemeden (Niger)–Approches géochimiques et hydrodynamiques. Thèse d'État de Docteur-es-sciences, Université de Paris XI, Orsay, France, 238p.

[13] **GUIRAUD R., HALIDOU S. (1981)**. La faille de Kandi (Bénin), témoin de rejeu fini-crétacé d'un accident majeur à l'échelle de la plaque africaine. C.R. Accad. Sci. Paris, 293, pp. 779-782.

[14] **GREIGERT J. (1957)**. Introduction à la connaissance hydrogéologique du Niger: deuxième partie, Structure des dépôts crétacés et tertiaires du bassin occidental du Niger. Dakar, Senegal.

[15] **GREIGERT J., POUNET R. (1965).** Carte géologique de la République du Niger au 1: 2 000 BRGM ed. Paris, France.

[16] **GREIGERT J. (1966a)**. Description des formations crétacées et tertiaires du bassin des Iullemmeden (Afrique occidentale). BRGM ed., 229 p. Paris, France

[17] **GREIGERT J. et POUGNET R. (1967).** Essai de description des formations géologiques de la république du Niger. *Publication Direction des Mines et de la Géologie, Niger, n°3, 273 pages.*

[18] **GREIGERT J., MARTIN G. (1977).** Etude pour le développement de socles hydrogéologiques de l'Ouest nigérien. Troisième campagne. Implantation de puits par sondages à la tarière mécanique et par géophysique. Rapport BRGM 77, 143p.

[19] **GREIGERT J. (1978)**. Atlas des eaux souterraines de la République du Niger. Etat des connaissances. Rapport BRGM, 79 AGE001. Orléans, France.

[20] **INC. (1986)**. Programme d'hydraulique villageoise dans les départements de Tahoua et Dosso. Secteur Géologique et hydrogéologique, rapport général. Ministère de l'Hydraulique et de l'Environnement de la République du Niger. Rapport technique INC, 269 p. Niamey, Niger.

[21] **KARIMOUNE S., OZER A., ERPICUM M. (1990).** Les modèles éoliens de la région de Zinder (Niger méridional), étude de photogéomorphologie, note préliminaire. Ed. AUPELF-UREF, pp 145- 161.

[22] **KOUAME K F., GIOAN. P, BIEMI. J, KOUADIO A. (1999):** Méthodes de cartographie Des discontinuités-images extraites d'images satellitales : exemple de la région semi-montagneuse à l'Ouest de la Côte d'Ivoire. *Télédétection.Vol I. pp. 1396156.*

[23] **KOUAME K F. (1999).** Hydrogéologie des régions de Montagne : apports des données de télédétection et des méthodes statistique et factale à l'élaboration d'un système d'information hydrogéologique à référence spatiale des aquifères discontinus du secteur Man-Danané (Ouest de la Côte d'Ivoire). Thèse Doct.3ècycle, Univ. Cocody, 215p.

[24] **KOUSSOUBE Y., SAVADOGO A N. (2000):** Les différentes signatures des fractures de socle cristallin en zone sahelo-soudanienne du Burkina Faso : cas du bassin versant de Bidi (province du Yatenga). La télédétection en Francophonie :analyse critique et perspectives. *Ed.AUF. pp. 263- 270.*

[25] **LASM T. (2000).** Hydrogéologie des réservoirs ractur és de socle : Analyses statistiques et géostatistiques de la fracturation et des propriétés

hydrauliques. Application à la région des montagnes de Côte d'Ivoire. Thèse Doct., Univ. Poitiers, France, 274p.
[26] **OUSMANE B. (1988)**. Etude géochimique et isotopique des aquifères du socle de la bande sahélienne du Niger (Liptako, Sud-Maradi, Zinder-Est). Thèse Doct. Univ. Niamey, 175p.
[27] **PROJET FAO/SF: 281/NIR 8. (1970)**. Etudes en vue de la mise en valeur du Dallol Maouri, Niger: les eaux souterraines. - Rome, Italie – 162p., cart., graph.
[28] **RADIER H. (1957)**. Contribution à l'étude géologique du Soudan oriental (A.O.F.). Bulletin du service géologique et de prospection minière, n°26, Dakar, 1959.
[29] **RAKOTONIAINA S. (1998).** Analyse en composantes principales d'une image multispectrale de télédétection. Revue Mada- Géo : journal des sciences de la terre, Vol. 2, ISSN 2074-4587 pp :3-5.
[30] **RAPPORT FINAL ADT DU SYSTEME AQUIFERE D'IULLEMMEDEN DANS LA PORTION NIGERIENNE. (2005)**. Projet régional MSP/GEF. Gestion des Risques hydrogéologiques dans le Système Aquifère D'Iullemmeden.
[31] **RAZACK M. (1984)**. Application de méthodes numériques et statistiques à l'identification des réservoirs fissurés carbonatés en hydrogéologie. Thèse Doct. Es Sci. ; Univ. Languedoc, 384p.
[32] **SALEY M B. (2003).** Système d'informations hydrogéologiques a référence spatiale (SIHRS), discontinuités pseudo-images pour la cartographie thématique des ressources en eau de la région semi-montagneuse de man (ouest de la côte d'ivoire). Thèse unique Doct., Univ. Cocody, 209p
[33] **SCANVIC J Y. (1983).** Utilisation de la télédétection dans les sciences de la terre. Ed. BRGM. Manuel et Méthodes. Vol. 7,160p.
[34] **TAQUET, PH. (1976)**. Géologie et Paléontologie du gisement de Gadoufaoua (Aptien du Niger). Cahiers de Paléontologie, CNRS, 192p.
[35] **TIRAT M. (1964).** Contribution à l'étude hydrogéologique du continental terminal. Rapport BRGM, NIA. 64. Ai, 77p. Niamey, Niger.- Orléans: BRGM, - Projet NIA. 64. A1.
[36] **TROMPETTE R. (1973)**. Le Précambrien supérieur et le Paléozoïque inférieur de l'Adrar des Mauritanie (bordure occidentale du bassin de Taoudeni, Afrique de l'Ouest). Un exemple de sédimentation de craton. Etude stratigraphique et sédimentologique. - Trav. Lab. Sci. Terre, Marseille (St- Jérome), 1 et 2, 573 p.
[37] **VALSARDIEU C. (1971)**. Etude géologique et Paléogéographique du Bassin de Tim Mersoï : Région d'Agadès (République du Niger). Thèse Université de Nice, 514 pages.
[38] **WRIGHT L. I., BRANCHET M. ET ALISSO I. (1993)**. Notice explicative de la carte géologique du bassin houillier d'Anou Araren / Solomi. Ministère des Mines et de l'Énergie, Niger, 20 pages.

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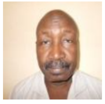

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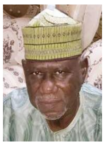

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