Research article Available online www.ijsrr.org ISSN: 2279–0543

International Journal of Scientific Research and Reviews

Characterization of Hydrological Network and Fracturing in the North of the Basin of the Comoé River in Côte d'Ivoire

Tie Y. H.[1*], Ouedraogo M.[1], Bamory K.[1], Savane I.[1] and Biemi J.[2]

[1]Université Nangui Abrogoua, 01 BP 10588 Abidjan 01, Côte d'Ivoire.
[2]Université Félix Houphouet Boigny, 08 BP 42 Abidjan 08, Côte d'Ivoire

ABSTRACT

The main objective of this work is to characterize the hydrologic and hydrogeologic networks Watershed of river Comoé, specifically in the northern part having outlet the locality of Aka-Komoékro in Daoukro's Sub-Prefecture in order to assign guidance for the implementation of drilling and inform the scientific community. It is to study the characteristics of the hydrographic network and fracturing in this area.

The network of the Comoé river takes all types of structures (dendritic, parallel, lattice, and radial rectangular) depending on the morphology of the crossing area. Gentle slopes and small drainage area gives a low and irregular regime to the river system. It footprints fractures in several places, giving it a route sawtooth.

The basin is densely fractured. Major fractures are oriented N0-N10, N20-N30 and N90-N100. In numbers, the main orientation is N0-90.

KEYWORDS: Comoé River, watershed, divide.

Corresponding Author :

Tie Yro Hyacinthe
Université Nangui Abrogoua,
01 BP 8200 Abidjan 01, Côte d'Ivoire.
E-mail : tieyroh@yahoo.fr / tieyroh@gmail.com

INTRODUCTION

Facing the poor physico-chemical and bacteriological quality of the surface water which often requires very expensive treatments, searching for drinking water has turned to groundwater which quality usually meets the standards of potability of WHO[1].

So therefore, the water supply in Africa, in particular in Côte d'Ivoire, is using wells dug in the otherness or boreholes dug for most in the basement.

Research of groundwater in middle of base is essentially based on the identification of fractures that are the witnesses of tectonic deformations. A drilling which does not cross a fracture of this medium cannot produce water. Failures are so many during drilling campaigns when implantation is not conducted in optimal conditions [2]. Côte d'Ivoire which 97.5% of the territory is made up of base consisting of aquifers cracked and the regolithis no exception to this rule.

Northern watershed of the Comoé River, one of the four largest basins of Côte d’Ivoire [3] with an area of 78,000 km^2, the subject of this study, has a low rainfall compared to the South of the country, and access to drinking water is difficult.

The main objective of this work is to characterize the hydrologic and hydrogeologic networks of watershed of comoé river, precisely in the northern part having outlet Aka-Komoékro locality, in the Sub-Prefecture of Daoukro, in order to provide guidance for the implementation of the drilling and to inform the scientific community.

MATERIALS AND METHODS

Studysite

The Comoé riveris one of the four biggest rivers of Côte d'Ivoire. It has its source in Burkina Faso, Peni and crosses Côte d’Ivoire from North to South to discard at sea in Grand Bassam. Its watershed also has a small incursion in Mali and Ghana. The study covers the northern part of the watershed with an area of 56,681 km^2, whether 72.6% of the total basin of the Comoé river.

The study area is covered, in Côte d'Ivoire, by four types of local climates: Sudanese climate, the Sub Sudanese climate, Baouléen North climate and Baouléen East climate [4]. Absolute minimum temperatures range from 12 °C in December to 21 °C in April and maximum temperatures range from 28 °C in August to 37 °C in February. Rainfall is low and irregular [5]. The major part of the studied basin beneath the isohyet 1200 mm.

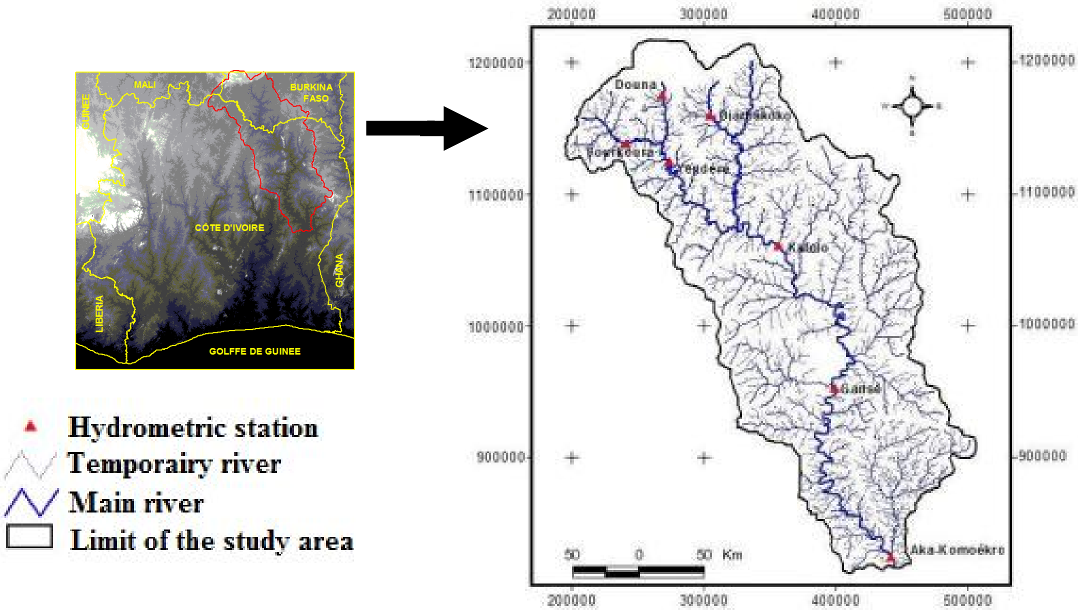


Figure 1: the area of study

Generally, the vegetation gradually changes from south to north of a dense forest largely degraded to an open forest then a wooded savanna and grassland savanna, marked by the presence of large plantations of cashew.

The relief is flat with few peaks in North and Centre. The entire study area has a low slope that partly influences the regime of Comoé river. From the geological point of view, the study area belongs to the Precambrian paleo-protorozoique field. It is dominated by granite and shale. Overall, soils are reworked type, indurated type.

Material and data for mapping lineaments

This study raised (table 1), geological maps and geomining satellite images, database mapping of Côte d'Ivoire (table 2), statistics and mapping software for data processing, and Office Automation (table 3). This material has enabled the thematic maps and different graphics interpreted in this study.

Table No. 1: Characteristics of satellite data

Data	Date of acquisition	Coordinates P/R	spectral Bands	Spectral Domain	Resolution space
ETM +	20/01/2002 29/01/2002 13/04/2000 02/18/2001	197/55 196/55 196/56 197/56	1 [0, 45-0, 51 µm] 2. [0, 52-0, 60 µm] 3. [0, 63-0, 69 µm] 4. [0, 75-0, 90 µm] 5. [1, 55-1, 75 µm] 6. [10, 40-12, 50 µm] 7. [2, 09-2, 35 µm] P. [0, 52-0, 90 µm]	Blue Green Red Near-infrared Middle infrared Thermal infrared Far infrared Panchromatic	30 × 30 m 30 × 30 m 30 × 30 m 30 × 30 m 30 × 30 m 60 × 60 m 30 × 30 m 15 × 15 m
TM	16/01/1986 24/12/1988 30/12/1990 16/01/1986	197/55 196/55 196/56 197/56	1 [0, 45-0, 53 µm] 2. [0, 52-0, 60 µm] 3. [0, 63-0, 69 µm] 4. [0, 76-0, 90 µm] 5. [1, 55-1, 75 µm] 6. [10, 40-12, 50 µm] 7. [2, 08-2, 35 µm]	Blue Green Red Near-infrared Middle infrared Thermal infrared Far infrared	30 × 30 m 30 × 30 m 30 × 30 m 30 × 30 m 30 × 30 m 120 × 120 m 30 × 30 m

Table No. 2: Characteristics of map used

Map	Degree square	Year of production	Scale
Geological	Agnibilékro-Kaya Dari Bondoukou Dimbokro Me M'Bahiakro Nassian	1995 1995 1995 1995 1995	1: 200 000
Geomine	Bounadiali Bouna-Téhini Dabakala Kong Korhogo Niellé	1982 1982 1982 1982 1982 1982	1: 200 000

Table No. 3: Mapping and digital processing software

Software	Use
Excel 3.0	Recording format DBF4, tables of values to make them usable by Arcview GIS 3.2
ArcView GIS 3.2	Digitization of maps, hydrographic networks and realization of most thematic maps
Surf 8.02	Design of thematic maps such as the density of fracturing, drainage
ENVI 4.3	Satellite image processing
Paint	Arrangement of the maps and figures
Excel 2007	Digital data processing and realization of graphics

Methods

The fracturing analysis can be done in two ways[6]:

- a quantitative approach giving fracturing cards,
- a qualitative approach that allows statistical analysis.

We used both of these approaches.

The Digitization of maps was performed at the Cartography and Remote Sensing Center (CRSC)). The resulting digital map is georeferenced to have normal coordinates. Then, we trace, using software ENVI 4.3, vectors (curves, hydrological networks, geological formations and the watershed contours).

The Different enhancement techniques of Landsat image as colorful compositions, the band combination, the main component analysis and directional filtering (Table 4) used in this work are based on the work of [7, 8,9].

Table No. 4:Matrices of the applied filters

Sobel N-S

1	1	1	2	1	1	1
1	1	2	3	2	1	1
1	2	3	4	3	2	1
0	0	0	0	0	0	0
-1	-2	-3	-4	-3	-2	-1
-1	-1	-2	-3	-2	-1	-1
-1	-1	-1	-2	-1	-1	-1

Sobel E-W

-1	-1	-1	0	1	1	1
-1	-1	-2	0	2	1	1
-1	-2	-3	0	3	2	1
-2	-3	-4	0	4	3	2
-1	-2	-3	0	3	2	1
-1	-1	-2	0	2	1	1
-1	-1	-1	0	1	1	1

0	1	1	1	1	1	2
-1	0	2	2	2	3	1
-1	-2	0	3	4	2	1
-1	-2	-3	0	3	2	1
-1	-2	-4	-3	0	2	1
-1	-3	-2	-2	-2	0	1
-2	-1	-1	-1	-1	-1	0

Sobel NE-SW

2	1	1	1	1	1	0
1	3	2	2	2	0	1
1	2	4	3	0	-2	-1
1	2	3	0	-3	-2	-1
1	2	0	-3	-4	-2	-1
1	0	-2	-2	-2	-3	-1
0	-1	-1	-1	-1	-1	-2

Sobel NW - SE

Before extraction of lineaments, roads and high voltage electrical wire are vectorized from multiple administrative maps included in the same coordinate system. Then, these linear anthropogenic elements are superimposed on different images photo-interpreted to avoid taking them into account in the extraction of lineaments. Linear elements are drawn using ArcView GIS 3.2 software.

The validation of lineaments card performed is based on the comparison of the great families of lineaments directions (from the processing of satellite image) with the directions of fracturing observed on geological map.

RESULTS AND DISCUSSION

Slope of the land

The map of slopes (Figure 2) highlights a field where the slopes are very low. Outside mountain areas, the rest of the basin is monotonous. However, this monotony is broken some times by grooves that can be interpreted as faults. Several classes of slope can be defined.

The class of the land of very low slope is along the rivers and especially of perennial rivers and in the different valleys. Slopes are more and more low towards the outfall, marrying the valleys left by the relief. Indeed, lower spaces become longer and wider towards the outfall and all slopes are oriented towards the river which is the unique valley of the basin.

The slopes are marked in the immediate vicinity of hills, plateaus and mountains of the area. Furthermore, the card slopes (Figure 2) shows major faults. These faults are, for the majority oriented N0-N10; N50-N60 and N160-N170, mainly in the sense of major accidents of Sassandra (N0-N10) and Man-Danané (N70-80) [10].

The Comoé basin is generally an area little rugged with high peaks not to exceed 800 m. The slopes are very low, giving the River a diet and irregular flow. This relief largely influenced the architecture of the hydrographic network, is printing many forms of the network (parallel, dendritic and rectangular). In the Man-Danané region, hydrographic trace architecture is essentially controlled by the geomorphology, tectonics, the nature of the underlying rocks and slope[10]. The hydrographic network is drawn over the ability to infiltration or runoff from streams.

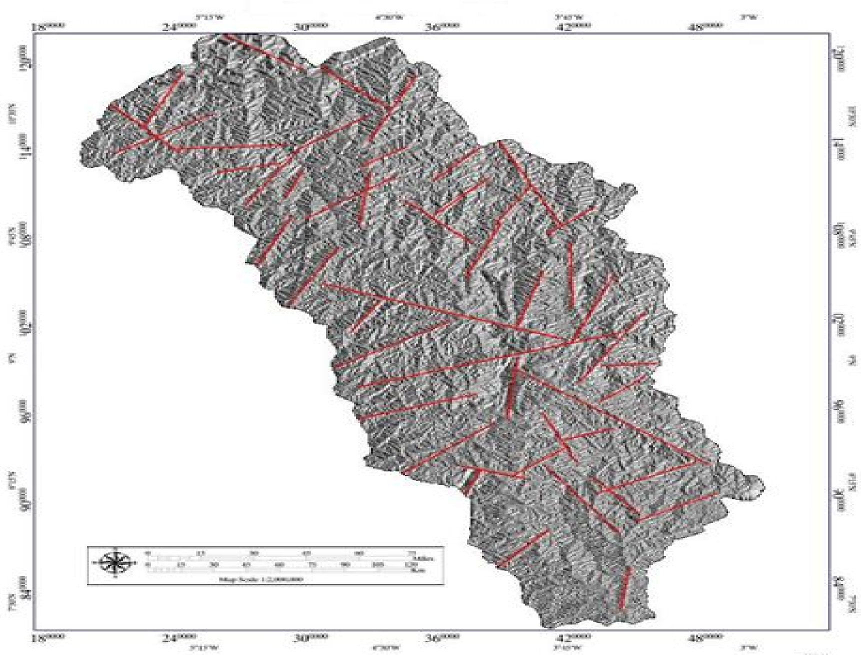


Figure 2: map of the study area slopes with a few major faults

Drainage

The study area is poorly draining. Indeed, much of the area has a drainage density of between 3 and 5 km/km^2. Maximum drainage density values range from 7 km/km^2 to 10 km/km^2 and occupy less than 10% of the total area of the basin (Figure 3). Drainage densities are lower in areas where elevations are highest. These areas are mainly located in the North and in the Center of the basin. However, the southern part of the area is more drained than the Central and Northern. Overall, the different drainage density classes have the same frequency, apart from class 0-1 km/km^2 which is the most dominant. There is therefore a close link between the drainage, slopes and terrain of the area.

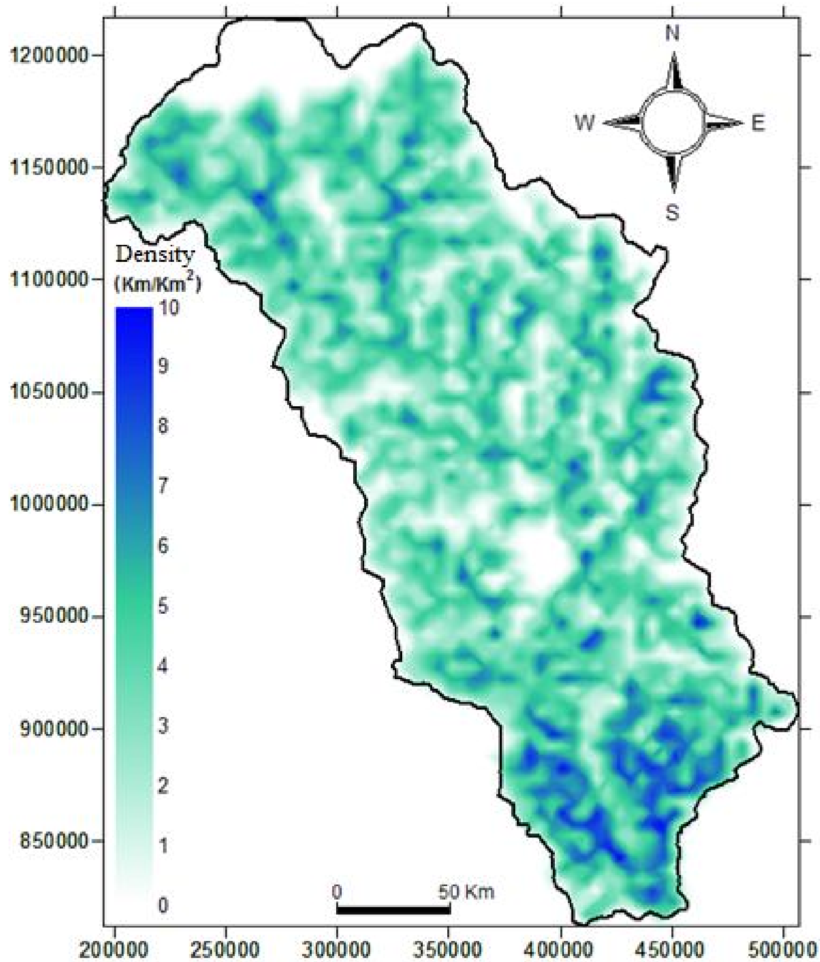


Figure 3: map of the drainage density

Structure of the hydrographic network

The hydrographic network of the study area is usually a dendritic and subdendritic. Figures 4 (A, B, C and D) have this type of network in different parts of the study area.

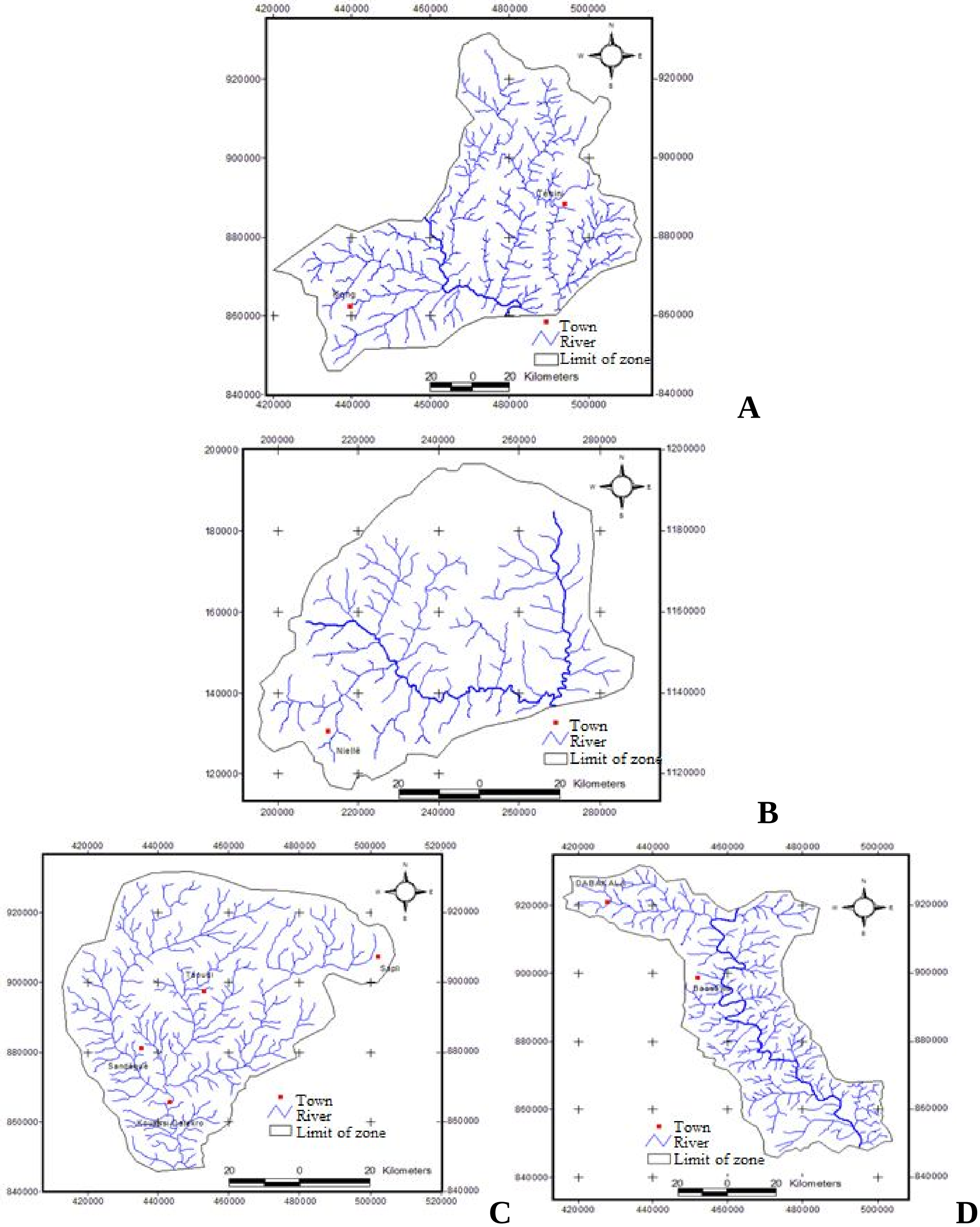


Figure 4 : Dendritic and subdendritic network

A: zone of Kong and Téhini **B : zone of Niellé**

C: zone of Tahoudi and Sandégué **D: zone of Dabakala and Bassawa**

Principal component on TM and ETM + images analysis

The principal component analysis applied to the bands of TM and ETM + images reveals that the first three components contain almost-all (99.75%) of the total variance present in the six soundtracks channel ETM + exploited. The results are presented in table 5.

Table No. 5: Percentage of information of the ACP in the bands

Band	Variance	percentage of information	Cumulative percentage
Band 1	5.86	97,63	97,63
Band 2	0.10	1.68	99.31
Band 3	0.03	0.44	99.75
Band 4	0.01	0.14	99.89
Band 5	0.01	0.08	99.97
Band 6	0.00	0.03	100.00

The first band (band 1) contains most of the information, or 97.63% of the expressed variance. The second and the third respectively were 1.68% and 0.44%. From the point of view of correlation, table 6 below shows that all bands are equal. Indeed, the report of the bands varies from 0.93 to 1. The first three channels that contain alone 99.75% of information were therefore selected for further processing.

Table No. 6: Correlation of the bands

Corrélation	Band 1	Band 2	Band 3	Band 4	Band 5	Band 6
Band 1	**1,00**	1,00	0,98	0,98	0,96	0,94
Band 2	1,00	**1,00**	0,99	0,98	0,98	0,95
Band 3	0,98	0,99	**1,00**	0,97	0,99	0,98
Band 4	0,98	0,98	0,97	**1,00**	0,97	0,93
Band 5	0,96	0,98	0,99	0,97	**1,00**	0,99
Band 6	0,94	0,95	0,98	0,93	0,99	**1,00**

Mapping the lineaments of the study area

The map in figure 5 includes all identified major lineaments. They are a total of 1536 for a cumulative of 10 800 km length. The network is dense enough and the various elements are interconnected in places. Nevertheless, certain areas are voids (Visual perception) on the map. They are generally mountainous areas. Lineaments lengths range from a few tens of meters to kilometers. The average length of lineaments is 7.3 km.

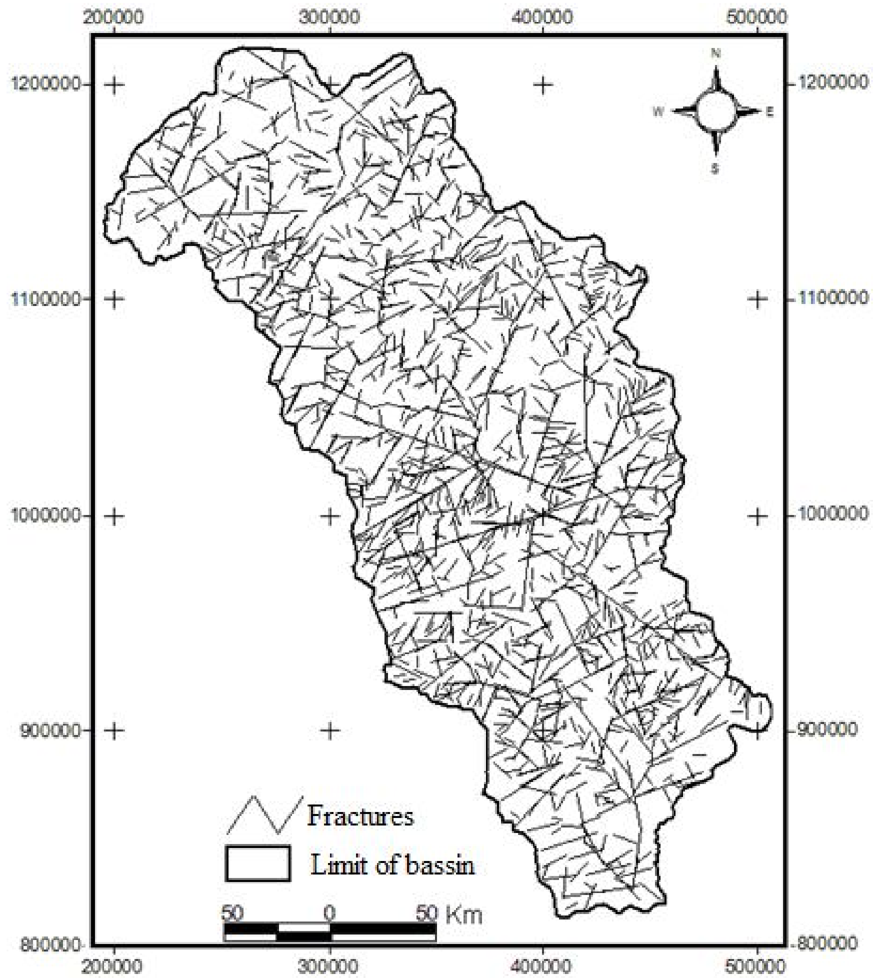


Figure 5: Map of the study area's major fractures

Geometric characterization of the field of fractures

Figure 6 shows the escutcheon of directional spectrum of the lineaments of the study area. This escutcheon shows that three classes are distinguished with respective frequencies of 12%, 9% and 8%. These classes are N0-N10, N20-N30 and N90-N100. Then come the N60-N70 and N70-N80directions with 7% and the N10-N20 and N150-N160 with 6%. N100-N110, N160-N170 branches each have a frequency of 5%. Single direction N80-N90 has a low frequency (2%). Orientation N0-N90 has a frequency of 56% in number of lineaments (Figure 7). This distribution, if it is expressed as length cumulative lineament in each direction, presents another face. Indeed, five (5) directions predominate. It's N0-N10 (9%), N20-N30, N50-N60, N70-N80 and N90-N100 directions with 8%. Two other directions (N10-N20 and N30-N40) have a frequency of 7%. The lowest distribution is the direction N170-N180 with 2%. In total, the orientations of the lineaments are not homogeneous, even if the N0-N10 direction is predominant.

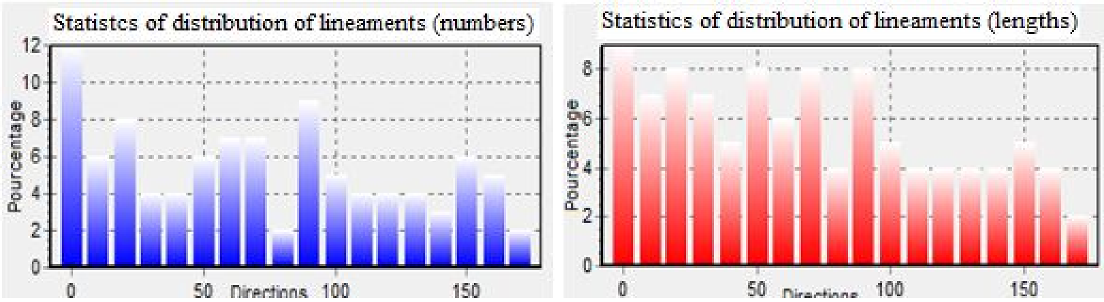


Figure 6: Curves of the lengths and numbers of fractures

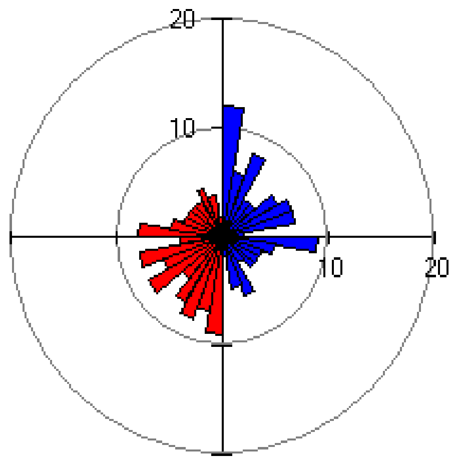


Figure 7: Directional fractures of the study area rose

The fracturing density distribution

Fracturing density distribution shows that the area is pretty well fractured. Indeed, the index of fracturing revolves around 50% (Figure 8). High densities are in the range of 5 km/km^2. This high density is almost uniformly distributed throughout the watershed. The far North and the southern tip of the basin are less fractured zones. Furthermore, we note that fracturing density is very low following a line crossing the North Basin to the South and sharing virtually into two almost equal parts. Fracturing is more intense in the centre (M'Bahiakro and Dabakala).

This result shows that fractures following major accidents at the beginning of the eburnean cycle oriented N0 to N10 or N170 to N180, which influenced the outline of the hydrographic network of the major rivers of the country [11]. In the area of Bondoukou, the fractures families' frequencies range between 2% and 10% [12]. Up to 10% are families of fractures N30-N40, N40-N50, N130-N140 and to some extent the families of N50-N60, N120-N130 and N140-N150 which frequencies oscillate between 8 and 10%.

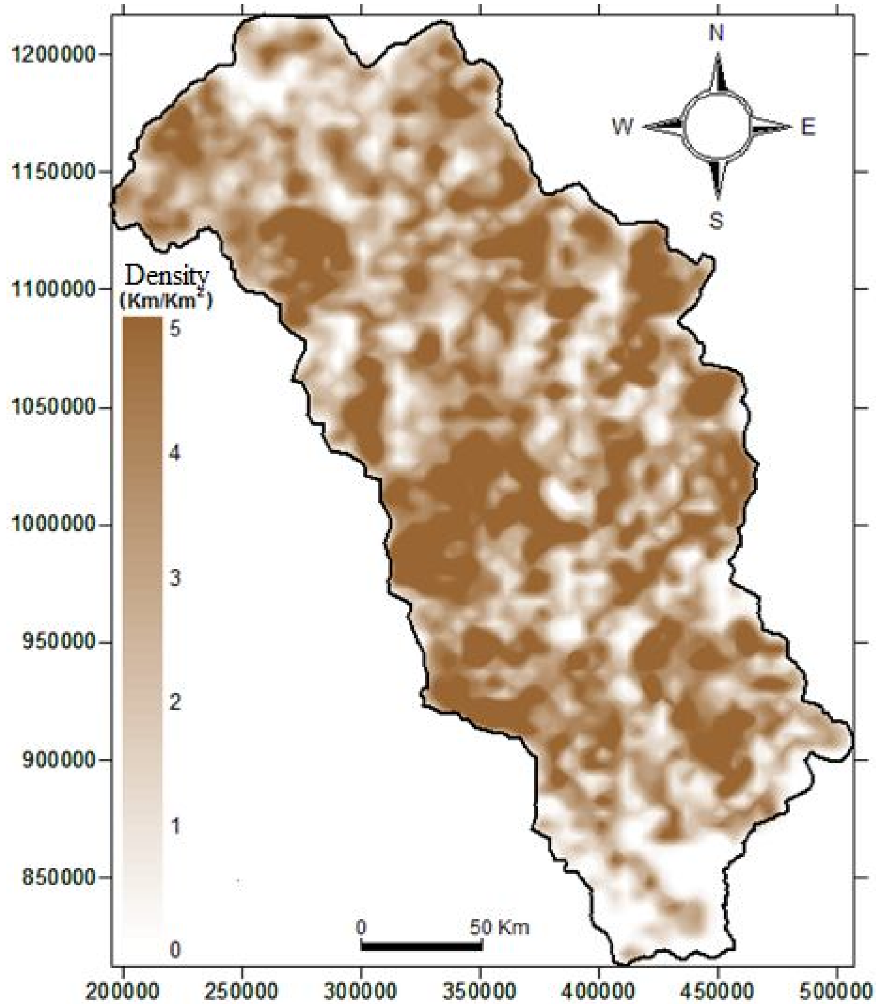


Figure 8: Fracturing density map

These authors have consolidated fractures in two large families which are: NE-SW (N30-N60) and NW-SE (N120-N160). The first representative branch axis in reference to major tectono-metamorphic deformation (eburnean orogeny) that has most marked the Baoulé-Mossi of Côte d'Ivoire field and the second akin to the Liberian leadership. It is likewise in Tiassalé that directional N0-N10 and N160-N170 families are the most represented with number frequencies between 20 and 25% [13].

Also, in the region of Odienné, preferential directions are N0-N10, N40-N50, N90-N100, N130-N150 and N150-N170 [2]. Also N0-N20, N30-N60, N80-N100 and N120-N170 branches were detected [14].

Furthermore, in the region of Dimbokro in Côte d'Ivoire, the following main fracturing directions were identified [9]: N-S (N0-N10 and N170-N180), NE-SW (N40-N50), EW (N90-N100, N110-N120) and NW-SE (N130-N140, N150-N170).

Similarly, the cumulative length frequency distribution analysis indicates a strong similarity with the distribution of the frequency in number of fractures. This result shows that the main directional classes of identified fractures appear longer. In other words the most abundant fractures in frequency are also the longest. This result also joined that in Bondoukou[12].

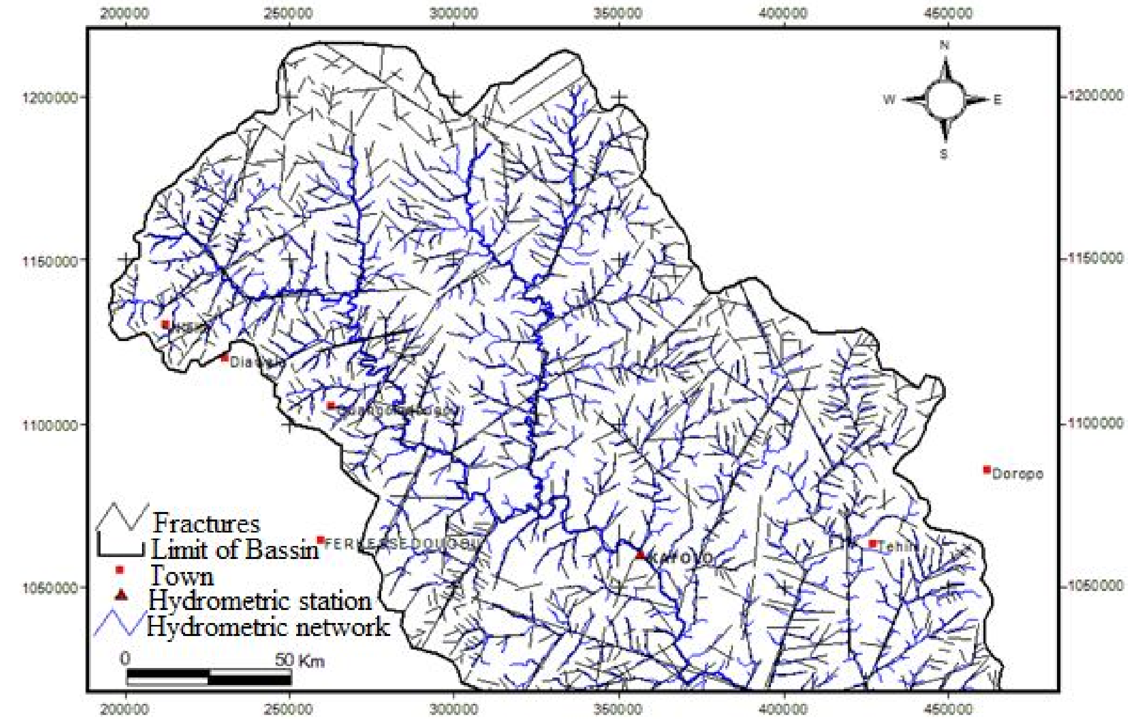
Furthermore, the work in the region of Korhogo[15] showed four main directions by analysis of the orientation of the number of major accidents (N170-N190, N30-N40, N90-N100, N120-N130) and a minor (N50-N80) direction. These same directions have already been highlighted in the Séguéla region [16, 1].

In the region of Dimbokro, the distribution of families of fractures is generally homogeneous because no family fractures exceed 10% in frequency. However, N20-N30, N30-N40, N40-N50, N50-N60 and N90-N100 families stand all with frequencies ranging between 7% and 10%[17].
Other studies have shown that fractures parallel to the direction of compressive stresses are open, while those that are orthogonal to the tectonic stresses are close[18]. The North-South direction and its dispersion are parallel to the constraints while the East-West direction and its dispersion are orthogonal. And so the directions N0-N80, close to the axis (N40) direction, predominant in our area are so open and productive. What omen that these fractures are likely to contain water in greater or lesser quantities according to their geometric properties. They are therefore favorable to the productivity of the works. The fractures were found in our area have therefore questionable hydraulic properties because some are opened and others are closed even if they are opened in their majority.

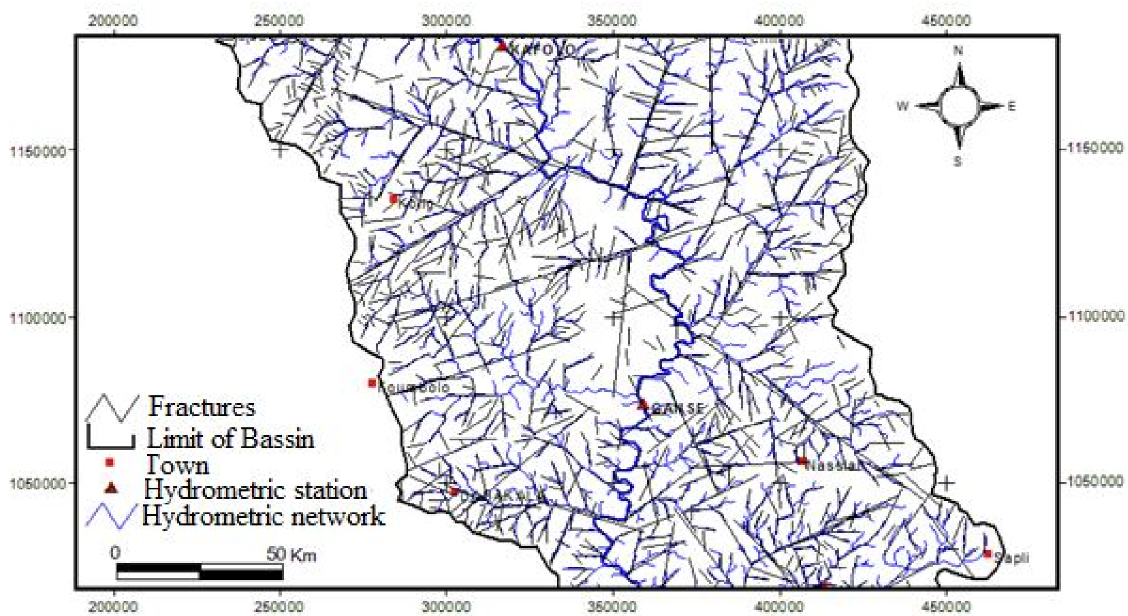
Coupling between the network of fractures and surface hydrological network

The following cards (Figures 9 A, B, C) pick up the link between the hydrographic network and major fractures of the study area. The analysis of these cards notices that the hydrographic network generally follows the fractures as well as the main bed of the river and the secondary tributaries. Therefore, the Comoé River is guided in the major part of its journey, by faults and fractures of the crossing area.

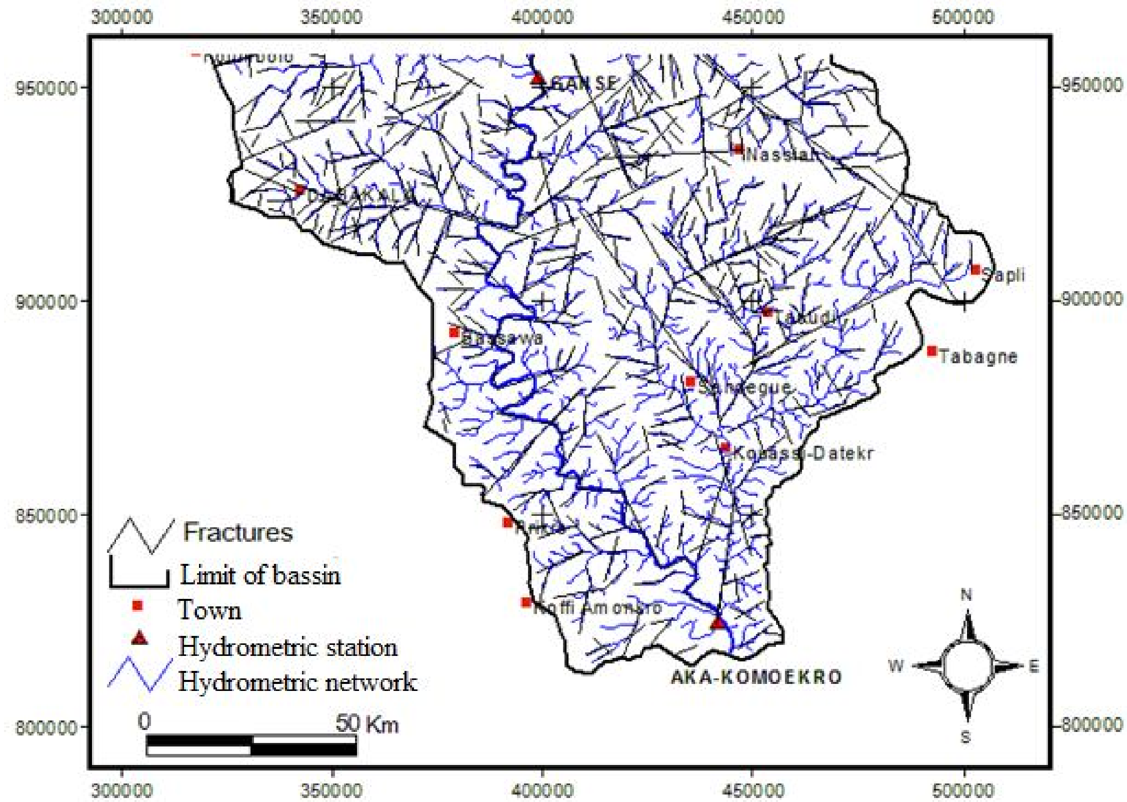
The coupling between the surface network and fractures is much more visible in the central area of the basin (Nassian, Kong, Koumbolo, Ferkessédougou, Ouangolo-dougou and Doropo). These fractures often take the Riverbed to orthogonal detours to its direction of departure. This is more pronounced between Gansé, Bassawa and Aka-Komoekro, where the river sank several times from East to West and from West to East while its main direction is North-South. However, the major arms to the North kept branch axis, as well as the main faults in this area.



A



B



C

Figure 9: Overlay of the hydrographic network and fractures (A): northern zone; (B): centre zone and C: South zone)

With respect to the coupling of the network of fractures with the hydrographic network, analyses show that the river borrows, on many occasions, fractures in the area. What forced him to several places to flow perpendicular to its overall direction North-South. It also generally borrows the axis direction. This result is consistent with those of some authors. Indeed, major accidents at the beginning of the eburnean cycle oriented N0 to N10 or N170 at N180, have influenced the route of the hydrographic network of the major rivers of the country[19]**.** An overlap between major tectonic directions identified on satellite images and the spatial distribution of all drains forming ground drainage in the watershed of Bandama are found [20].

CONCLUSION

This study has highlighted the physical structures and characteristics of the hydrographic network and the lineaments comparable to fractures of the study area by the application of remote sensing and satellite image processing methods. Thus, the hydrographic network of the Comoé river adopted several types of structures on the basis of the morphology of the crossing zone. The slopes are low and there is little drainage. The hydrographic network generally married fractures and has a route sawtooth. The river therefore borrows faults and major fractures in the area.

The application of directional filters allowed highlighting the dense network of lineaments. Associated major fractures are oriented in general in the birimian direction and are likely to be productive.

REFERENCES

1. Biémi, J. Contribution à l'étude géologique, hydrogéologique et par télédétection des bassins versants subsaheliens du socle précambrien d'Afrique de l'Ouest : Hydrostructurale, hydrodynamique, hydrochimie et isotopie des aquifères discontinus de sillons et aires granitiques de la Haute Marahoué (Côte d'Ivoire). Université Nationale d'Abidjan. 1992 : 493.
2. Kouadio, K.E. Savané, I. Lasm, T. Biémi, J. Hydrogeology prospecting in crystalline and metamorphic area by spatial analysis of productivity potential. EJSR. 2008; 22: 373-390.
3. JICA. Plan directeur de gestion intégrée des ressources en eau en République de Côte d'Ivoire, rapport principal. JICA. 2001 : 446 .
4. Brou, Y. T. Akindès, F. Bigot S. La variabilité climatique en Côte d'Ivoire : entre perceptions sociales et réponses agricoles. CA 2005 ; 14 : 533-540.
5. Anonyme. Schéma directeur pour le développement de la région du Zanzan. Haut-Commissariat au développement des régions de la savane du centre et du Nord. 1998; 97.
6. Saley, M. B. Système d'informations hydrogéologiques à Référence Spatiale, discontinuités pseudo-images et cartographies thématiques des ressources en eau dans la région semi-montagneuse de Man (Ouest de la Côte d'Ivoire). Université de Cocody. 2003 ; 210.
7. Savané, I. Bénié, G. B. Guyon, Q. H. & Biémi, J. Application de la télédétection à la recherche des eaux souterraines en milieu de socle cristallin : cas d'Odienné, Côte d'Ivoire. AUPELF-UREF, TRE, PUQ. 1995 ; 5 : 111–120.
8. Kouamé, F. Gion, P. Biémi, J. *et* Kouadio, A. Méthode de cartographie des discontinuités-images extraites d'images satellitales: exemple de la région semi-montagneuse à l'ouest de la Côte d'Ivoire. Télédétection .1999 ; 1 : 139–156.
9. Koita, M. Caractérisation et modélisation du fonctionnement hydrodynamique d'un aquifère fracturé en zone de socle. Région de Dimbokro-Bongouanou (Centre Est de la Côte d'Ivoire). Université de Montpelier II. 2010 ; 235 .
10. Kouamé, F. Hydrogéologie des régions de montagne : apports des données de télédétection et

des méthodes statistique et fractale a l'élaboration d'un système d'information hydrogéologique à référence spatiale des aquifères discontinus du secteur Man-Danané (Ouest de la Côte d'Ivoire). Université de Cocody. 2009 ; 235.

11. Yao T K. Hydrodynamisme dans les aquifères de socle cristallin et cristallophyllien du sud-ouest de la Côte d'Ivoire : cas du département de Soubré. Apports de la télédétection, de la géomorphologie et de l'hydrogéochimie. Conservatoire National des Arts et Métiers (France). 2009 ; 337.
12. Youan T M, Lasm T, Jourda J P, Kouamé K F, Moumtaz R. Cartographie des accidents géologiques par imagerie satellitaire landsat-7 ETM+ et analyse des réseaux de fractures du socle précambrien de la région de Bondoukou (Nord-Est de la Côte d'Ivoire). R T. 2008 ; 8 : 119-135.
13. Abé P S, Kouassi F W, Boko C S, Loukou N K, Kouassi E G. Contribution de la prospection électrique à l'identification et à la caractérisation des aquifères de socle du departement de Sikensi (Sud de la Côte d'Ivoire). EJSR. 2011; 64: 206-219.
14. Savané, I. Doumouya, I. & Doumbia, L. Une approche à partir des modèles statistiques pour la détermination de la productivité des puits en contexte de socle cristallin dans la région d'Odienné (Côte d'Ivoire). Hydrogéologie, Ed. BRGM. 1997 ; 4 : 19-26.
15. Jourda, J.P. Djagoua, E.V. Kouame, K. Saley, M. B. Gronayes, C.C. Achy , J. J. Biemi, J. et Razack, M. Discrimination et cartographie des unités lithologiques et des accidents structuraux majeurs du département de Korhogo (Nord de la Côte d'Ivoire) : Apport de l'imagerie ETM+ de LANDSAT. CPI. Télédétection. 2006 ; 6 : 123-142.
16. Biémi, J., Gwyn, Q. H. J., Deslandes, S. et Jourda, J. P. Géologie et réseaux de linéaments régionaux du bassin versant de la Marahoué (Côte d'Ivoire) : cartographie à l'aide des données Landsat TM et du champ magnétique total. TGR. 1991 ; 7 : 135-145.
17. N'go Y A, Lasm T, Koita M & Savane I. Extraction par télédétection des réseaux de fractures majeures du socle précambrien de la région de Dimbokro (centre est de la Côte d'Ivoire). R T. 2010 ; 9 : 33-42.
18. Savané, I. Bénié, G. B. Guyon, Q. H. & Biémi, J. Application de la télédétection à la recherche des eaux souterraines en milieu de socle cristallin : cas d'Odienné, Côte d'Ivoire. AUPELF-UREF, TRE. 1995 ; 5 : 111–120.
19. Yao Théodore Koffi. Hydrodynamisme dans les aquifères de socle cristallin et cristallophyllien du sud-ouest de la Côte d'Ivoire : cas du département de Soubré. Apports de

la télédétection, de la géomorphologie et de l'hydrogéochimie. Conservatoire National des Arts et Métiers (France). 2009 ; 337.

20. Kamagaté B, D L Gone, I Doumouya, I Ouattara, M Ouedraogo, A Bamba et I Savané. Relation nappe-rivière dans le bassin versant du Bandama en milieu de socle fissuré en Côte d'Ivoire : approche couplée hydrochimie–télédétection. International Formulae Group. 2011 : 67-86.