ESJ Natural/Life/Medical Sciences

Fracturing and Groundwater Productivity Linkages in the Koumfab Watershed in Northern Togo

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Doi:10.19044/esj.2023.v19n21p49

Submitted: 29 May 2023
Accepted: 04 July 2023
Published: 31 July 2023

Cite As:
Katansao P.E., Gnazou M.E., Tairou M.S., Gnazou M.D.T. & Ljiljana V.(2023). *Fracturing and Groundwater Productivity Linkages in the Koumfab Watershed in Northern Togo*. European Scientific Journal, ESJ, 19 (21), 49. https://doi.org/10.19044/esj.2023.v19n21p49

Abstract

The Koumfab watershed, located in the Dapaong region of northern Togo, overlies the sandstone-pelite formations of the lower megasequence of the Volta Basin and the granito-migmatitic bedrock of the south-eastern edge of the West African Craton. All of these Precambrian formations have a dense network of lineaments or fractures, giving them the characteristics of discontinuous and highly exploited aquifers. The lineament map of the Koumfab watershed, obtained from aerial photographs and the digital terrain model, identifies three main families of fractures running N-S to NE-SW (N0° to N40°), NE-SW to ESE-WNW (N60° to N110°) and ESE-WNW to SE-NW (N120° to N180°). Analysis of the correlation between lineaments and borehole flow rates has enabled us to identify areas with high storage potential. This potential is mainly controlled by lithological and lineament parameters. Boreholes drilled along kilometre-long lineaments underlain by crystalline and sandstone formations are more productive, with generally high flow rates (Q > 5m3/h). The basement formations found throughout the Koumfab catchment are major reservoirs with hydrogeological potential that are already in great demand.

Keywords: Lineaments, hydrogeological potential, basement aquifer, Koumfab watershed, North Togo

Introduction

The water supply problems have risen with increasing drought in the Savanes region, Togo according to the report of (PNUD, 1982). The Dalwak reservoir, created in 2002 with a capacity of 10 million m^3, has alleviated water scarcity of the town of Dapoang (Rapport expert solidaire, 2014). Despite the multitude of small water reservoirs and the higher density of boreholes, the availability of water for the population remains very low for the rest of the region. Furthermore, the development of cattle and goat farming in the region made the surface water unfit for consumption which requires exorbitant treatment costs. Availability of groundwater in the region depends on the state of fracturing of the bedrock (Bertone & le Guellec, 2008; Jourda et al., 2015; Alhassane et al., 2018). This explains the interest of this study, which assesses the hydrogeological potential of the Birrimian granito-migmatitic formations and those of the Neoproterozoic sandstone-clay cover in the Koumfab watershed. This study presents the results of the mapping of the network of lineaments or fractures based on aerial and satellite coverage of the sector and the analysis of the parameters of the boreholes installed in relation to the network component.

1- Geological and hydrogeological background

1.1 - Overview of the geology of the study area

The Koumfab watershed is located in northern Togo between longitudes 0°4'30" and 0°15'0" East and latitudes 10°46'12" and 10°52'47" North (Figure 1). Geologically, it covers a portion of the south-eastern edge of the West African Craton, representing the bedrock of the formations of the lower megasequence of the Volta Basin (Collard et al., 1985). The substratum of the West African Craton corresponds to the peneplain zone that opens out into Burkina Faso.

This is the edge of the Palaeoproterozoic or Birimian domain. In the Dapaong region, this edge of the craton comprises granitoids (granodiorites, tonalites, quartz diorites, monzogranites, syenogranites) and metamorphic rocks (migmatites, orthogneisses, amphibolites) accompanied by a quartz and pegmatite vein procession. These rocks are Eburnian in age (2064 ± 90 Ma), (Sylvain et al., 1986) that form the megasequence of the Bombouaka supergroup (Affaton, 1990). According to Affaton (1990), it consists of two sandstone sequences (Dapaong and Mount Panabako groups) sandwiching an essentially silt-clay sequence (Fosse-aux-lions group). The Birimian basement located in the extreme north-west of Togo is the most stable of the country's geological units. It was not affected by the Pan-African orogen (Duclaux, 2003).

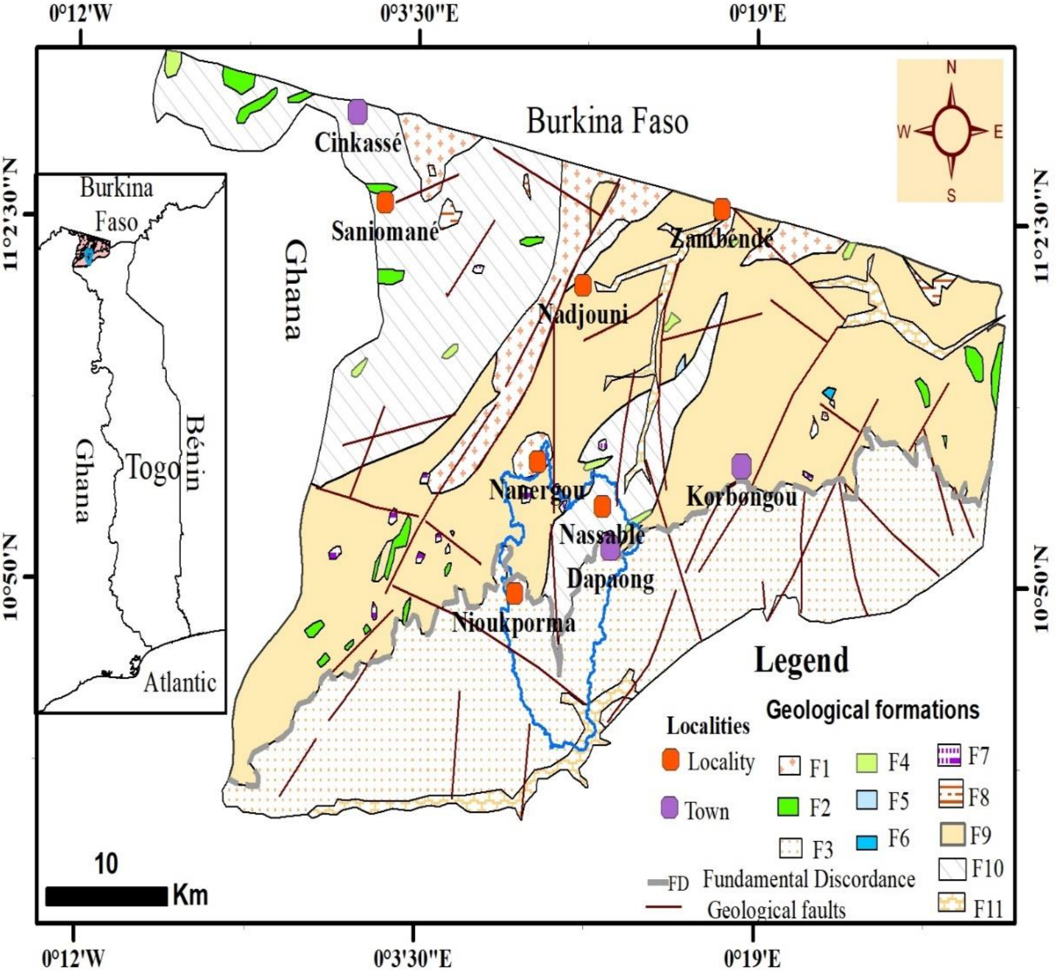

Figure 1. Geological situation of the study area (red polygon) in the local geological context according to (Collart et al., 1985; slightly modified by Laré, 2022). F1= Alkaline to synogranite granites; F2= Coarse-grained amphibolites; F3= Dapaong sandstones; F4= Fine-grained amphibolites; F5= Basalts; F6= Basalts associated; F7= Biotite granites; F8= Biotite granites and amphibolites; F9= Graodiorites-Tonalites and quartz diorites; F10= Migmatiyes-Gness and Orthogness; F11= Recent alluvium. deposites.

The Volta Basin covers an area of 32,200 km^2 (Affaton, 1990) and is in direct contact with the Birrimian basement. It rests in fundamental unconformity on this basement and has a monoclinal structure dipping slightly to the south-east (figure 2). The sedimentary pile of the Volta Basin is subdivided into three supergroups. These are, from bottom to top, supergroup

I or Bombouaka supergroup, supergroup II or Pendjari supergroup, supergroup III or Tamalé supergroup. Of the three supergroups, only the first two outcrop in Togo.

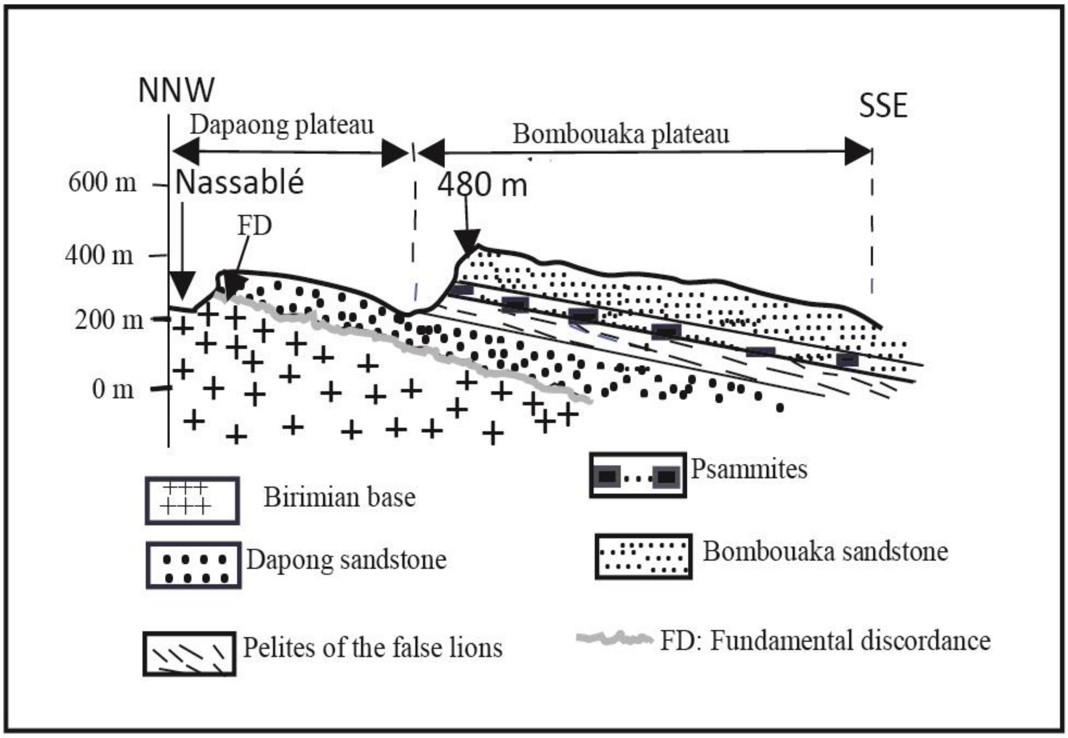

Figure 2. Lithostratigraphic cross-section of the basement and supergroup I formations of the volta basin: Source, (Affaton, 1990).

The koumfab watershed straddles the Birimian basement and the Volta basin and has a bedrock composed of alkaline granites, biotite and amphibolite granites, granitoids, tonalites, migmatites, gneisses, orthogneisses, meta volcano sediments and Dapaong sandstones. This Dapaong sandstone formation forms the base of the large Volta sedimentary basin that overlies the basement (Collart et al., 1985; Affaton et al., 2013).

1.2 – Hydrogeological background

From a hydrogeological point of view, the formations of the Volta Basin are very consolidated and are considered as basement formations. Thus, in the Koumfab watershed, there are alterate aquifers made up of surface layers and basement aquifers (Gnazou et al., 2016). The former corresponds to the supergene soils cover of sandy and sandy-clay nature. The average thickness of this soil cover is about 30 m (Lamouroux, 1969). This type of aquifer is often tapped by large diameter wells. Fracture aquifers are represented by all the lithological components of the watershed. Also the porosity (n) in the zone is between 0.001 – 0.39. The specific storage (Ss) is $<10^{-2}$ m^{-1} (Clark, 1985; Vouillamoz et al., 2005), similarly the hydraulic conductivity varies between 46.10^{-8} -10^{-3} m/s. Isotopic analysis by Akara et al., (2022) shows recent recharge attributed to groundwater in the area except for a few samples.

2- Hydroclimatic aspect of the Koumfab watershed

The Koumfab watershed is drained by the Koumfab River and its tributaries (Figure 3). This river is the main source of water for the Dalwak dam, which is operated by the Togolese Water Company (TWC) to supply drinking water to the town of Dapaong and its surroundings.

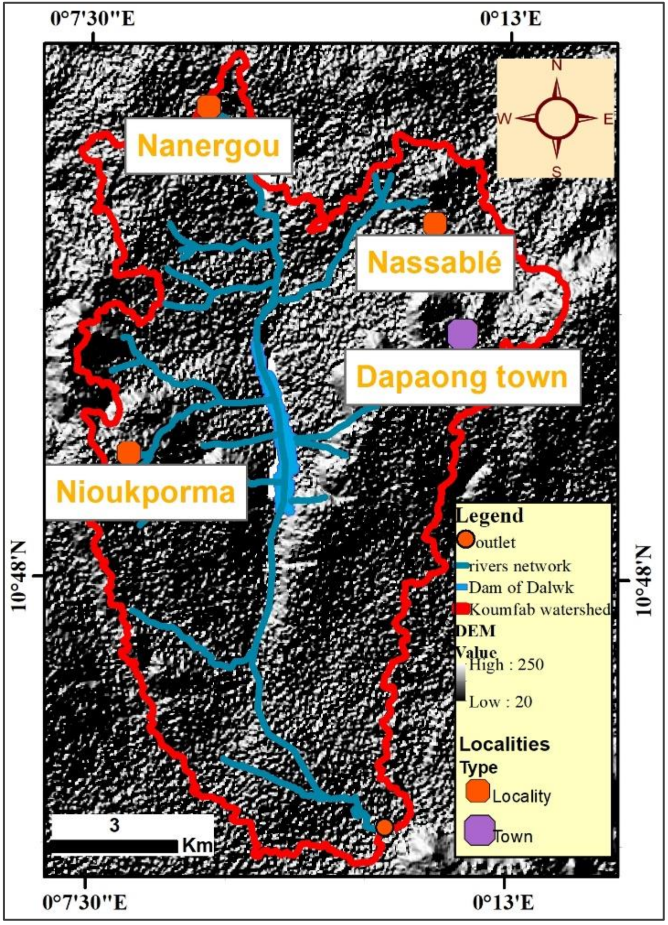

Figure 3: Hydrographic map of the Komfab basin showing the morphostructural features of the area

Climatically, the Koumfab watershed, like the rest of the Savanes region, has a Sudano-Sahelian climate with two seasons: a dry season from November to April and a rainy season from May to October (Figure 4). Maximum rainfall is 1110 mm/year. Previous studies (Haan, 1993; Adewi and Badameli, 2010) have shown that the area experienced rainfall surpluses between 1950 and 1969, with rainfall exceeding 1,200 mm/year, but also deficits in 1970, 1980, 1982 and 1990, with less than 900 mm/year. Temperatures in the area vary seasonally between 25° and 32°C over the course of a year. There was a maximum temperature of up to 36°C and a minimum of 20°C (Haan, 1993). The best time for recharge is August, which is the wettest month with a low actual evapotranspiration (AET) rate. As a result, infiltration is estimated at 177.34 mm/year at an average temperature of 28.2°C (Katansao, 2021).

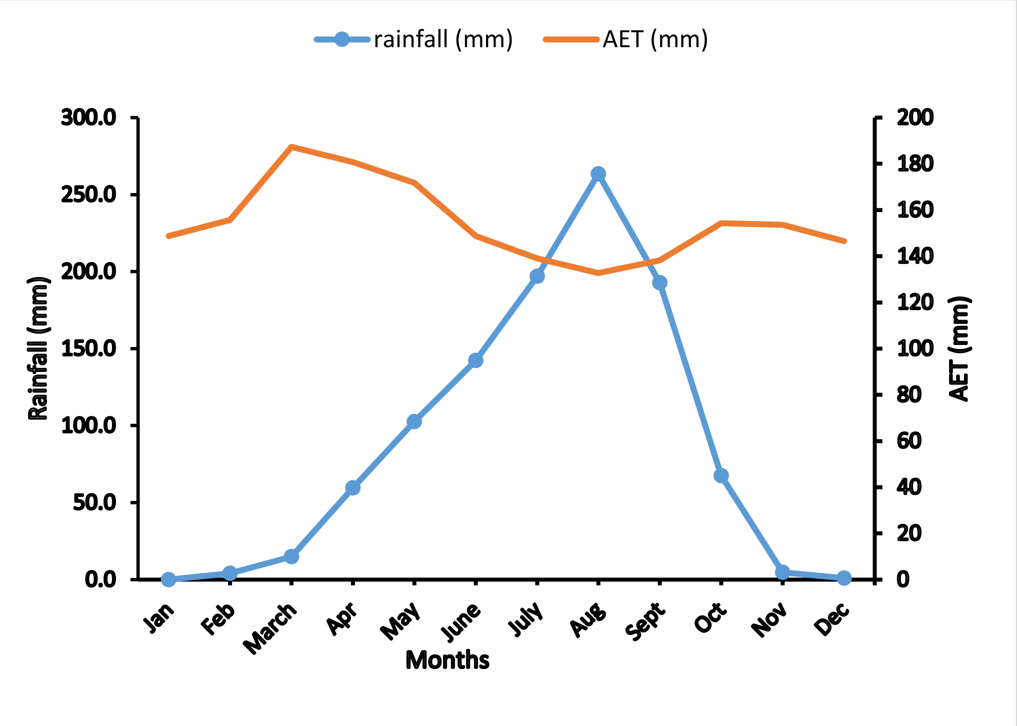

Figure 4. Annual variation curve of rainfall (in blue) and evapotranspiration (in red)

3 – Materials and methods

In order to map the lineaments and assess the hydrogeological potential of the formations represented in the Koumfab catchment, a 30 m resolution digital elevation model downloaded from the United States Geological Survey (USGS) website was used. Spatial analysis tools such as Hillshade (shading tools) in Arcgis 10.5 and Qgis 3.14 were then used to highlight the tectonic faults (visible fractures, cracks and outcrop ridges). Lineaments were extracted by considering the many fracture markers (the straight sections of watercourses, cliffs, depressions and lithological contacts), (Norman, 1976; Scanvic, 1983). These operations resulted in a fairly exhaustive mapping of the lineament network, the components of which were defined in terms of number and weight (cumulative length of fractures or lineaments in a given direction) using Tectonics FP software (version 1.7.9).

In order to highlight the role of fractures in the productivity of aquifers in the Koumfab watershed, technical (flow rates, depths and the lithological nature of the aquifers tapped) data from 81 boreholes obtained from the Ministry of Water and Village Hydraulics (MEHV) were linked to the lithology and parameters of the lineaments as well as their interconnectivity.

4- Results

4.1- Presentation of the lineament map

A lineament map of the study area was produced based on the digital elevation model (Figure 5). It is associated with the drilling points and major fractures of the geological map of Collart et al., (1985).

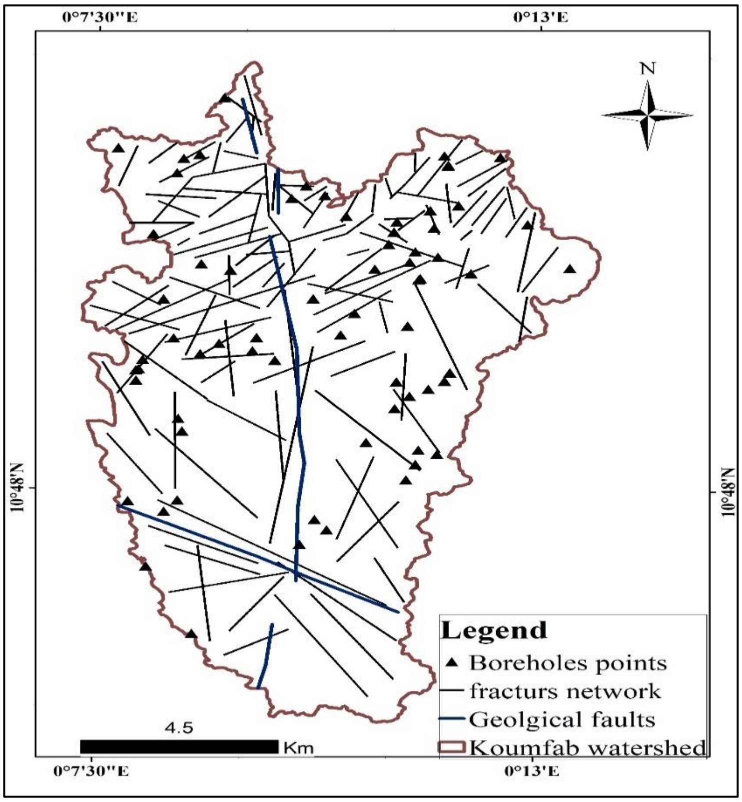

Figure 5. Lineament map obtained by processing the DEM of the area associated with the drilling points

This map shows a dense network composed of several families of hectometric to kilometre-long lineaments distributed in various directions. These lineaments are superimposed on the major fractures of the geological map. On the lineament map, the density of the fracturing is more accentuated in the north corresponding to the crystalline basement formations than in the lithologically sandstone south. The intensity of the fracturing in the basement would be accentuated by the exfoliation process underway in the area.

4.2- Analysis of the lineament network

The azimuths of the lineaments obtained have allowed us to establish a directional rosette showing the different orientations of the lineaments (figure 6). The rose diagram shows three families of lineaments: the majority of lineaments are oriented N–S to NE-SW (N00°-N40°), the mean lineaments are NE to SE (N60°-N110°) and the minority ones oriented NWN-SES (N120°-N180°).

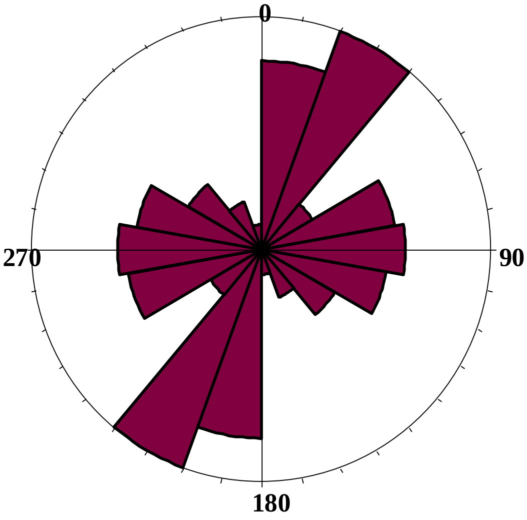

Figure 6. Rose diagram showing the directional synthesis of the lineament in the study area

To assess the importance of the network components, the cumulative lineament weights (cumulative length of fractures or lineaments in a given direction) were determined according to their families (Table 1). This distribution shows that the medium fractures are much more represented.

4.3- Analysis of borehole flow rates in relation to lineaments or fractures and lithology

Table 1. Cumulative weights of the three families of lineaments

Type of fractures	**Majority fractures (N00°-N40°)**	**Medium fractures (N60°-N110°)**	**Minorities fractures (N120°-N180°) or N41°-N59°)**
Lengths (m)	68599.59	90303.75	52335.7
Cumulative weights (%)	32.48	42.74	24.78

Different correlation studies have been carried out to identify the influence of lineaments on groundwater reserves (N'Go et al., 2005; Hung et al., 2005; Augustin, 2011; Ouedraogo, 2016; Zondokpo et al., 2022). The first correlation was between borehole flow and depths. This analysis shows that the average depth of the boreholes is 65.17 m with an average flow rate of about 4.65 m^3/h. Three classes of flow rates are identified: low flow rates varying between 0.8 m^3/h and 5 m^3/h, medium flow rates between 5 m^3/h and 10 m^3/h and high flow rates above 10 m^3/h. The most productive depth range is between 40 m and 80 m (figure 7). This depth range corresponds to the depth range of water occurrences. It should also be noted that depths above 90 m are almost unproductive, as almost all boreholes reaching this depth are reported as negligible except for a few. This analysis gives an idea of the depths of the fractures fed. The high flowing boreholes with depths below 40m probably benefit from a contribution from the weathering reserves.

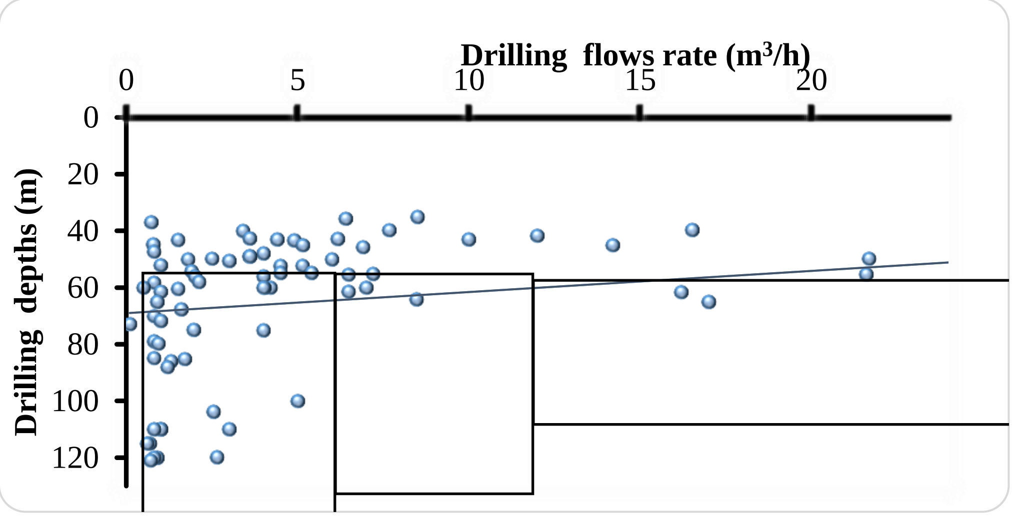

Figure 7. Cloud of the variation of drilling depths according to their flow rates

Analysis of the average flow rates of boreholes located on the lineaments and those not located on the lineaments showed that the latter had a significant impact on borehole productivity (Table 2).

Table 2. Comparison of the average flow rates of boreholes located on lineaments and those independent of lineaments

Position of the borehole	**Boreholes located on the lineaments**	**Drilling independent of lineaments**
Average flow rates (m^3/h)	5.8	2.8

This comparison led to the graph in Figure 8. This graph relates the flow rates of the boreholes to the cumulative length of the lineaments and their connectivity (number of fractures connected to the main fracture carrying the borehole). It is clear from this graph that the length and number of connected fractures act synchronously on the flow rates, since more than 70% of the boreholes with a significant flow rate are located on more or less interconnected fractures with a length of one kilometre.

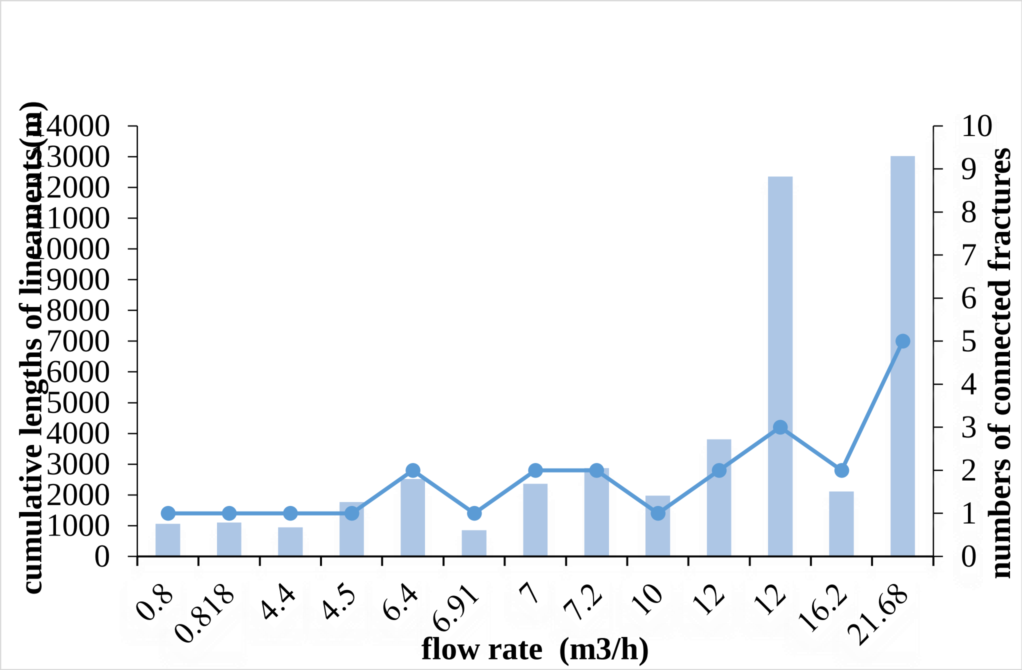

Figure 8. Cumulative histogram of fracture lengths superimposed on the curve of the number of connected fractures versus their flow rates

It can be seen on figure 8 that the boreholes with large flow rates of between 12 m^3/h and 16 m^3/h are located on lineaments that are interconnected to at least two other lineaments whose cumulative length is of the order of a kilometre. This is the cumulative length of the main lineament on which the borehole is located and those connected to it (the number of connected lineaments being variable). Therefore, the flow rates of the boreholes increase proportionally with the length of the lineaments and their interconnectivity. It has been found that the longer the lineament and linked to other lineaments, the greater the storage capacity. In fact, this is reflected in the high flow rates of boreholes installed in these areas.

Finally, a correlation is established between the lithological facies of the zone and the productivity of the boreholes (Table 3). It shows the differences in productivity between the formations of the crystalline basement and the Dapaong sandstone.

Table 3. Productivity of the birimiant basement and the Dapaong sandstone

Geological formations	**Crystalline base**	**Dapaong sandstone**
Maximum flow rates (m^3/h)	16.5	10
Minimum flow rates (m^3/h)	1	0.1
Average flow rates (m^3/h)	5.8	2.1

It could be concluded from the analysis of Table 3 that the crystalline basement formations have a higher productivity than the Dapaong sandstones due to their more intense fracturing conditions mentioned above.

Conclusion

The crystalline formations of the Birimian basement and the Volta Basin in northern Togo show the markers of Eburnian fracturing (Affaton et al., 2000), which can be identified on the ground and on aerial images. Thus, these formations offer an ideal setting for the circulation and storage of vital fluids (water). This study has enabled an assessment of the water potential of the area through the analysis of lineament parameters coupled with drilling data. First, a lineament network map of the area was drawn up and an analysis of the network was carried out. From this analysis, three families of fractures were identified, namely those oriented NNE-SSW (N00° to N40°), known as the majority, then the medium fractures of direction N60° to N110° and the minority fractures oriented SSE-NNW (N120° to N180°) representing.

The correlations between borehole flow rates and lineament parameters have shown that parameters such as length and interconnectivity have an influence on borehole productivity but are not the only determining factors that control productivity. Thus, other factors such as the lithological nature of the aquifers and the depths of wells could provide further explanation of the productivity of wells and thus the hydrogeological potential of the area. In order to make this study much more exhaustive and detailed for rational and sustainable planning and management, additional studies should be carried out, such as geophysics, which offers more interpretation of the basement environment. Also, hydrogeochemical and isotopic studies should be carried out in the area to gain a better insight into the chemical quality and isotopic signatures of these waters leading to rational and sustainable planning of the resource.

Conflicts of Interest: The authors have no conflicts of interest to declare.

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