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Groundwater flow modelling and hydrogeological systems characterisation in fractured granito-gneissic basement from the Bankim area: a combine use of Landsat 8 OLI/TIRS sensors/SRTM and field observations

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***Abstract*–** The problem of groundwater supply in Bankim exists and no proper solution has been found so far. This study is based on the structural data (fractures network) collected from bedrock exposed on the surface and lineament interpreted from satellite imagery of the Bankim Area. The modelling of groundwater flow in these fractured networks was carried out using a theoretical approach based on the geometric characteristics of the fractures. The characterisation of the geometric parameters, the study of network connectivity and the evaluation of suitable groundwater potential zones are done by overlaying the lithological map, geomorphologic map, lineament map and lineament density map, using visual interpretation of a scene from Landsat-8 imagery and Digital Elevation Model extracted from Shuttle Radar Topography Mission. The results show that the major fracturing direction is NW-SE which intersects the NE-SW fractures in the field. About 472 structural elements are identified, ranging in size from 750.6 m to 9054.9 m with an average length of 1821.3 m on the shaded relief images. Most lineament clusters in the northern part of Bankim, between Mbiridjom, Kimisso, Sokolong, Nassaro and Echamba on the one hand and in the south-east, notably in Bankim, Nyakong and Guimbonlo on the other hand. About 11% of the area has good groundwater potential while 18% is moderately good which corresponds to high to moderate lineament densities situated at average altitude of 800 m and about 71% of the area has poor groundwater potential corresponding to low lineament density areas.

***Keywords*–** *Groundwater, fractures, lineaments, granito-gneissic basement, Bankim area.*

I. INTRODUCTION

Freshwater is a precious and scarce natural resource at global scale. Although 71% of the earth's surface is covered by water, only 3% of this water is fresh, 70% retained in the form of snow or glaciers. The remaining 27% is groundwater, contained in hard rocks or water tables, fossil groundwater tables. Therefore, the aquifers represent one of the main resources of freshwater resources in the world [16].

Nowadays, the problem of access to drinking water in Cameroon is still acute; this is due to high demographic pressure, insufficient investment in this sector coupled with significant climate change, which considerably increases demand however not answer by the supply. While only 20% of the population in major cities of Cameroon (Douala, Yaoundé) do not have access to good water quality, 70-80% in the other cities and regions do not always have access to safe water [13] [14]. These waters are mostly stored in natural reservoirs or aquifers after a long journey within the ground and thus represent an important reserve that can be mobilized at any moment. These reservoirs are either porous rocks or fractures along hard rocks or the weakness zones (shear zones, foliation or gneissification) of some deformed rocks. Water is mobile through these reservoirs and crosses the geological layers or runs along the rocks, leaching them.

Populations as well as that of Bankim by ancient hydraulic methods, exploit the surface and underground water from wells and drillings for its consumption as well as for these various activities. Bankim is composed almost exclusively of granite and gneiss basement rocks that are permeable to fractures that they recorded. The study of these aquifer systems is therefore fundamental, particularly for groundwater collection and protection. The crystalline and crystallophyllous basement rocks are intrinsically very low permeable. Fractures in these rocks are at the origin of almost all their permeability properties (fracture permeability). Depending on their density, size, arrangement in the environment and physical properties, fractures considerably modify the hydraulic properties of basement rocks [9] [11]. Indeed, crystalline and crystallophyllous rocks have a very low interstitial porosity; therefore, the formation of aquifers is only possible through the action of the fracturing-alteration couple [12]. In granito-metamorphic terrains such as Bakim, the most superficial altered layer (saprolite) has significant porosity and low permeability. When it is saturated with water, it forms a capacitive reservoir [20]. The underlying fractured-altered level, which also results from alteration processes, is an anisotropic and heterogeneous milieu. It is characterized by dense horizontal fracture network in the first few meters and a decrease in density of subhorizontal and subvertical fractures with depth. Its hydrodynamic properties are controlled by weathering processes [12] [20]. This fractured-altered horizon plays a transmissive role. When it is tapped by drilling, it generally provides water resources in all seasons [6]. Pre-existing fractures in the basement (veins, old fractures, etc.) are generally marked by a deepening and verticalization of this fractured-altered horizon. It is therefore clear that fracturing, both old (veins, fractures, etc.) and more recent (alteration profiles), is

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one of the main parameters for characterizing hydrogeological systems in the basement environment.

The objective of the present work is to exploit discrete fractures from remote sensing data, especially Lansat-8 satellite images, combined to field geological investigations to determine the hydrogeological properties and hydrogeologic model of the Bankim granito-gneissic basement rock.

II. FRAME WORK OF THE STUDY AREA

Location and Morphology

Bankim is located in the Adamawa Region, Northern Cameroon, within latitude 6° 00' and 6° 30' N, and longitudes 11° 12' and 11° 42' E (Fig. 1); especially in the Tikar Plane on the Foumban-Bankim Shear Zone, South-eastern extension of the Central Cameroon Shear Zone (CCSZ). In the Bankim area, the CCSZ print is represented by a NE-SW (N40E) trending coridor, of about 14km width Pan-African granitoids In the Tikar plaine, the mean altitude is around 700 m (Fig. 1). The morphology of Bankim area is marked by (i) a series of hills aligned and elongated NE-SW (N40E), that are parallel to the well-known CCSZ; (ii) and two secondary mountains ranges trending SW-NE (N70E) from Bandam to Nyakong (Fig. 1). The hills are more or less covered by drift boulders of various sizes at their summits and on their flanks; flagstones are mostly observed in the valleys and along the riverbeds.

The slums and new urban peripherals are still included in the city. The region is characterised by low to middle income neighbourhoods with more than 90% of the urban population with no access to public utilities or basic services. Bankim has poor sanitation facilities with no centralised sewage system and it is made up of unregularized widespread use of septic tanks and pit latrines which are almost never emptied. Water supply is much more done through wells that remain very deep and boreholes whose flow is generally low and water availability is not regular.

Climate

The climate in the study area is humid tropical, characterised by two seasons: (1) a rainy season lasting seven months (April-October) and (2) a dry season lasting five months (November to March). September is the wettest month (299.52 mm of rainfall), December and January are the driest months (0 mm of rainfall). The average annual rainfall varies between 1500 and 2000 mm and the average annual temperature is between 23°C and 27°C (Fig. 2).

Hydrography

The hydrographic network in Bankim area is mainly parallel for rivers of the same order (e.g. order one rivers) and dendritic for order one and order three to four (or sometimes order two) rivers (Fig. 3), flowing in the NE-SW, N-S, NW-SW and E-W direction, parallel to the major structures that can be found to area (Faults, Foliation, Shear structures, etc.; Fig. 3) [15] and correlated to the deformation phases in the area [23] [15] [32]. Trending NE-SW, Mbam and Mappe rivers are the most important rivers in the Bankim area. In the North-western part of Bankim, rivers are predominantly flow in the N-S trending

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direction. This N-S trending direction is also represented by the deformation features (Faults, shear plans, etc.), all of which can be correlated to D3 deformation phase [15]. The flow directions of the rivers in Bankim area thus correspond to the directions of the deformation structures, suggesting a tectonically controlled flow in the region.

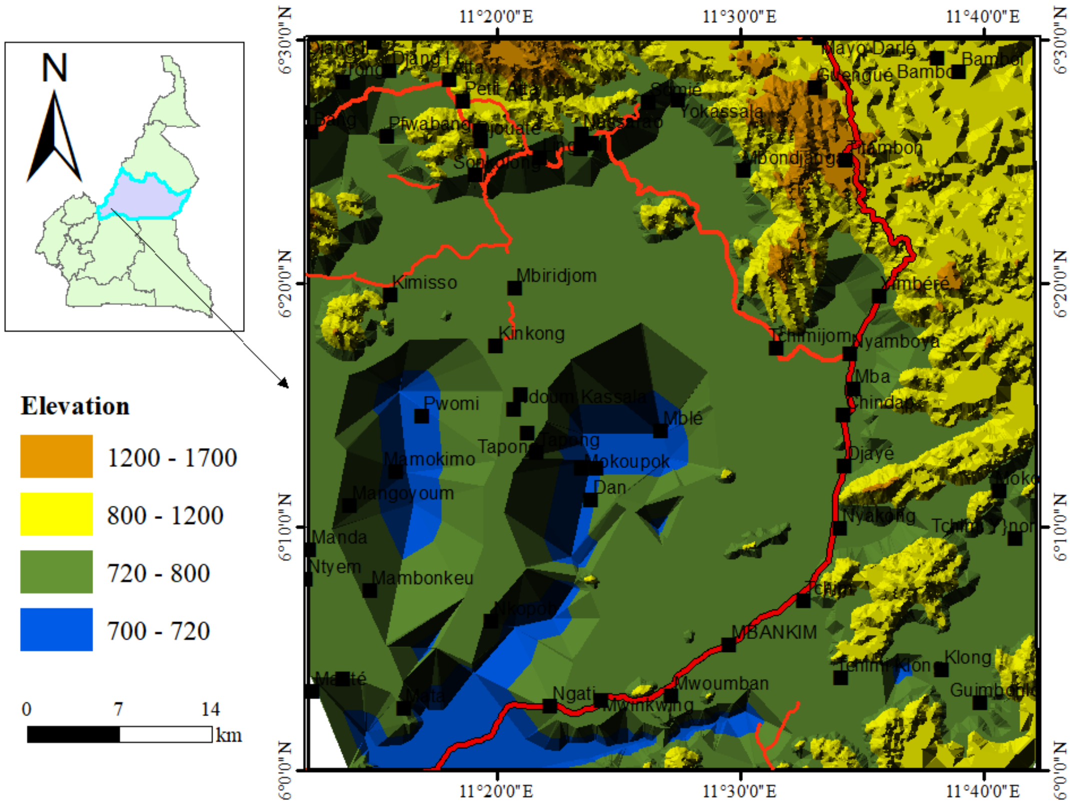

Figure 1: Localisation and digital elevation model of the Bankim Area extracted from SRTM image.

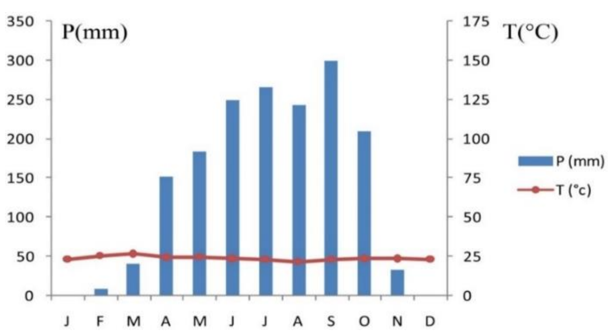

Figure 2: Mean monthly rainfall and temperature in Bankim from 2008 to 2012 (Banyo Meteorological station)

Geology and hydrogeology

The Bankim area is part of the Adamawa domain of the Pan-African Belt of Central Africa (PBCA) in Cameroon [23] [15] [1] [32]. The geological and structural map of this area extracted from the combined geological and structural map of Cameroon [27] shows that it mostly constituted of crystalline rocks (Fig. 3) include intrusive igneous (granites, granodiorites, monzogranite and monzonite) and metamorphic rocks (orthogneisses, migmatitic gneiss and mylonites). Granites form larges intrusive bodies (pluton) while dolerite; aplite and pegmatite tend to occur as linear features of restricted extent, such as dykes or veins [15]. The protoliths of these rocks are from ancient Archean to Mesoproterozoic crust

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formed in an active continental margin setting and remobilised during the Pan-African orogeny. During this orogeny, the rocks in Bankim were intensely deformed and fractured in response to high stresses and allows the Bankim area to be known as an intensely deformed and fractured metamorphic zone [23] [15] [1] [32]

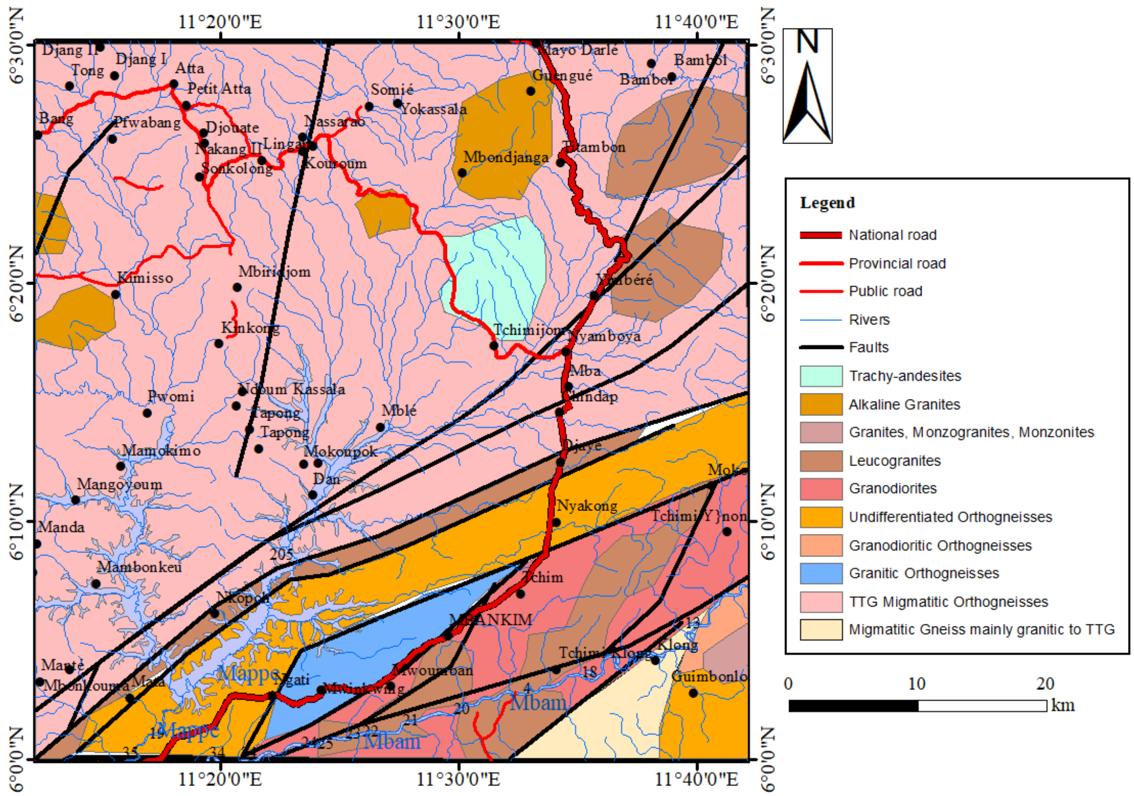

Figure 3: Combined geological and structural map of the Bankim area from **[27]**, showing hydrographic network.

The crystalline rocks are characterised by very low primary porosity and permeability, although this can be significantly increased by weathering and fracturing. As such, the climate, topography and structures recorded by rocks often more account for differences in well yield than the rock type. The weathered layer, in particular, can be an important source of groundwater, and thick, really extensive weathered layers can form reliable aquifers. While in arid and semi-arid regions the weathered layer is usually thin (< 1 m), in humid tropical regions, such as Bankim area, its thickness may reach up to 100 m [30].

Generally, coarse-grained rocks as granites, orthogneisses and gneisses are more brittle and have a coarse-grained weathering product, therefore they tend to develop and preserve open joint systems. The structure of the fracture networks and their hydrodynamic characteristics are the main elements that can explain the hydraulic functioning of fractured environments [7] [10]. Therefore, the heterogeneity and anisotropy that characterise them do not always allow for their use as continuous milieu type approach for modelling groundwater flows [31]. In this case, the discrete approach may be appropriate. This paper shows the contribution of a discrete fracture hydrogeological model to the study of fractured aquifers in the granito-gneissic basement of Bankim.

III. DATA AND METHOD

Data used

The first part of this study aims at evaluating the geological material that is important for building up a conceptual understanding of the hydrogeological process operating in the Bankim area. Although the availability of outcrops is often limited in Bankim area, detailed information on fracture and fault distributions were collected from outcrops exposures in which fracture properties are directly measured and from geological and structural map of the study area extracted from the combined geological and structural map of Cameroon, [27]. At larger scales, the locations of major fracture zones and faults are obtained from remote sensing, including a digital elevation model (DEM) extracted from Shuttle Radar Topography Mission (SRTM) and a scene from Landsat-8. The Landsat-8 OLI consists of a free of cloud terrain-corrected scene (path/row = 187/56) covering the Bankim area that was downloaded on the 27th January 2018 from the USGS.GOV Earth Explorer website. The visible and near infrared (VNIR) and short-wave infrared (SWIR) (bands 1-7) of the Landsat-8 data with a spatial resolution of 30 m were used. In addition, a SRTM 1-arc second elevation data product was used for the orthorectification of the radar image as well as for a shaded relief analysis.

Fracture network mapping

The mapping of the granito-gneissic basement fracture network of Bankim was carried out in two phases: firstly, the characterisation of the fractures based on the geometric information collected on the surface exposures, and secondly the processing of Landsat 8-TM images for the identification and extraction of lineaments and the structural validation using complementary geoscientific data. The term “lineament” used in this study describes any structure that has a straight or curvilinear line [17] [24] and whose interpretation has a geological significance. The geometric analysis of fractures was carried out in the field using compass and clinometer and was performed using StereoWin32 software for statistical analyses, especially in the lower hemisphere of Schmidt diagrams following conventional techniques [28] and the Landsat 8 images processing were performed using several software programmes such as Global Mapper, Erdas, Envi, ArcGIS, and Adobe Illustrator CS6.

Pre-processing and image enhancement

Images acquired by the land observation system cannot be directly overlapped with maps as they are affected by geometric deformations. These deformations are related to errors in positioning on its orbit due to the Earth’s rotation on its axis during the recording of images, as well as the effects of the Earth’s landscape. They are amplified by the fact that some satellites take oblique images. There is a large variety of techniques for the improvement of the satellite images quality. The choice of a method depends on its application, the type of data used, the experience and preferences of the image analysed.

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Different types of treatments were carried out in this work. These treatments aim to obtain an enhanced spectral signature for the lithology and to make the lineament easily detectable. Measurement requires a pre-processing which assumes a good sensor and conditions of data acquisition.

The Landsat 8 OLI image used in this work corresponds to the L1T (corrected terrain) level, with a Universal Transverse Mercator (UTM) projection and a World Geodetic System WGS 84 datum. The pre-processing operations consisted of atmospheric correction and radiometric calibration without the geometric correction because the Lansat 8 OLI images are geometrically corrected in advance by the United States Geological Survey (USGS) using the UTM projection with the WGS84 map datum. After the correction of the images, they were improved in order to increase their visual perception and to better visualize discontinuities.

Principal component analysis (PCA)

Principal Component Analysis is a statistical method widely used in geological studies [2] [25] [18]. It involves a mathematical procedure that transforms a number of correlated variables into a set of uncorrelated variables called principal components [2] [25] [18]. This technique is used to reduce the redundancy between the reflections of spectral bands and his purpose is to combine different information sources in order to improve certain features or data properties that are less obvious in the original image. Six bands (bands 2-7), each one with a 30 m resolution, were used for the PCA technique. The result of the first two bands represents information contained in the original multispectral image with the nine bands. The processed images obtained contain the maximum information and were thus combined by coloured composition. In order to improve the contrasts of the image and avoid redundancies, it was wise to apply the PCA to the raw image of the study area. Thus, the application of the PCA to the first three bands made it possible to obtain a good percentage of the first three bands.

Spatial filtering and shaded relief images

After the fusion and the enhancement of the images, the directional convolution filtering was performed for visual interpretation and manual lineament extraction. According to [8], directional filtering is a spatial domain filtering technique and edge enhancement filter that selectively enhances image features having specific direction gradients and consists of changing a pixel value based on that of its neighbor's and also consists of the recalculation of the value of each pixel by analysing the surrounding radiometry. This is a commonly used technique in geological applications to highlight geological structures [3] [4]. The main objective of this process is to find the best way for lineament identification and the enhancement of geostructural information in the images corresponding to structural discontinuities.

IV. RESULTS AND DISCUSSION

Characterising fractures

The directions (angle with respect to north) of fractures were collected from surface exposures. The dip amount (angle from horizontal) are mostly vertical, therefore it is not expressed. The orientation is expressed in terms of numbers, such as N165°E implying a 165° direction measured clockwise from north. The fracture strike is perpendicular to the dip direction. Three main generations of fractures are recorded by rocks in the study area: (1) the NW-SE, (2) the N-S and (3) the NE-SW to E-W trending fractures. N-S to NW-SE ones are dominant and seem to a latter fracture (Fig. 4) because they crosscut the fracture strike in NE-SW to E-W direction. This NE-SW to E-W earlier fracture is poorly represented in the Bankim area, although the major faults described on the structural map of the Bankim area, interpreted from aerial photography images [27], predominantly display NE-SW. This observation can nevertheless be justified by the NE-SW alignment of plutons outcrop in Bankim area, which on the aerial photography images appears as lineament or shears zone. It is known that the Pan-African Belt of Central Africa in Cameroun, area is crossed by large NE-SW trending faults [34] [22] [23] [15] [1] that controlled the emplacement of granitic pluton. This emplacement may be the cause of their low appearance on the outcrop exposure.

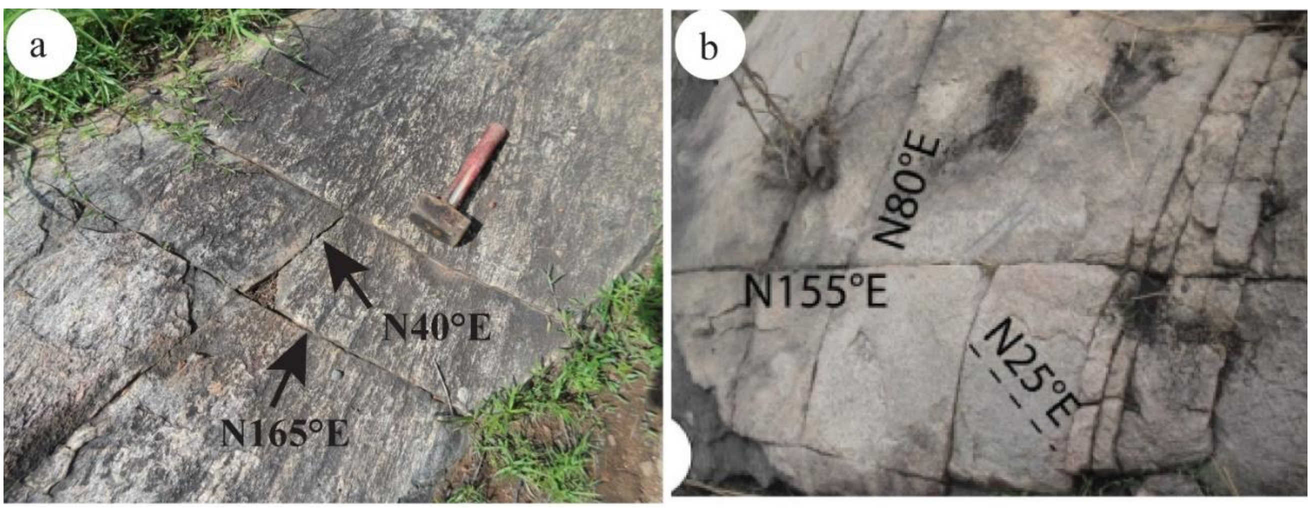

Figure 4: fractures networks on surface exposures in the Bankim area

Data from field observations are presented in Table 1. Rose diagrams (Fig. 5) is constructed for number of joints in a particular direction, with the directions often grouped into 10° intervals. The length of petals here is a measure of relative dominance of the trend and the resulting strike petals have a mirror image about the centre of the rose (Data on the amount of dip cannot be incorporated in the diagram).

The ability of fractures to act as path way for groundwater flow is affected by the degree to which they are interconnected. Fracture connectivity increases with increasing fracture length and fracture density, as the chance of fracture intersection increases. Connectivity in the Bankim area seem to be represented by the ratios of fractures that cut across other fractures (Fig. 4). Fracture length is large relative to fracture spacing, and all fracture terminations are crossing.

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Table 1: Fracture directions recorded by bedrocks of the Bankim Area

Trends	Trends	Trends	Trends	Trends	Trends	Trends	Trends
N150°E	N28°E	N130°E	N141°E	N75°E	N74°E	N155°E	N172°E
N150°E	N25°E	N128°E	N181°E	N65°E	N176°E	N150°E	N127°E
N148°E	N75°E	N136°E	N137°E	N65°E	N175°E	N150°E	N140°E
N165°E	N130°E	N140°E	N110°E	N48°E	N162°E	N160°E	N115°E
N155°E	N145°E	N134°E	N150°E	N55°E	N135°E	N05°E	N80°E
N154°E	N120°E	N141°E	N116°E	N55°E	N160°E	N175°E	N155°E
N70°E	N127°E	N136°E	N145°E	N63°E	N140°E	N155°E	N135°E
N105°E	N115°E	N109°E	N140°E	N130°E	N151°E	N165°E	N90°E
N75°E	N135°E	N86°E	N135°E	N185°E	N175°E	N165°E	N130°E
N55°E	N145°E	N86°E	N140°E	N35°E	N130°E	N96°E	N145°E
N45°E	N135°E	N106°E	N115°E	N170°E	N40°E	N95°E	N150°E
N51°E	N165°E	N187°E	N130°E	N165°E	N175°E	N160°E	N150°E
N88°E	N145°E	N168°E	N130°E	N170°E	N145°E	N20°E	N130°E

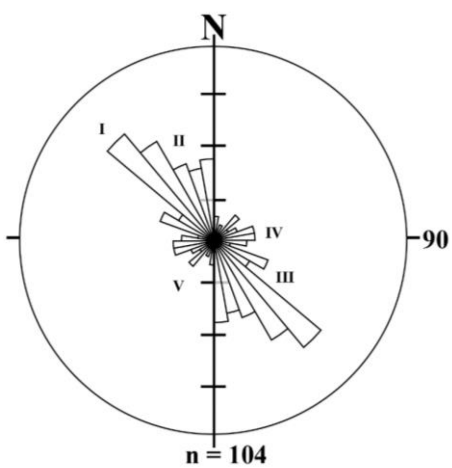

Figure 5: Rose diagram of 104 vertical fractures measured on the outcrops surfaces in the Bankim area. Vertical fractures can be subdivided into four different sets. Set I (max value representing 16,4% between 130° and 140°) appear to be the most dominant. Set V is roughly orthogonal to Set I.

Lineament Mapping

Linear features often reflect subsurface geology, and may denote the presence of faults or major fractures. Statistical analysis of lineaments using remote sensing data provides regional-scale information on fracture orientation and density [25] [18]. Lineaments were manually extracted, consisting to list or identify all the linear and lineaments of the Bankim Area. The directional convolution filtering was applied to Landsat-8 OLI band imagery to enhance the geological structural information and highlight the main lineament directions in the study area. Four principal directional filters: N-S, E-W, NE-SW and NW-SE with a 7x7 kernel size were applied (Fig. 6).

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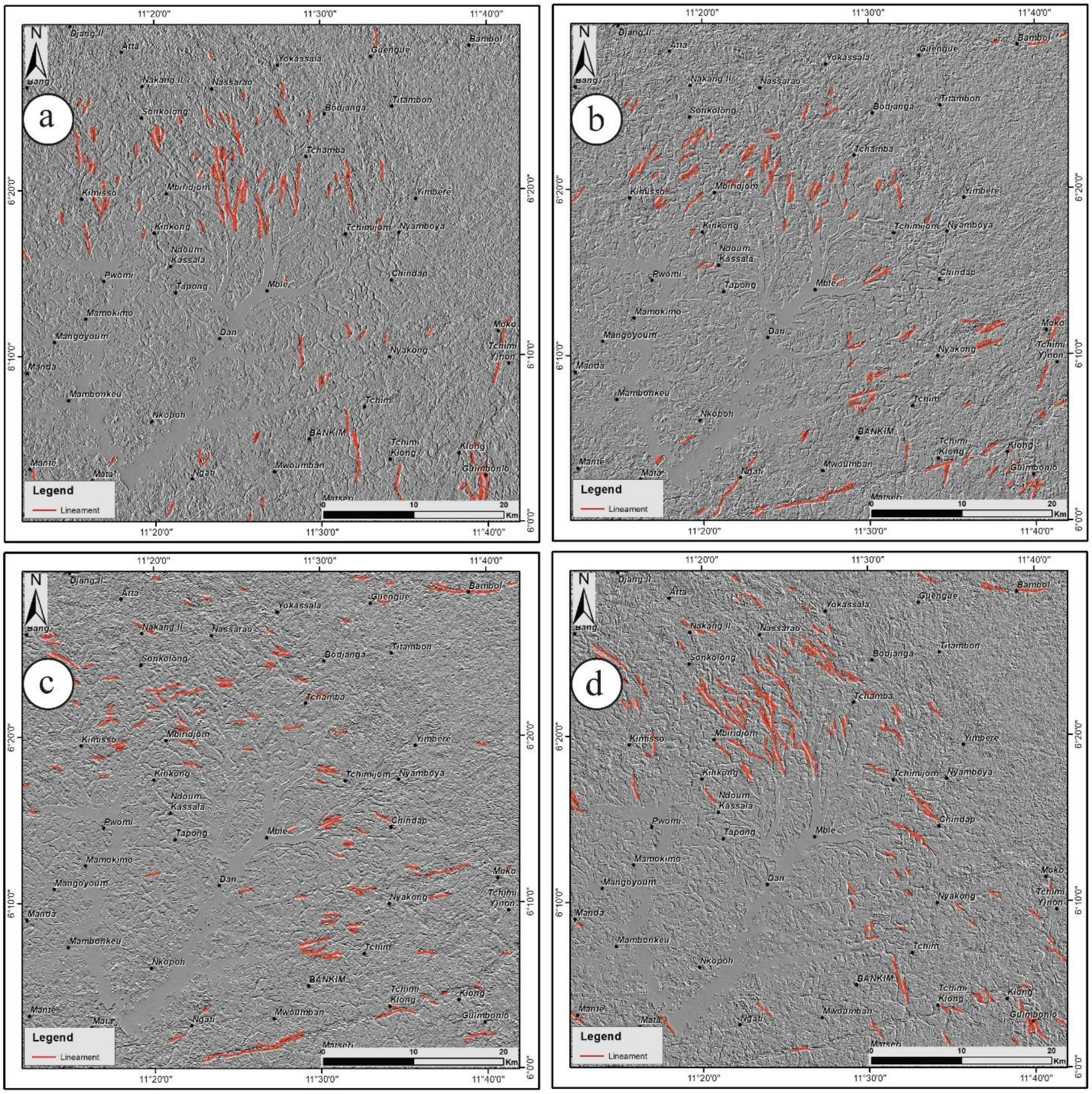

Figure 6: Shaded relief images with varying sun azimuth and angle in the four main directions: 1) N-S direction (0), 2) NE-SW direction (45), 3) E-W direction (90), and 4) NW-SE direction (135)

According to [29], the linear details observed on the images are related to various geological structures, such as faults, geological contacts and folds. Thus, the discontinuities on the images can be the expression of crest lines, limits between the geological formations, shear corridors and valleys. The images discontinuities surveys on the whole processed images (except for roads, high voltage lines etc.) allowed detail lineament extraction and thus the lineament maps of the Bankim area (Fig. 7). The directional filter's angles were assigned as follows: N-S by 0°, NE-SW by 45°, E-W by 90° and NW-SE by 135°. The number of the lineaments on the map is about 472 structural elements, ranging in size from

750.6 m to 9054.9 m with an average length of 1821.3 m.

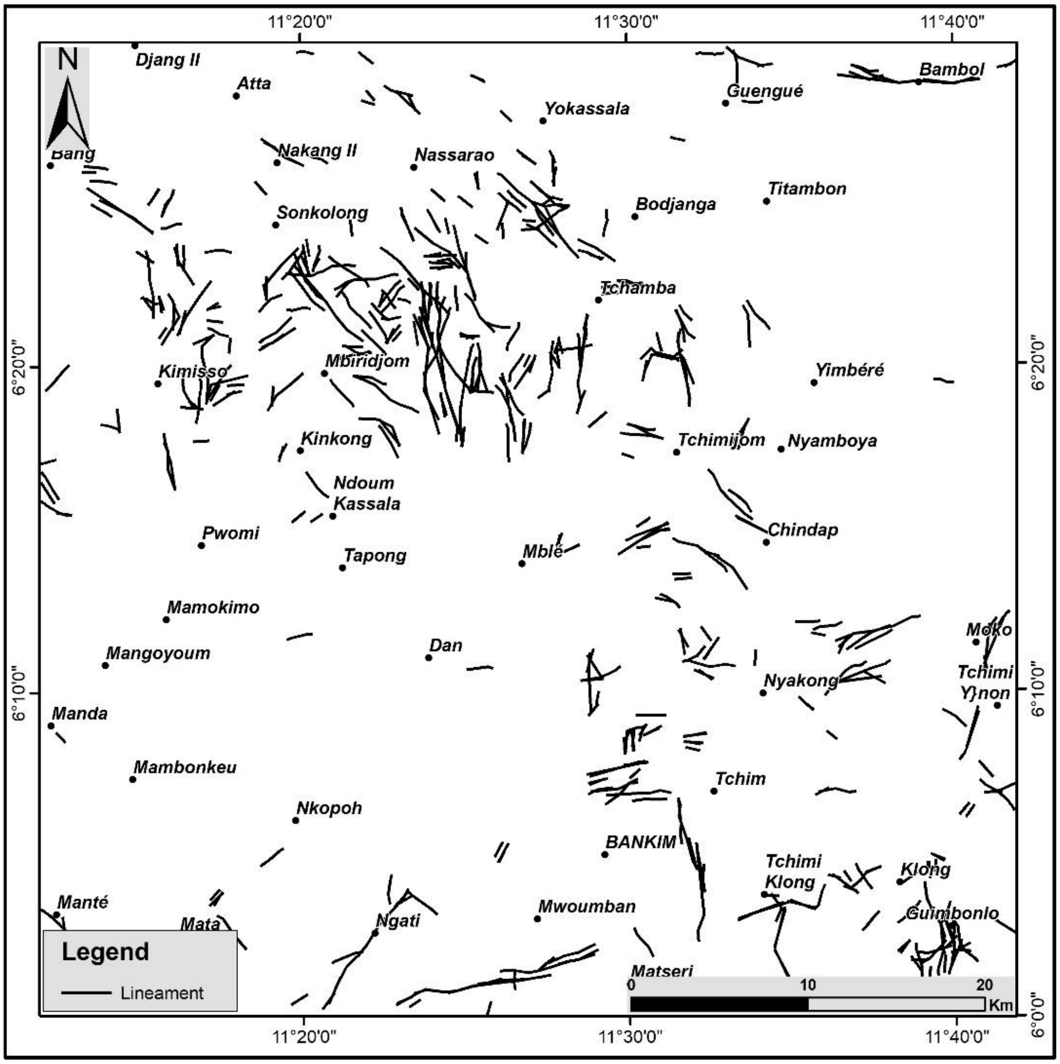

Figure 7: Lineament map of the Bankim area

The statistical analysis of the lineaments was carried out on about 348 lineaments and the number of lineaments per unit area is used for describing lineament density. The number of lineaments per unit area in the Bankim area shows that the predominant direction is NW-SE such as that of the measurement of plans directions on the bedrock. This information is not directly related to the hydrogeology. It is often been found that wells located on lineaments, and particularly on the intersection of lineaments, produce higher bore yields than those located elsewhere.

Groundwater modelling in the Bankim area

Modelling is important for improving the understanding of system behaviour. In this study, it provides a framework for synthesising data from field investigations and remote sensing, and improving conceptual understanding of water flow and transportation behaviour and the factors controlling

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them. The development of a conceptual model can provide an adequate representation of the hydrogeological system and show how does the model performs in comparison to field observations. However, it is more important to understand from the outset what level of detail is needed to adequately represent the system being studied. The geology of a fractured system helps to identify features that may be important in controlling the hydrogeology. Field observations indicate that fractured rock system seems to be dominated only by a few major features and the modelling approach is the discrete fractured model in which the major fractures are explicitly modelled (Fig. 8). The discrete fracture network approach can explicitly account for flow path geometry and fracture properties are suited to smaller-scale modelling studies. The approach is generally limited by the data available on fractures as well as the ability to extrapolate properties from smaller scale tests to larger regions of interest.

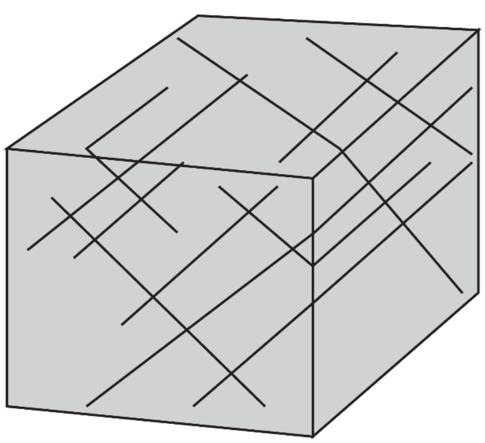

Figure 8: Discrete fracture model, in which the major fractures are explicitly modelled

V. DENSITY OF LINEAMENT

The purpose of the fracture density analysis is to calculate frequency of the fractures per unit area. There are essentially three classes (low, average and high) in the map shows the concentration of the lineaments of the Bankim area (Fig. 9). The drainage density represents the precipitation amount which could seep into the basement. Therefore, the higher the drainage density is, the higher the recharging probability is [26]. The hight density is observed around the localities of the Mbiridjom, Kimisso, Goumbonlo and Bankim. The areas with elevation of 800 meters have high densities of lineament while mountains areas and hills have very low densities. The mountains in the northern and northeastern part of the study area (Fig. 3) is a part of Adamawa Plateau, constituted mainly of granitoids [33] while the Bankim area is in the Tikar Plain, known as an intensely deformed and fractured zone, constituted of mylonite, orthogneisses, granite [23] [5] [15] [1]. This can justify the high densities of lineament fractures in the moderate elevation while low in the mountain areas.

The degree of hydraulic interconnection between the above lithologic units as surface water circulates through these discontinuities is verified by the degree of fractures intersection. The density and degree of lineament connection determine the level of anisotropy of groundwater flow in the fractured aquifer, as in an environment with a high degree of interconnection where groundwater flow is steadfast [25]. Fracture intersection density map (Fig. 9) shows the frequency of intersections per unit area. The intersection density maps were used to classify the areas of diverse fracture orientations. If the fractures do not intersect in the aforesaid area, the resultant map will be represented by a plain map with almost no density contours and the fractures will almost be parallel or sub-parallel. The groundwater potential zones map of the study area (Fig. 9) indicates areas with very high density of lineaments. The flow of water is generally from North to South, Northeast to Southwest. This north to south and northeast to southwest directions are the two major direction of the tectonic deformation that affected the Bankim area [15] [1], justifying the hydraulic activity controlled by tectonic deformation that have severely affected the region.

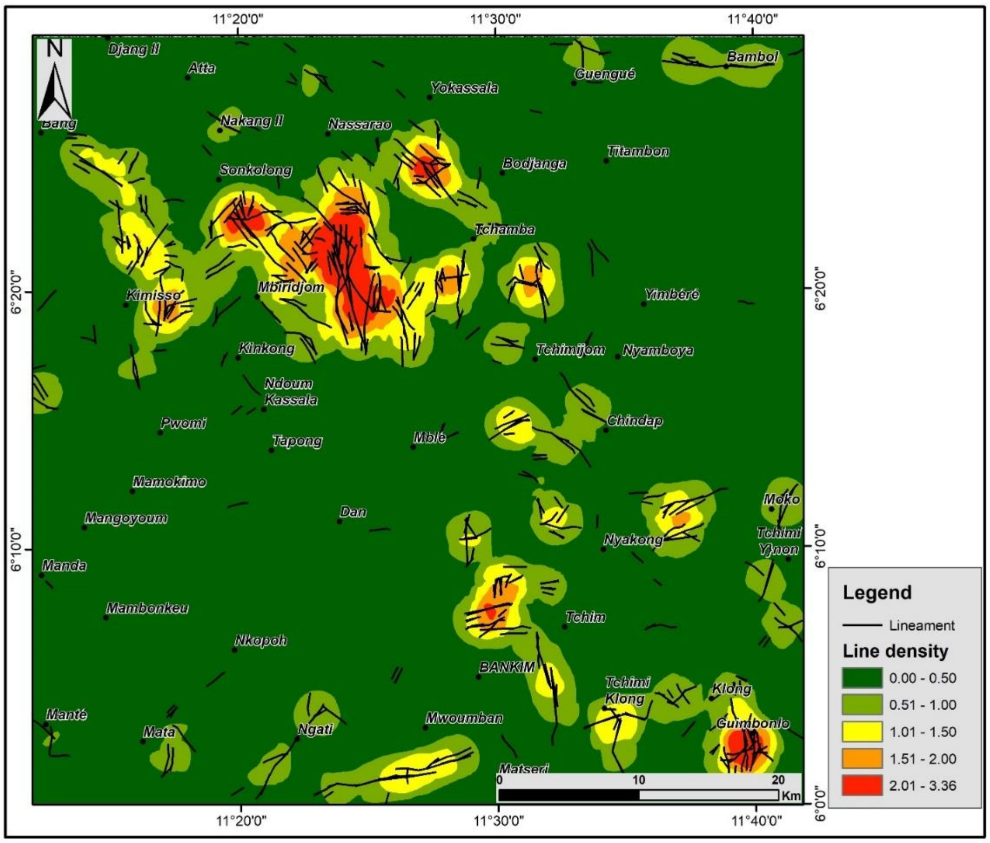

Figure 9: Groundwater potential zones map

VI. GROUNDWATER POTENTIALITY

The architecture of the fracture network is highly dependent on the fracture characterisation media and the experience of the photo-interpreter. The Landsat-TM satellite images used in this study have a spatial resolution limitation that may lead to undersampling of small fractures and, therefore, bias in the network mapping. In order to achieve a finer description of the fracture network and to take into account different spatial scales of measurement, it would be desirable to use other images of finer spatial resolution such as SPOT images that should also be coupled with field investigations for a better characterisation of the geometric systems of Bankim.

The groundwater yield of crystalline rocks is directly depending on the degree to which the rock has been

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fractured. Contact zones between theses rocks are also favourable zones for the location of good productive wells capable of yielding large volumes of water. The Bankim area is knowns as an intensely deformed and fractured zone [23] [15] [1]. This strong fracturing and deformation that these rocks have undergone makes them susceptible to develop secondary porosity. Boreholes or wells that cross fractures or weak planes of this rocks will be regularly supplied with water unlike those that do not cross fractures will have little or no water. Steeply inclined fractures such as in Bankim area with subvertical to vertical dipping are commonly expressed at the land surface as lineaments; and wells drilled along such lineaments or along known fracture traces consistently yield more water than randomly located wells. Most of the lineaments in the Northern part of Bankim area are NW-SE trending lineaments while they are NE-SW in the southern part of the Bankim. In Bankim, NW-SE dominates the structural trend followed by NE-SW and E-W. This can be an indication of the directions of groundwater movement in the area. These NE-SW directions in the southern part of Bankim coincide with the NE-SW directions of the major fractures on the structural map of Bankim. In the Bankim fracture network, the intersection of fractures of several directions is one of the most important results. It may reflect a large water exchange and recharge system. Hydrogeological modelling of such a network can take into account large structures in a deterministic way and small fractures in a stochastic way [19].

VII. CONCLUSION

Satellite remote sensing, using visual interpretation of Landsat 8 OLI_TIRS images was coupled with field structural data to map fracture networks and identify suitable groundwater potential zones in the Bankim area. Field observations and geometric parameters have shown that fractures in the Bankim area intersect each other and the main direction is NW-SE while the major fractures found on the structural map have a NE-SW as a main trending direction. These two directions are the main direction of water flow in the Bankim area. The Landsat image processing show that the number of the lineaments on the map is about 472 structural elements identified, ranging in size from 750.6 m to 9054.9 m with an average length of 1821.3 m and the high potential zones are observed around the localities of the Mbiridjom, Kimisso, Goumbonlo and Bankim. About 11% of the area has good groundwater potential while about 18% is moderately good then and 71% of the area has poor ground water potential corresponding to low lineament density areas. The high percentage (71%) of area with poor groundwater potential may justify the high degree of random wells drilled in the area and imposed the necessity of taking in to consideration the model proposed in the present paper for future drilling with aim of high groundwater productivity.

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