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Contribution of Geoelectricity and Remote Sensing to Study the Basement Fractured Zones in the Bandjoun Region (Cameroon)

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Abstract: The main source of drinking water for the rural population in the locality of Bandjoun, in the koung-khi division (West Region of Cameroon) is groundwater. The increase in population combined with the difficult environmental conditions of the division have increased the water shortages. This study aims to use geophysical techniques to identify areas with high groundwater potential. The methodology adopted includes the processing of radar (Shuttle Radar Topography Mission) and optical (Land Satellite Operational Land Imager) satellite data which made it possible to study the parameters of the environment. Furthermore, informtion from terrain parameters such as blurring was extracted and used to produce the fracturing map. Using these techniques, it has been shown that Bandjoun have two types of aquifers, namely: surface aquifers (0 to 15 m of depth) and deep aquifers (20 m to 50 m of depth). Several parameters were recorded and interpreted on the physicochemical and water level: temperature, electrical conductivity, pH, TDS, Na^+, K^+, Ca^{++}, Mg^{++}, Cl^-, HCO_3^- and Fe^{+++}, the concentrations are classified as follows: $HCO_3^- > Ca^{++} > Cl^- > Mg^{++} > Na^+ > Fe^{+++} > K^+$. Fractured zones are potentially aquifers environments and the productivity of these deep aquifers depends in part on the nature of the geological facies and their mineralogy. It appears that groundwater is chemically unsuitable for human consumption.

Keywords: Cracked Aquifer, Vertical Prospecting, Basement, Drilling, West-Cameroon

1. Introduction

Bandjoun, headquarter of the Koung-khi division, encounters difficulties in accessing groundwater resources. In fact, there are few hydraulic productions with quantities of water generally lower than the average. The water deficit of the populations is priceless. Knowledge of the fracturing zone constituting the main underground drainage axes is fundamental for the search for groundwater [1]. This work involves the use of geophysical methods for prospecting the city's groundwater. Specifically, this will include electrical resistivity and remote sensing methods. The objective is to map the networks of fractures facilitating the identification of areas of alteration or tectonic anomalies in order to better supply the population of Bandjoun and its surroundings with groundwater. The biophysical characteristics of the area are: The life of the Bandjoun people; Precipitation which is about 1517.6 mm per year, the average annual temperature of 20.90°C. August appears to be the rainiest month, and January the least rainy. The aridity indices show that the months of December, January and February are the dry months, while the months of April to October are wet, March and November being between these two types. According to J. Guiffo, the overall morphology of the relief of Bandjoun is that of the high lands [2]. K. Kouame specifies that it consists of lowered hills, leveled by erosion, and "V" and "U" valleys in which the permanent and intermittent rivers flow [3]. Two main types of landscapes can then be identified: V-shaped and U-shaped landscapes. The maximum altitude is 1,800 m and the average altitude is 1,400 m.

2. Geological and Structural Contexts of the Study Area

The study area (Figure 1) lies between longitudes 10°23'-10°35' E and latitudes 5°14'-5°26' N. It is located in the CVL environment and covers approximately 353 km^2 and a density of 345 hab/km^2.

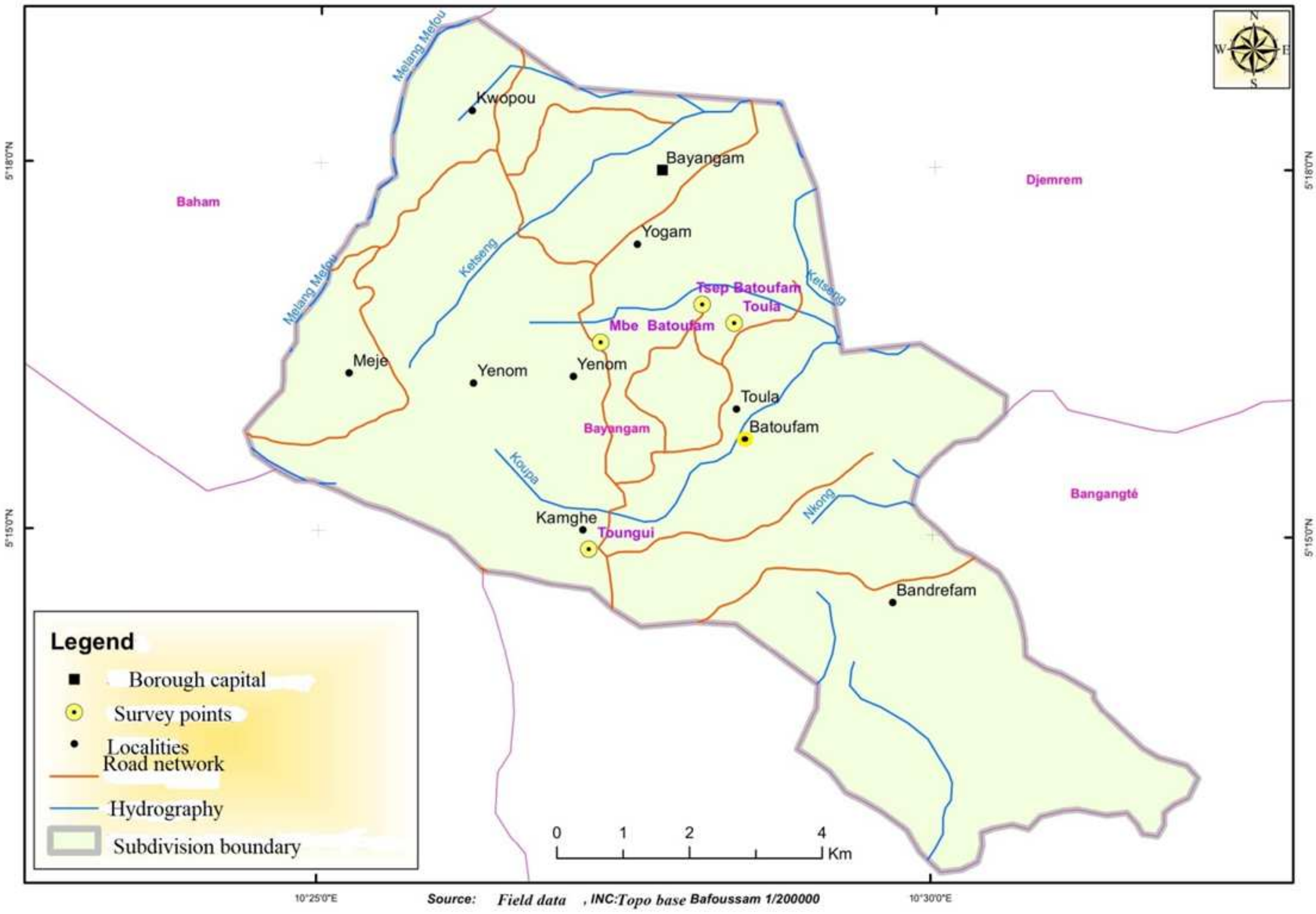

Figure 1. *Location map of Bandjoun modified from J. Dumort* [4].

The geological coverage of the region (Figure 2) mainly includes basement and volcanic formations; the latter covering the former over most of the Bamileke plateau. The basement formations are mainly made up of calc-alkaline embraceous gneisses, always found in anticline position [5]. The study area is located at the foot of the eastern slope of Mount Bangou, and belongs to the Volcanic Line of Cameroon (LVC) under which the pan-African base rests [6]. The Pan-African Chain of Central Africa is made up of formations as complex as they are varied. In their vast majority, we find granitoids (leuco granites, biotite granites, two micas granites, biotite and amphibole granites, biotite and garnet granites, granodiorites, diorites, monzonites, syenites and gabbros), with which the garnet-biotite-disthene gneiss, biotite-muscovite-garnet gneiss, pyroxene gneiss, migmatitic gneiss, migmatites, amphibolites, granulites and quartzites [7].

The hydrographic network of the West region in general consists, in the East, of tributaries of the Sanaga (Métchié, Mifi, Nkoup, Ndé, Noun), in the South, tributaries of the Nkam (Ménoua, Makombé, Ngoum and Mwanké), and mainly for the locality of Bandjoun, the hydrographic network is directed by the Noun River which plays the role of main collector (Figure 3).

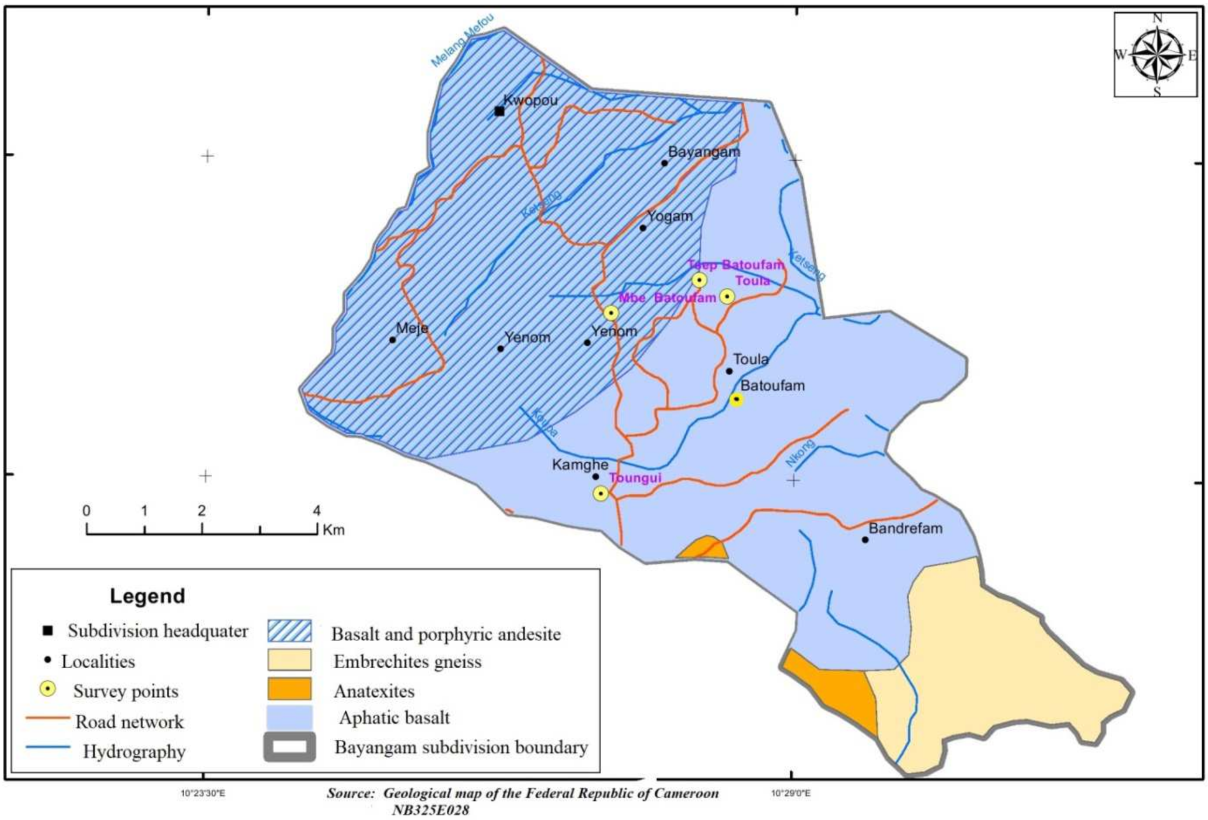

Figure 2. *Geologic map of Bandjoun modified from J. Dumort* [4].

Figure 3. *Map of hydrographic basins modified from L. Boutot et al.* [8].

L. Guoping et al. distinguished the tanks of altered zone, cracks, and faults as everywhere in the basement zone. Weathered zone aquifers are shallow and result from the weathering of compacted or fractured bedrock [9]. Cracks or fracture aquifers are deeper. They are set up by tectonic events and consist of open and interconnected fractures in which water circulates and is stored. The presence of a basement aquifer is therefore subject to the existence of cracking and / or alteration.

Bandjoun has a tropical climate with two unevenly distributed seasons, with savannah vegetation and periforest galleries. The economy is based on agricultural and pastoral activities, associated with periodic commercial activities. With a general geomorphology of the high plateau made up of lowered hills and valleys, the hydrographic network uses the Noun as the main collector. There is a wide variety of soils developed on a base mainly dominated by the Basalts.

3. Materials and Methods

3.1. Data and Material

These are the monthly and annual rainfall records from the meteorological stations of Bafoussam and Foumban covering the period 1940-2013 [5, 10]. In addition, there are monthly records of maximum and minimum temperatures (1980-2010), relative humidity and wind speed (data from TAMSAT). The Hydroclimatic data underwent several upstream pre-processes operations, including extensive checks (entry errors and consistency), statistical processing (various tests of data quality and accuracy) and recognition tests for missing data.

The hydrogeological data are made up of technical sheets of boreholes and wells made during the hydraulic campaigns undertaken by the Cameroon ministry of water and energy (MINEE) and the company GEOFOR [11]. They provide information on the geographic coordinates of the structure, its total depth, the geology of the aquifer, the thickness of the altered zone and the aquifer, the static and dynamic level of the water table and the operating rates. This information was useful in the preparation of training sites and validation of lineaments for the mapping of fracture zones. They were also used to validate the potential water reservoirs of the geological formations of the Bandjoun studied region. Some boreholes do not record all of the hydrogeological parameters important for multi-criteria analysis. It is therefore recommended to estimate these parameters by interpolation over the entire study area or to work only on the portion with the highest number of hydrogeological parameters.

The mapping of water potential depends on several environmental factors and their mapping is complex. Several studies have demonstrated the advantages of satellite images from different sources [12, 13]. In this study, certain types of images were processed: the new optical OLI / TIRS images from LANDSAT 8, digital terrain models and estimated rainfall data from satellites (TAMSAT). Landsat OLI (Operational Land Imager) scenes 186/056/2018/0111 and 187/056/2018/0127 were used for the mapping of the fracture zones. Thanks to their spectral resolution, they made it possible to discriminate the main land use units of the study site. With 30m spatial resolution and 12 spectral bands, these images taken on September 06, 2018 have been downloaded for free from the United States Geological Survey (USGS) Image Database at http://earthexplorer.usgs.gov/ and received by email at custserv@usgs.gov.

3.2. Field Survey and Prospecting Strategy

The field missions carried out enabled the acquisition of ground observation data. Software and programs have facilitated image processing and the production of thematic maps. The processing of images from the TAMSAT method and LANDSAT satellite images was carried out with ENVI 5.1, Jointem 1.4 Res2Dinv and ArcGIS 9.1 [14, 15, 16]. ENVI 5.1 has a module entirely dedicated to the atmospheric and radiometric correction of LANDSAT 8 OLI / TIRS images [15]. Validation and adjustment of TAMSAT images, digitization, spatialization of data and creation of thematic maps were established using ArcGIS 9.1. For the analysis of major discontinuities (fractures, fold faults), Surfer 11 was used [17].

Numerous hydrogeological studies have demonstrated the importance of using satellite images to map fractures of tectonic origin. The enhancement techniques used, including spatial filtering, have proved their worth in the humid tropical region as undelined by Niemke [18]. This consists in separating the information as much as possible in order to obtain a specific channel at high frequencies. The spatial filtering aims at better distinguishing the lineaments. The structural lineaments are read manually. The lineaments and the mapped structural elements are then validated by field knowledge, existing geological maps. The work of different authors was used to compare the results obtained [5, 19, 20]. During the validation step, lineaments having a non-tectonic origin are deleted. These are roads, tracks, power lines and many more. The selected lineaments therefore have a fracturing value.

Remote sensing and electrical geophysics make available a very vital contribution to the location of alteration zones and faults, which are all zones favorable to the presence of water in rocks. The prospective study has two parts of investigations. The first is based on geomorphological examination and the implementation of electrical methods on the Bandjoun site. The second is based on the choice of sites for drilling. Geophysical methods measure the physical parameters of the subsoil from the surface. The electrical resistivity method consists in injecting a direct current into the ground (Figure 4) using electrodes commonly named A and B and in measuring the potential difference between two other electrodes named M and N which are located between A and B. Data along a profile is important for a lateral investigation to determine anomalies in the basement, while electrical data favor understanding of the succession of layers of land. The technique used is essentially that of the Schlumberger type electrical sounding. For these measurements, the emission line lengths (distance between the current sending electrodes A and B) were variable from AB = 500 m. For these distances, the apparent resistivity curves were established by 12 measurement points. In order to come as close as possible to the theoretical conditions of the Schlumberger electrical sounding, the ratio (AB / MN) was 3 to 10 with two disengages (a = 0.5; 5 and 25 m). For the measurements of potential differences, we have used a four-channel TERRAMETER SAS 1000 resistivity meter, the TERRAMETER SAS 1000 is associated with the LUND ES1064C box, fully automatic with a sensitivity of the order of microvolt. The current is sent to the ground using an external 1200W AC / DC converter powered by a standard 220V - 50Hz generator. The measurement is made entirely automatically through the microprocessor control: automatic correction of the Spontaneous Polarization (PS), automatic accumulation of measurements for the improvement of the signal / noise ratio and display of error messages in the event of measurement problems. All parameters such as current, voltage, geometric parameters, location parameters, etc. are stored in memory. A serial link makes it possible to transfer data to a PC and in a conventional format that is easily interpreted.

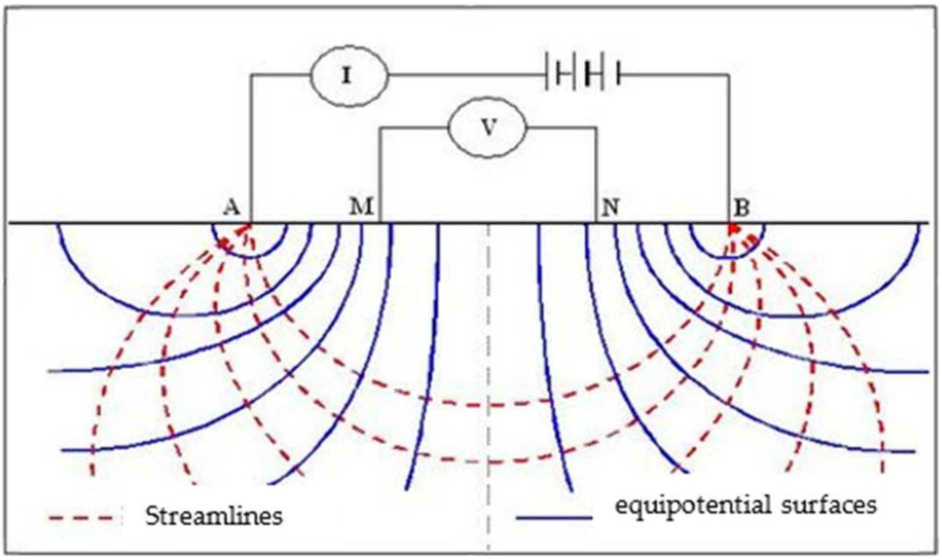

Figure 4. *Principle of electric prospection by current considered direct modified from R. Lagabrieller et al.* [21].

3.3. Data Preprocessing

Data preprocessing group together the operations required before image analysis and information extraction. They correspond to the radiometric and atmospheric improvements and the surveys carried out.

a. Atmospheric and radiometric corrections to LANDSAT images

It is important to eliminate any influence from the atmosphere: hence the value of radiometric and atmospheric corrections. A correction of the atmospheric effects was undertaken on each of the 12 bands of the LANDSAT OLI images. The main atmospheric effects, including absorption by water vapor, carbon dioxide, oxygen and ozone, diffusion by molecules and the visibility of the scene were taken into account. Several techniques make it possible to deduce the influence of the atmospheric properties of recorded objects thanks to the phenomenon of reflection (reflectance) [22]. In this study, ENVI's Atmospheric Correction module predicts the actual reflectance of ground targets for a cloudless atmosphere. The FLAASH tool specifies several information required as input on the date and conditions for taking pictures [23]. It has as priority:

1) To permit the calculation of the visibility of the scene from local atmospheric conditions;
2) The application of several types of sensors, both old and recent (Landsat 8 OLI);
3) To process images regardless of the date and direction of acquisition.

The atmospheric correction of scenes 186/056/2018/0111 and 187/056/2018/0127 was done in three steps:

1) The first step consisted in calibrating the digital accounts of each band. For this, the digital accounts have been converted into luminance values captured by the satellite using the parameters provided in the image header files;
2) In the second step, these luminances thus obtained are transformed into exo-atmospheric reflectance. This step is the most complex and difficult; it requires information on weather conditions at the time of image recording;
3) Finally, the application of the MODTRAN model of the FLAASH tool made it possible to assess the importance of the effects of the atmosphere on the images and to correct them; thus, giving real reflectance images (Figure 5) of objects on the ground.

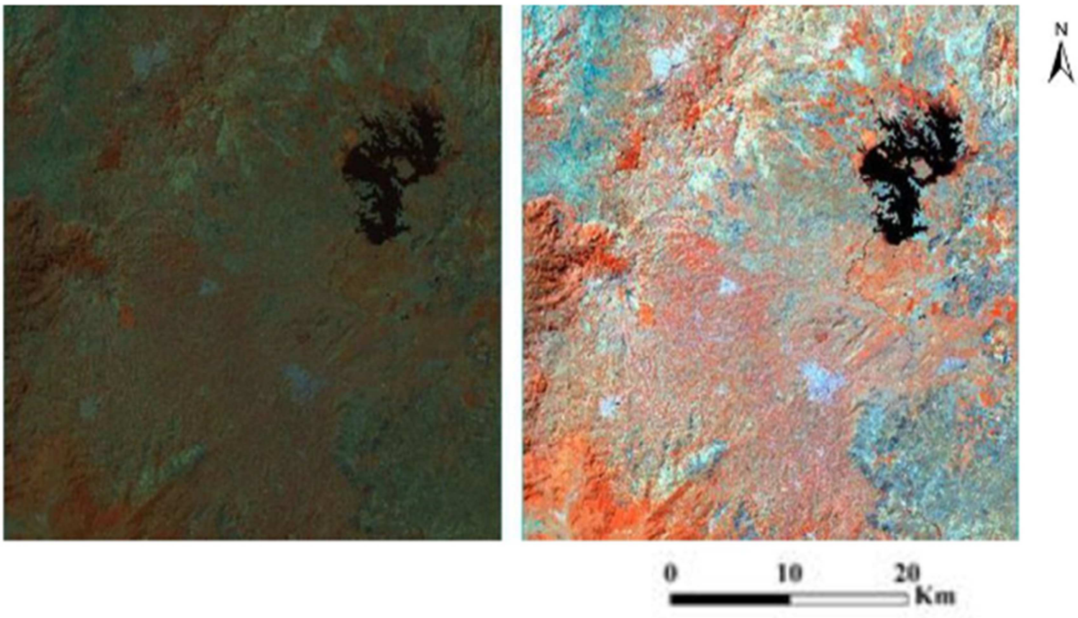

Figure 5. *Atmospheric rectification of the LANDSAT 8 OLI image: significant representation of OLI 567 obtained before and after rectification.*

b. Realization of the structural map

The validation of the structural map was accomplished by taking into account the results of previous works, in particular, field work and the interpretation of tectonic alteration zones. Several databases assisted in the creation of the fracturing map. From this map, we extract the linear, density, and drainage anomalies. The choice of the fractures made it possible to retain those which have a significant length on the image, which, in several cases express the alignment of watercourses and vegetation; agree with drainage anomalies, are recurrent in a given direction and, if possible, the whole image. In short, the fractures thus mapped were the subject of a statistical analysis. This made it possible to produce a linearity density map.

c. Fracture density map

The fracturing density represents the cumulative length of fractures per unit area. It is expressed (equation 1) in km / km^2 [24].

$$D_f = \frac{\sum L_{cf}}{S} \quad (1)$$

where L_{cf} is the cumulative length of the fractures and S is the area.

d. Lithologic cartography

Two methods of analysis and interpretation of the results of image processing for a geologic mapping dominate in geophysical literature. Photo-interpretation which consists of making a visual assessment and manual digitization of the limits of the different geologic formations and the directed or non-directed classification [3, 25].

e. The thickness of the altered zone

The altered zone are residual surface formations resulting from the alteration and fragmentation of the parent rock. They contain reservoirs called surface aquifers. The layers of land used come from drilling data distributed in and around Bandjoun.

f. Transmissivity

The transmissivity was determined following pumping tests carried out during the establishment of 12 boreholes collected during one year on depths less than 5 m in order to know their distribution within Bandjoun and to deduce an interpolation from it. upwelling data.

g. Induced permeability

The fracture-induced permeability assesses the likely existence of water reservoirs in cracked media. Cumulative lengths of fractures to a higher degree cause high permeabilities and larger reservoirs. Consequently, the more the region is fractured, the more the induced permeabilities are corrected. To determine the permeability induced by fractures in the Bandjoun region studied, the method of Francis was used [26]. It is a method specific to cracked media which determines the permeabilities induced by fractures. It has been used successfully in several studies [27]. It integrates two variables: the hydraulic conductivity K (m/s) of the region studied and the empirical coefficient of proportionality C (without unit) between the opening and the length of the fractures.

4. Results and Discussion

4.1. Preliminary Results for the Mapping of Fractures

4.1.1. Extraction of Fractures

In the Bandjoun region where the effects of relief are weak, the practically monotonous relief and the vegetation mainly marked by savannas and crops influence very little the spatial continuity of the lineaments. Several local lineaments could be enhanced with black hues on these formations. The blurred parts of the relief (Figure 6) accentuates regional and local lineaments on these formations.

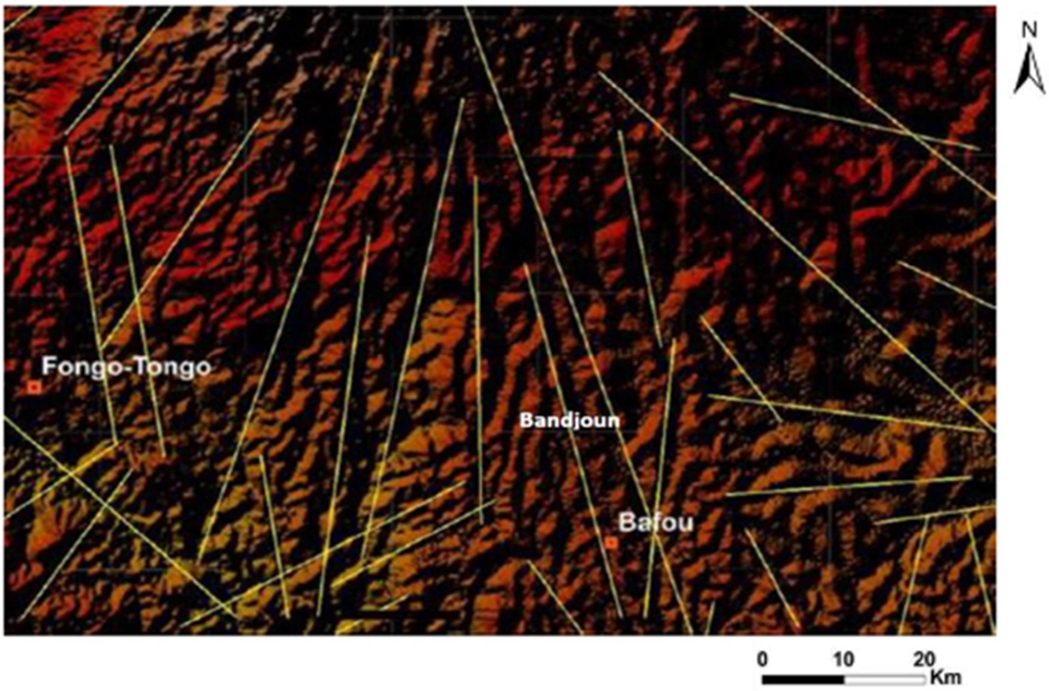

Figure 6. *Blurring of the relief enhancing the lineaments on the basalts.*

4.1.2. Fracture Map and Analysis of Extracted Fractures

The combination of the different results gives a linear map which emerges from the lineaments with different lengths and directions. This map has several lineaments. This high number of lineaments is representative of the region studied. These lineaments were assigned a fracturing value (Figure 7) after a validation phase. This fracture network is dense with several fractures. This shows that the locality would have undergone several tectonic phenomena which led to this very pronounced fragmentation of the geological formations.

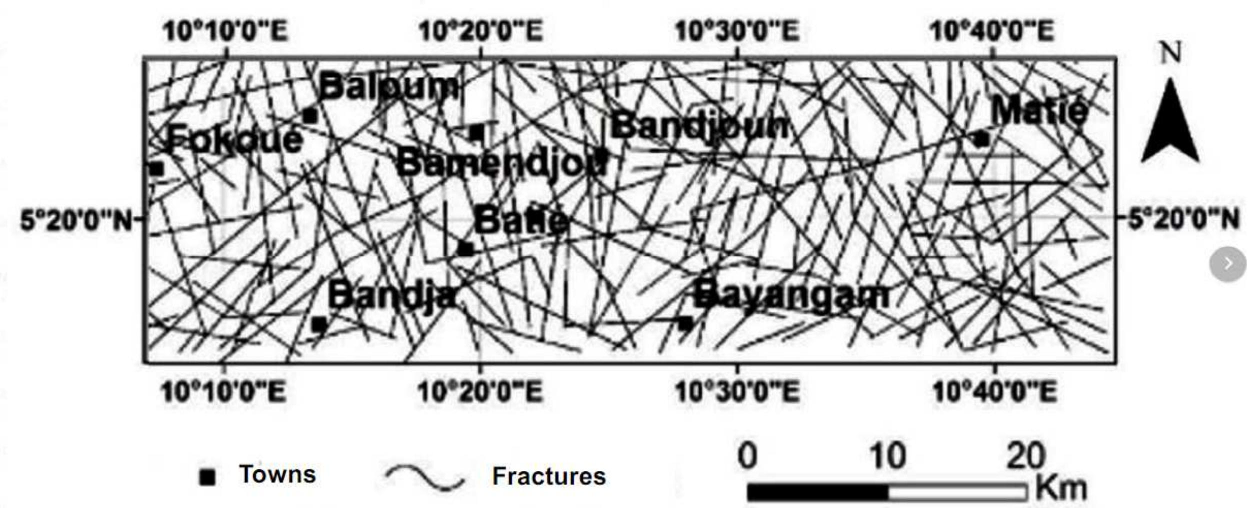

Figure 7. *Bandjoun fracturing map.*

The high fracturing density observed in these formations can be explained by the fact that these basement rocks have undergone tectonic movements originating both from the Pan-African orogeny and those linked to the Cameroon line. On the other hand, the younger rocks, essentially linked to the tectonics of the Cameroon line, are the least fractured (fault, shear). All these accidents therefore constitute points of weakness that use groundwater (because water circulates between the cracks in the fractured rock) and are of great interest for the productivity of boreholes.

4.1.3. Density of Fracturing

The fracture density map in number of fractures and in cumulative lengths (Figure 8) shows that the region studied is well fractured.

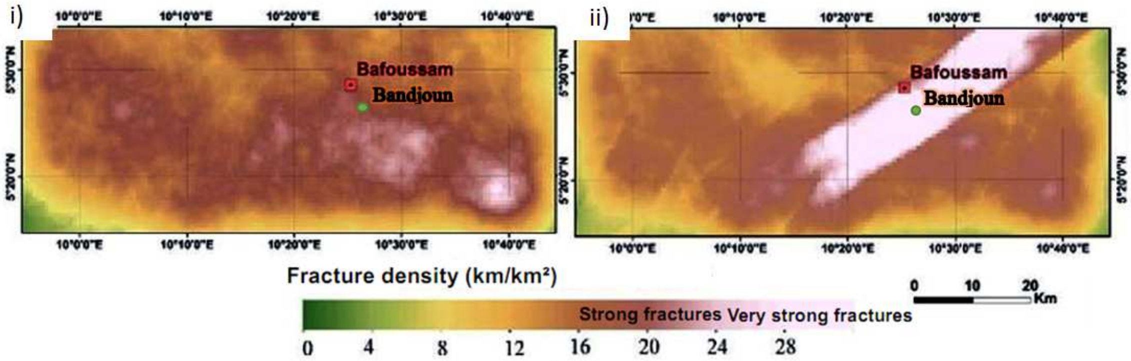

Figure 8. *Fracture density maps: (i) number of fractures; (ii) cumulative length.*

A high-density area appears in the heart of Bandjoun on the digital density map and in cumulative length, while the East-south part of the study area seems to disappear on the cumulative length map. The map on the left shows discontinuities while that on the right (ii) is almost continuous. Thus, the areas of low-density surround those of high. From a geologic point of view, the high fracturing densities recorded dominate the basement areas and thus allow a better understanding of the geometry of the aquifers.

4.2. Geoelectric Method

The horizontally stratified terrain response for Schlumberger electrical prospecting methods has been implemented. In order to validate the direct calculation, we compared the results obtained by the latter with other results calculated by a 1D interpretation and modeling software JOINTEM [14].

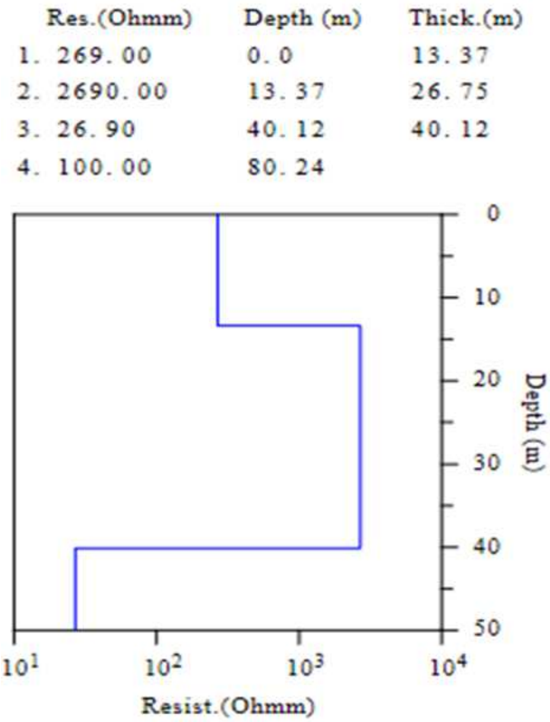

Figure 9. *Four-layer model with thicknesses of 14, 27 and 4 m and resistivities of 269, 2690, 26.9 and an infinite half-space of 100 ohm-m.*

To do this, synthetic data was generated from the four-layer model shown in figure 9 by the software Jointem 1.4. The response of this model in the case of electrical prospecting (Schlumberger array) are apparent resistivities (ρ_{app}) with 7 outputs per decade and a maximum AB / 2 of 250 m was used. The results obtained for the Schlumberger method are shown in Figure 10.

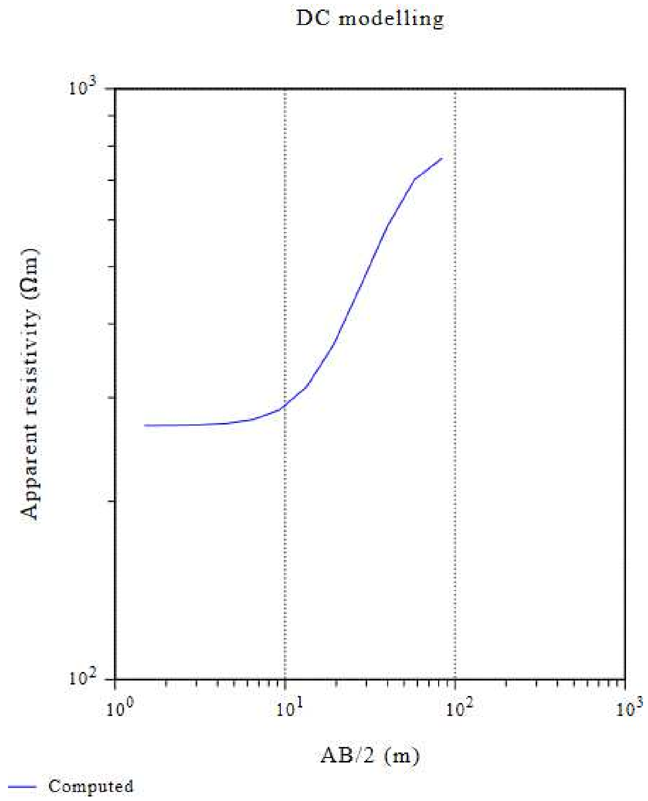

Figure 10. *Response of the four-layer model of figure 9 for the Schlumberger method. Representation of apparent resistivities with 7 outputs per decade and a maximum AB/2 of 250 m by the JOINTEM software.*

The determination of the initial model depends on the number of layers. Thus, by varying the latter, several solutions can be obtained while keeping an overdetermined system and the question that arises at this time of our work is how to choose the one that best interprets our terrain? The ratio of the degree of resolution (DR) to the mean square error (RMS) answers this question. We take the synthetic data that was generated from the three- or four-layer model, and to get closer to a practical case, we disturb these data with a low-level Gaussian noise of 1%. The joint inversion of these data while keeping an overdetermined system gives several solutions. S. Friedel evaluates the degree of resolution of the parameters found and obtains that it varies between 0 and 1, and the resolution is perfect for the value 1 [28]. S. Bougchiche then obtains the best solved solution which coincides with the higher degree of resolution [29]. Thus, we arrive to say that the best solved solution is the one with the highest degree of resolution and the lowest RMS, the latter is evident, the one with the highest DR / RMS ratio. Thus, we obtain the result of the joint inversion of the synthetic data (Stations of Mbe, Toungoui, Toula, Bayangam 3) generated from the layer model of Figure 9 (Figure 11) adjustment of the response of the solution to the apparent Schlumberger resistivities, (Figure 12) coincidence of the best resolved solution according to our selection criterion with the model sought.

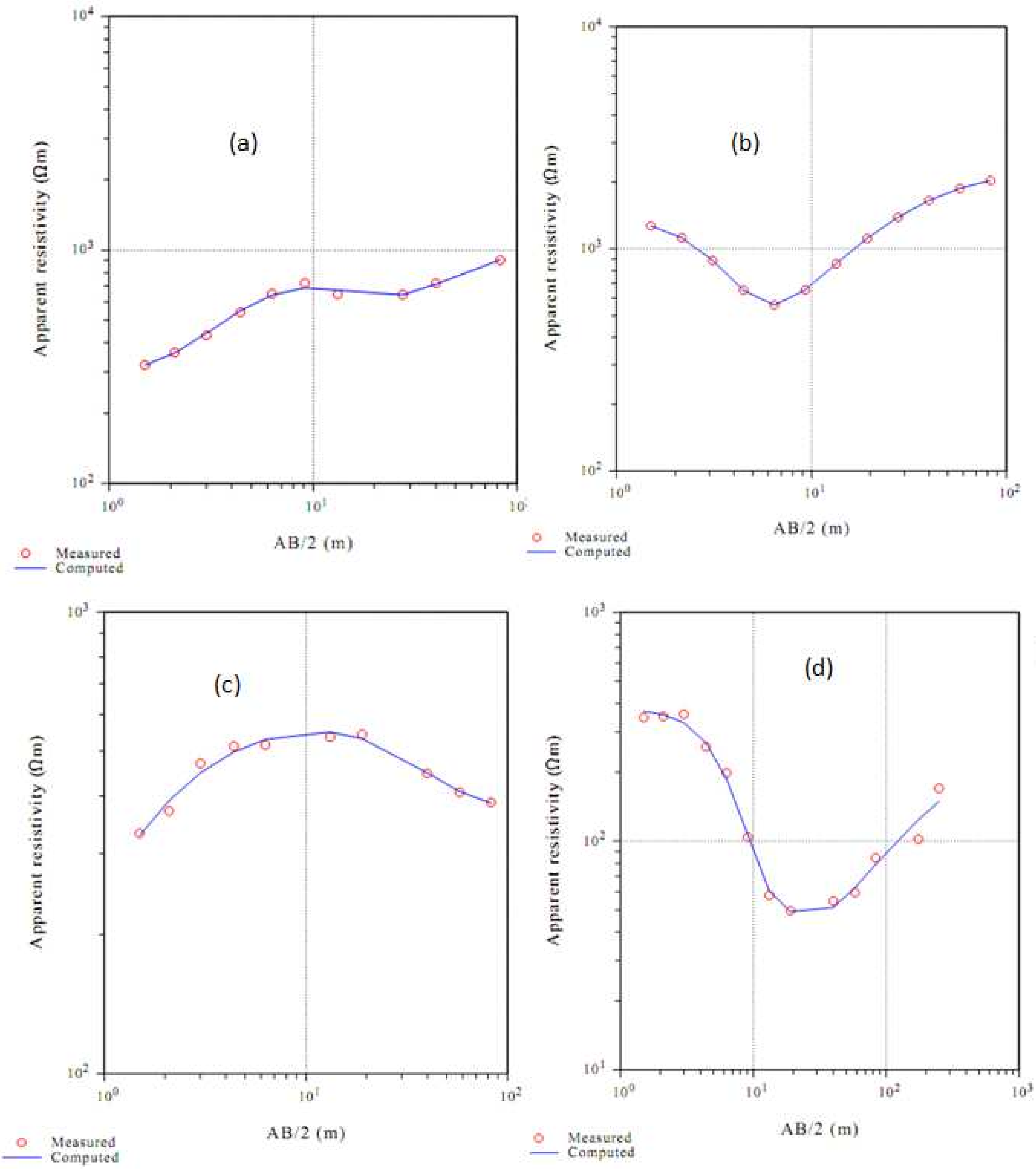

Figure 11. *Adjustment of the response of the solution to the apparent Schlumberger resistivities of some stations a, b, c and d.*

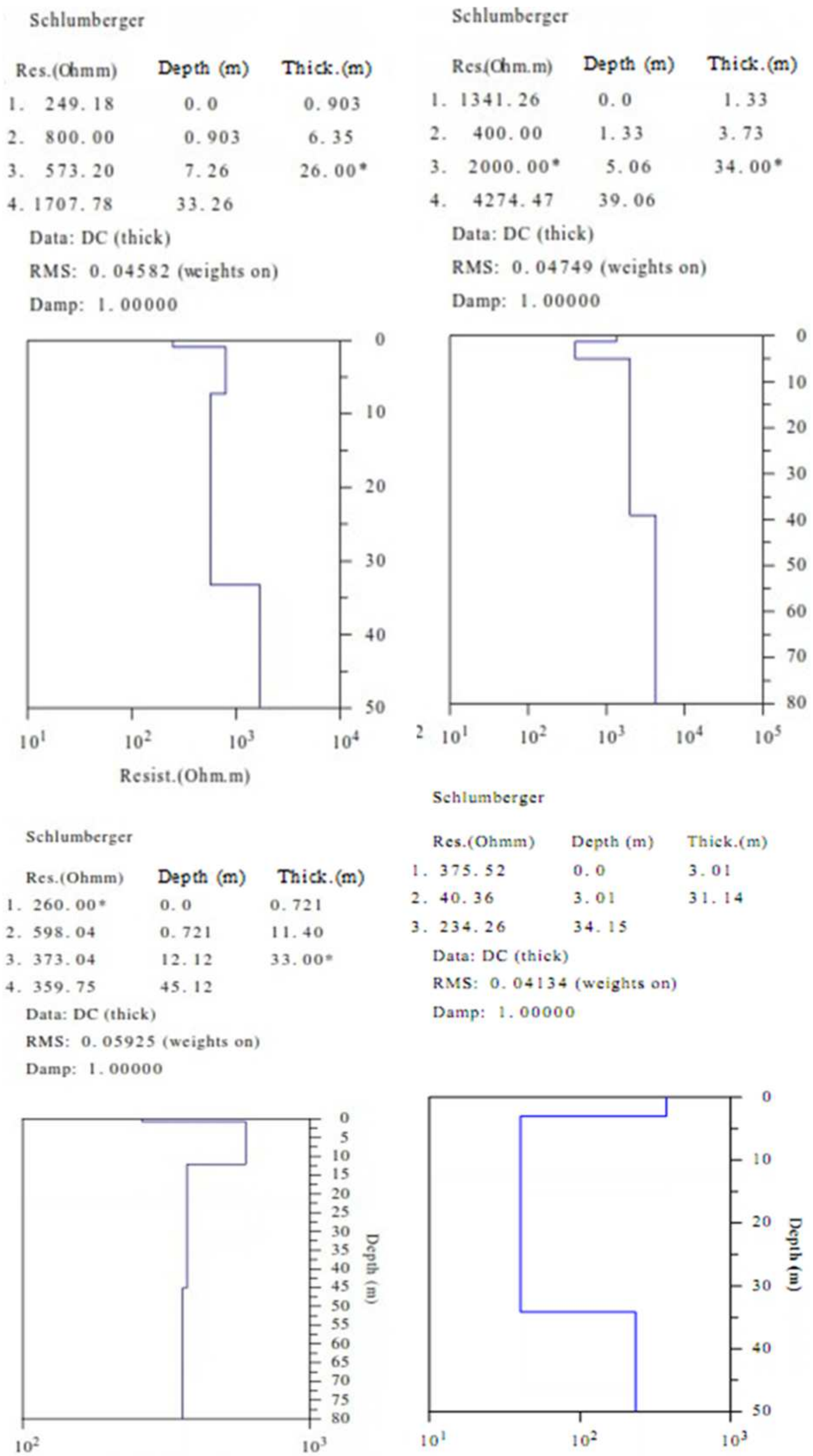

Figure 12. *Results of the inversion of the sounding curve of some stations a, b, c and d.*

When the geophysical anomalies highlighted are of tectonic origin, they can be potentially very productive. Thus, the study of the influence of the proximity of boreholes to fracturing shows that boreholes located in the vicinity of several fractures have a higher success rate than the others. The holes drilled from geophysical anomalies (Figure 13) have proven the usefulness of the method insofar as appreciable results have been obtained (piezometric measurement of boreholes in the study area).

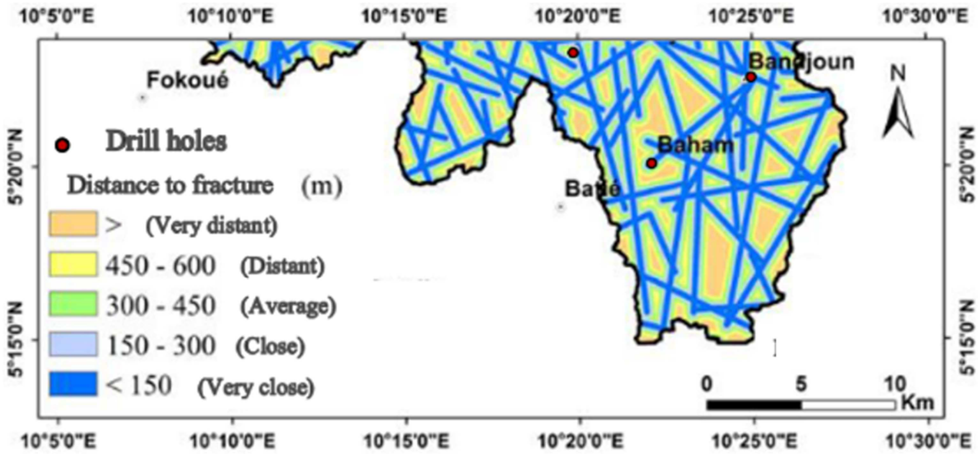

Figure 13. *Distance to fracture map.*

4.3. Confirmation and Mapping of Parameters

The recharge, the depth of the water table, the distance to fracturing, the geology and the density of fracturing all contribute to the deep study of the Bandjoun subsurface.

4.3.1. Recharge

The classification of recharging is based on the statistical principle of Stewart [3]. Five (05) classes are distinguished: very weak, weak, medium, strong and very strong. Blue colors represent areas likely to be rich in groundwater. Recharge here vary between 280 to 380 mm (Figure 14) and the strong refills (27.44%) dominate. This shows that the recharge is sufficient to ensure good groundwater potential.

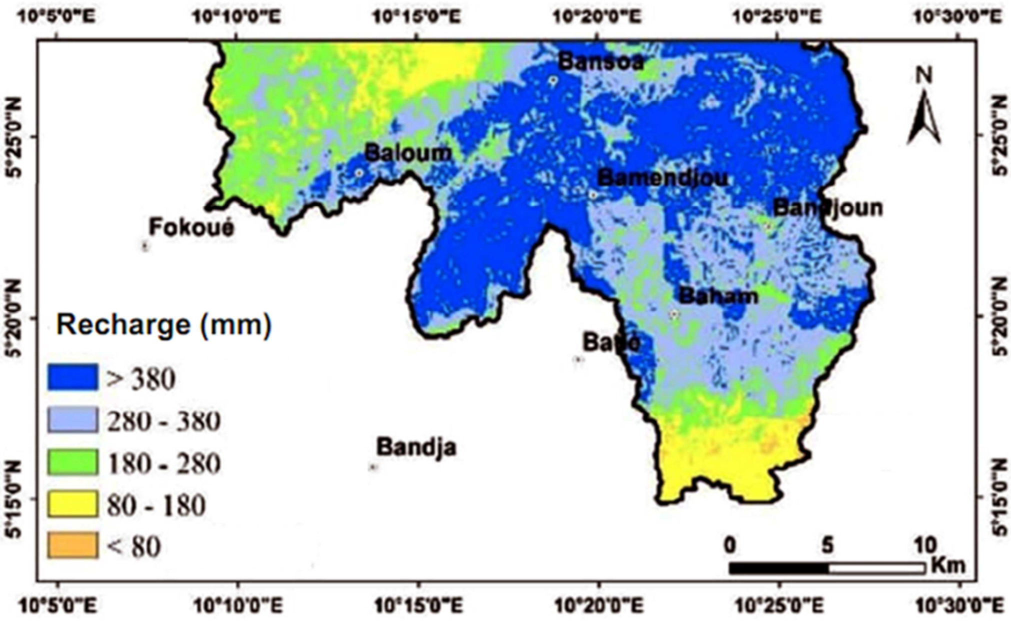

Figure 14. *Spatial distribution of Bandjoun recharge.*

4.3.2. Depth of the Water Table

The depths of the aquifers (Figure 15) vary from 0 m in the areas of very slight slopes to 35 m. Most of them are at a water table depth of less than 15 m. The high values for water depths are also encountered in areas of low recharge and represent areas of low groundwater potential.

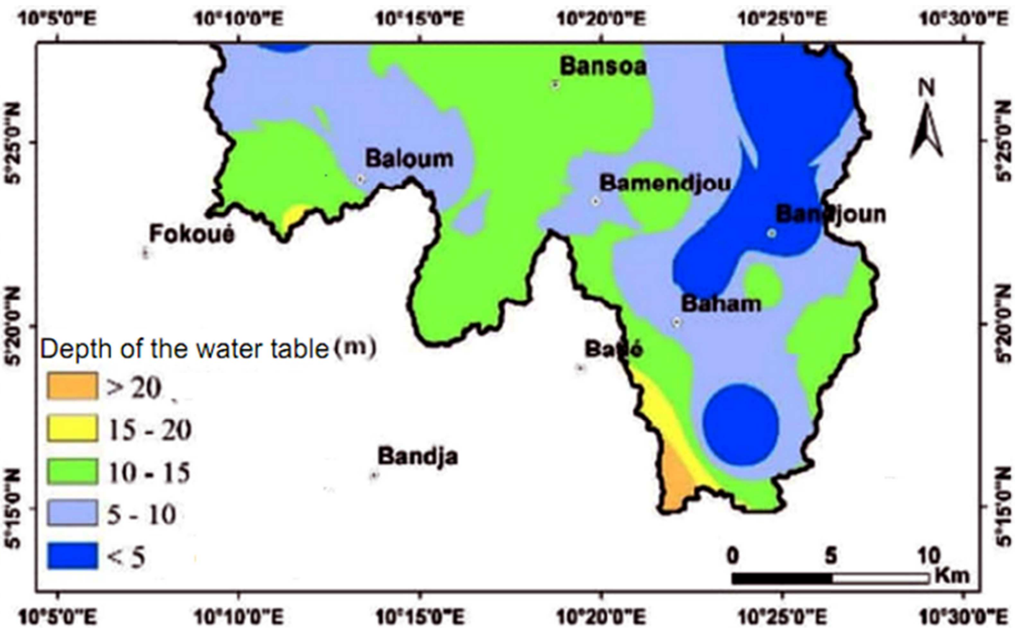

Figure 15. *Map of water table depths.*

The combination of electrical methods and remote sensing made it possible to see in detail the basement of Bandjoun. The electrical resistivity method shows, the more a zone is victim of tectonic accidents such as: faults; the shears…, the greater the chances that the water will pass through these accidents or fractures. Moreover, the information given by the site (a) is very different (Figure 11) from the information on the site (b) and almost different from (c) and (d). The reason could come from the fact that the site (b) is close to the Noun River which loads the water tables and in addition the distance which separates (a) and (b) is about 2 km. In addition, Figure 13 shows a blue circle in the south-eastern corner which, by analogy to Figure 12, should have a depth greater than 20 m. But it is rather less than 5m; this would seem to testify to the non-linear character of natural phenomena.

The 2D ERT of study area shows maximum resistivity of 120 Ωm and 1147 Ωm indicate very weathered rocky terrain. Similarly, the minimum values of aquifer resistivity (3.23 Ωm and 130 Ωm) were observed at Bandjoun define the presence of freshwater respectively. As the resistivity of fresh Groundwater water varies between 10 Ωm to 100 Ωm [30].

One of the profiles is seen in Figure 16.

Profile Toungoui- Bayangam

Array Used: Wenner-Schlumberger, Electrode Spacing: 12.5 m, Depth Covered: 164.1 m.

The profile Wenner-Schlumberger trends South to North direction to a length of 1721 m (Figure 16). In the pseudo section, we can identify the presence of water layers showing the resistivity from 14.9 to 59.9 Ωm (Table 1). Total depth covered by the profile is 164 m. The profile is characterized by an aquifer is marked on the extreme left side (58 m to 120 m; 220 m to 320 m electrode spacing), middle (583 m to 658 m; 770 m to 883 m electrode spacing) and the extreme right side (1196 m to 1258 m; 1421 m to 1558 m) of the profile up to the depth of 48 m.

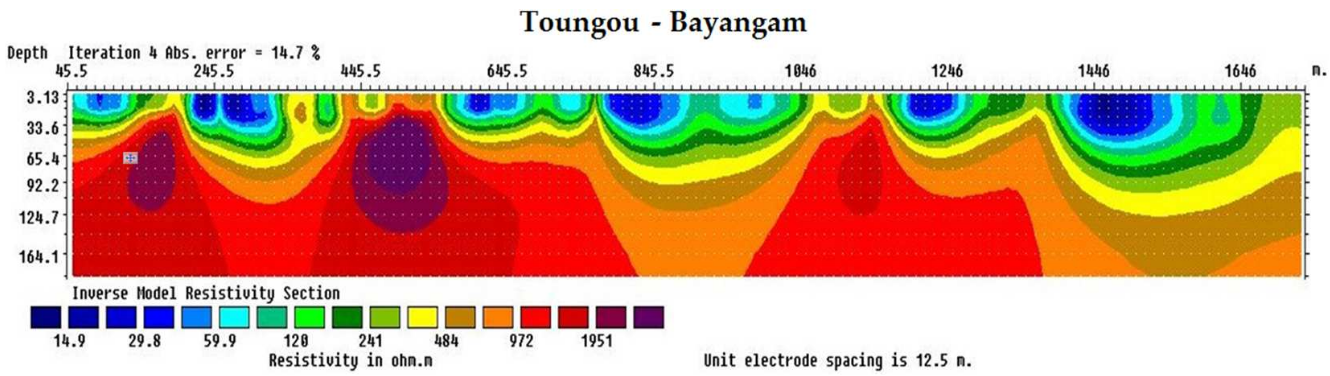

Figure 16. *2D ERT imaging pseudo section depicts distribution of groundwater aquifers.*

The water points examined have an Fe concentration below the guideline d with the exception of two boreholes. The exchangeable Na^{+} ions can replace the alkaline earth ions (Ca^{++} and Mg^{++}) in clays, thus causing the clogging of the pores of the soil and therefore its waterproofing (Figure 17).

Table 1. *Zones identified with respect to resistivity ranges in Ωm.*

Content	Resistivity Ranges (Ωm)
Aquifer	14.9 -59.9
Weathered Rocks	120 - 241
Hard Rocks	484 – 1951

The study of the Bandjoun subsoil indicates that it is very fractured, and thus favors a strong mineralization of the groundwater. The origin of dissolved ions can be assessed with sample tracing, depending on the variation in the ratio of Na^+ / (Na^{++} Ca^{++}) and Cl^- / (Cl^- $+HCO_3^-$) versus Total Dissolved Solids (TDS). Total dissolved solids (TDS) describe inorganic salts present in solution in water. For boreholes in the study area, they vary between 50 mg/L and 587 mg/L. Fe^{+++} concentrations varied between 0.02 mg/L and 1.01 mg/L. Iron is essential for the human body, but very high concentrations affect the organoleptic properties of water and also stain laundry. The guide value of the World Health Organization (WHO) and the Cameroonian Standard (NC) for iron in drinking water is 0.3 mg/L [31].

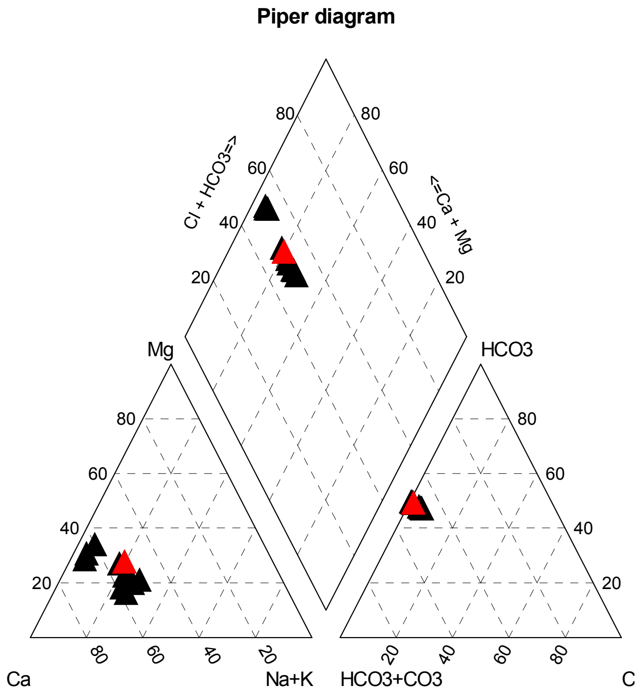

Figure 17. *Piper diagram of some drilling.*

4.4. Discussion

The effects of the electric soundings indicate that the weathering profile in the formations of the Bandjoun region can be divided into several distinct landscapes in which different aquifers are encountered such as:

1. Lateritic curasse which in some cases may contain sand or clay. It can be considered as organic earth in places where this curasse has a small thickness, case of the locality of Batoufam (Figure 12) where the majority of the prospected points showed lateritic curasses less than 2m thick.
2. Clay-sandy altered zone formed in most surface aquifers. This was materialized by the presence of water on the majority of the points prospected by modeling of electrical soundings. On the modeled electrical sounding curves, the altered zone aquifers can have varying thicknesses between 3 and 12 m in some areas, such as Toungui and Tsep in Batoufam.
3. The fractured zone of the basement grouping together the aquifers very cracked in places. M. Ouedraogo clarified that these types of aquifers form a composite aquifer whose hydrogeological properties are ideal in sectors where the listed landscapes are present and where they best combine their hydrodynamic properties [32]. This author supposes that because of the connection between surface aquifers (altered zone) and fissured aquifers (fractured), their modes of supply or recharge can be combined, because it is the coupling of the altered zone and the fissured substratum that constitutes the exploitable aquifer system. From this test, we can come to understand that the aquifers of altered zone and fractures offer unevenly distributed water resources. It is the waters of these altered zone that the riparian population of Bandjoun manages to capture by peasant mechanisms such as wells or sumps, because this rarely exceeds the depths of 15 m when it is a traditional well and 25 m. for a modern well. In some places in the study area such as Toungui and Toula, "surface water" wells were found a few meters from the ground surface. With M. Youan Ta et al., we believe that these aquifers may be due to the many interstitial spaces of rock particles which, when communicating, allow water to flow through the rock [33]. It was noticed that the presence of a water table more than 20 m in the majority of the cases of the prospected points, is influenced by the fractures affecting the basement. Moreover, M. Youan Ta et al. underlines that the productivity of these aquifers considered deep would depend in part on the nature of the geological facies, their mineralogy and the tectonic phenomena that have occurred during the geological history in the region. It would also depend on the importance of surface formations. The structures regularly encountered when it comes to fractured aquifers are: porphyritic basalt and andesite (weakly represented in the area), aphyric basalts are the most frequent, all resting on the granite basement where quartz offers a much greater productivity. The absence of permanent piezometric measurements would prevent a good evaluation of hydrodynamic parameters making it possible to follow the evolution of water tables and, consequently, their effective supply in the field. This makes the characterization of aquifers complicated in West Cameroon in general and in the Bandjoun study region in particular. We are therefore forced to consider mainly the data obtained during the drilling.

5. Conclusion

Ultimately, this study has as overall objective to give the contribution of geoelectricity and remote sensing to the study of fractured zones in the Bandjoun region. The coupled structural diagram highlighted numerous structures as well as superficial and deep fractures. This study benefited from several types of data whose processing made it possible to make a fairly precise mapping of several terrain variables. LANDSAT 8 images have been declared very important for geologic reconnaissance and Vertical Electrical Surveys (VES) for geophysical exploration. The geophysical investigation made it possible to identify structures and define the characteristics of aquifers. The adopted methodology allowed a deep study of the formations of tectonic origin thus giving us an idea on the recharge, the depth of the water table, the distance to fracturing etc. In addition, the Physicochemical data showed that the waters are moderately to highly mineralized and the Piper diagram highlights a type of chemical facies: Calcium chloride, the conductivity of the water is generally high and oscillates between 35 µS cm^{-1} and 480 µS cm^{-1}. This knowledge allows us to make a water forecast in certain localities of Bandjoun (Yenom, Toungui, Toula, Mbe, Yogam, Tsep, Meje and Kwopou). On the economic front, maps of fracturing and soundings could guide future hydrogeological investigations and campaigns to establish productive boreholes. The results obtained can be used by the decentralized administrative authorities of the West region - Cameroon to more effectively tackle the recurrent problem of drinking water supply. This study showed that Bandjoun has many fractures, located in the vicinity of the Noun River and therefore has good groundwater reservoirs. The effective establishment of boreholes and the repair of existing ones could greatly help to improve the water problem and allow harmonious and sustainable development of the entire region.

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