Journal Homepage: - www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)

Article DOI: 10.21474/IJAR01/19527
DOI URL: http://dx.doi.org/10.21474/IJAR01/19527

RESEARCH ARTICLE

Hydro geophysical investigation for ground source heat pump system installation in semi-arid region of Cameroun.

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Manuscript Info

Manuscript History
Received: 25 July 2024
Final Accepted: 27 August 2024
Published: September 2024

Key words:-
Hydrogeophysical Investigation, Ground Source Heat Pump (GSHP), Borehole Heat Exchanger (BHE), Thermo Physical Properties, Pumping Test

Abstract

Hydrogeophysical parameters of the ground play a vital role in heat transfer of ground source heat pump (GSHP) systems. Then, the investigation of the ground is necessary for the design and planning of GSHPs. This paper deals with investigations of Hydrogeophysical parameters of GSHP systems in Cameroon. Eighty-four drillings with the average deep of forty-seven meters have been performed in the Far North region of Cameroun in order to get hydrogeological and hydro geophysical characteristics of ground for shallow energy utilization. The results of geological study, vertical electrical sounding, pumping test, thermophysical properties, groundwater property and well data could help to understand better the heat transfer of borehole heat exchanger (BHE) and geo localization of potential GSHP in residentials of Logone et Chari, Cameroon. Closed systems of GSHP could be installed in the study area.

1. Introduction

Africa is currently experiencing a period of economic growth. Its population is proliferating, and its economies grow and diversify. To be sustainable, such growth requires a significant investment in the energy sector.

In Cameroon, the literature reveals the absence of a scientific survey, poor policies, insufficient financial resources, untrained personnel, and unawareness of stakeholders for GSHP utilization.

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Potential for geothermal energy exists in Cameroon. However, the exact capacity is unknown since no investigation has carried out to estimate this potential despite some recent academic/research works of Domra et al. (2015, 2017). Nevertheless, hot springs are found in extensive areas: Ngaoundéré area, Mt Cameroon area and Manengouba area with Lake Moundou (EUEI-PDF, 2013).

The populations of the semi-arid area in Cameroon have many problems concerning the climatic conditions. Throughout the arid season from October to April, air temperatures reach 45° C, and during the rainy season from May to September, temperatures drop till 15° C. Therefore, the use of GSHP installation for heating and cooling purpose contribute for a population comfort.

Logone et Chari is located in the region of the Far North region of Cameroon. This division expands on an area of 12,133 km² with a population of about 500,000. The study has been conducted on four cities selected upon the criteria of population density.

According to Tatiénou Paul and Lekédji Timothée (1991), the Logone-Chad domain contains a generalized aquifer with similar hydrodynamic and hydrochemical characteristics, whose resources are essential. Its intensive exploitation can be envisaged, the surroundings of the axes of feeding by the hydrographic network would constitute the most promising zones.
For the design and optimal performance of geothermal systems, various types of parameters have to be specified. Those are economical, technical, design, hydraulic and thermal parameters. The study of 84 drilling wells has been made in the Far North region of Cameroun in order to determine the hydrogeological and hydro geophysical characteristics of ground for shallow energy utilization.

The GSHPs cover a wide category of systems that may use groundwater, ground, or surface water as heat sources or sinks. About the technology used, GSHP systems can be classified into four categories (ASHRAE, 1999):

GWHP, groundwater heat pump systems, also known as open-loop systems, are the original type of GSHP system, first installed in the late 1940s. There are vertical GWHP systems, which involve wells and well pumps in order to supply groundwater to a heat pump.

GCHP, ground-coupled heat pump systems, also known as closed-loop GSHP systems. They were developed during the 1970 s with the advantage of overtaking the problems related to the groundwater quality and availability.

Surface water heat pump systems (SWHPs), in two different configurations: In the closed-loop in which heat rejection-extraction circulatory system is positioned at an optimized depth within a lake, pond, reservoir, or, in general, open channel. In the open-loop type, in which the screened intake area is used to extract water from the surface-water body. Then, water is discharged to a receptor; Standing column well systems (SCWs), in which water is pumped out and in a standing column in a deep wellbore.

The Conceptual model of a ground-source heat pump system for cooling and heating of residential and other significant spaces of our study is given in Figure 1.

In order to boost the capacity of low enthalpy geothermal energy potential like GSHP in Cameroon, it is essential to examine the characteristics of ground for successful borehole heat exchanger installation.

Africa is experiencing significant economic growth, with its population rapidly increasing and its economies diversifying. To sustain this growth, substantial investment in the energy sector is essential.

In Cameroon, there is a notable lack of scientific surveys, inadequate policies, insufficient financial resources, untrained personnel, and a general lack of awareness among stakeholders regarding the utilization of Ground Source Heat Pumps (GSHP).

Although Cameroon has potential for geothermal energy, the exact capacity remains unknown due to the absence of comprehensive investigations, despite some recent academic research by Domra et al. (2015, 2017). However, hot springs are present in several areas, including Ngaoundéré, Mt Cameroon, and Manengouba with Lake Moundou (EUEI-PDF, 2013).

The semi-arid regions of Cameroon face significant climatic challenges. During the dry season from October to April, temperatures can soar to 45°C, while in the rainy season from May to

September, they can drop to 15°C. Installing GSHP systems for heating and cooling can greatly enhance the comfort of the population.

Logone et Chari, located in the Far North region of Cameroon, spans an area of 12,133 km² and has a population of about 500,000. This study focuses on four cities selected based on population density.

According to Tatiénou Paul and Lekédji Timothée (1991), the Logone-Chad domain contains a widespread aquifer with similar hydrodynamic and hydrochemical characteristics, making its resources vital. Intensive exploitation is feasible, particularly around the feeding axes of the hydrographic network, which are the most promising zones. For the optimal design and performance of geothermal systems, various parameters need to be specified, including economic, technical, design, hydraulic, and thermal factors. A study of 84 drilling wells in the Far North region of Cameroon was conducted to determine the hydrogeological and hydrogeophysical characteristics of the ground for shallow energy utilization.

GSHPs encompass a wide range of systems that can use groundwater, ground, or surface water as heat sources or sinks. Based on the technology used, GSHP systems can be classified into four categories (ASHRAE, 1999):

Groundwater Heat Pump Systems (GWHP): Also known as open-loop systems, these were the original type of GSHP system, first installed in the late 1940s. Vertical GWHP systems involve wells and well pumps to supply groundwater to a heat pump.

Ground-Coupled Heat Pump Systems (GCHP): Also known as closed-loop GSHP systems, these were developed in the 1970s to address issues related to groundwater quality and availability.

Surface Water Heat Pump Systems (SWHP): These come in two configurations. In the closed-loop system, the heat rejection-extraction circulatory system is positioned at an optimized depth within a lake, pond, reservoir, or open channel. In the open-loop system, water is extracted from the surface-water body through a screened intake area and then discharged to a receptor.

Standing Column Well Systems (SCWs): In these systems, water is pumped out and in a standing column in a deep wellbore.

The conceptual model of a ground-source heat pump system for cooling and heating residential and other significant spaces is illustrated in Figure 1.

To enhance the capacity of low enthalpy geothermal energy potential, such as GSHP, in Cameroon, it is essential to examine the ground characteristics for successful borehole heat exchanger installation.

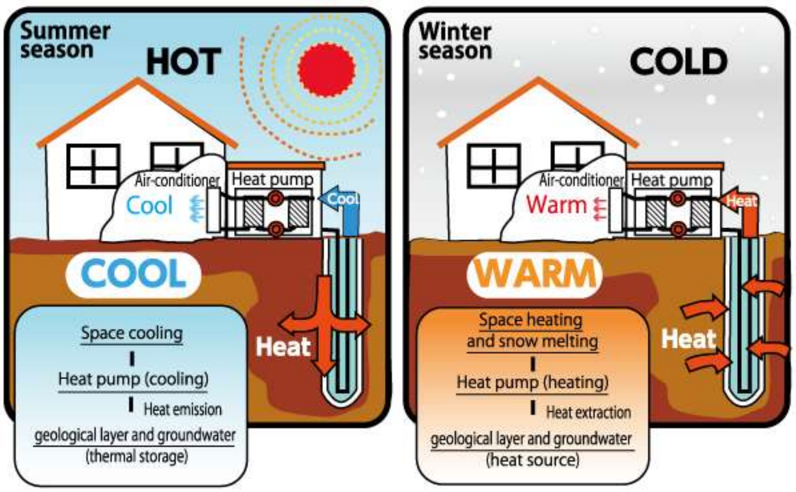


Fig.1. Concept of ground-source heat pump system of our study.

The aim of this paper is to investigate Hydro geophysical parameters for a successful vertical heat exchanger of a borehole for heating and cooling buildings. The main content of this paper is organized as geological survey and study areas; materials and methods; and Result and Discussion

2. Geological survey and study area

2.1. Study area

The research area encompasses four localities within the Logone et Chari division: Kousseri, Goulfey, Makary, and Logone Birni. Situated along the Lower Logone River, south of Lake Chad, this region spans latitudes 11º 02’ to 12º 52’ N and longitudes 14º 18’ to 15º 05’ E, as depicted in Figure 2. The climate here is influenced by two distinct climatic forces. The Logone River, a major tributary of the Chari River, stretches 1,000 km and originates from the volcanic Adamawa Plateau in the western Central African Republic and northern Cameroon.

The dominant soil types in this area are vertisols and black hydromorphic clays (Brabant and Gavaud, 1985), primarily composed of montmorillonite, which are expansive clays. These soils are typical of regions with seasonal humidity or irregular drought and flooding patterns.

Vegetation in the study area is heavily dependent on the availability of surface water. During the rainy season, the landscape becomes swampy, while in the dry season, shrub savannah, grassy plains, and bare soils are more prevalent. Economically, the region is primarily used for livestock breeding and recessional agriculture, including crops like sorghum and millet. Additionally, rice, corn, peanuts, and vegetables are cultivated mainly for subsistence.

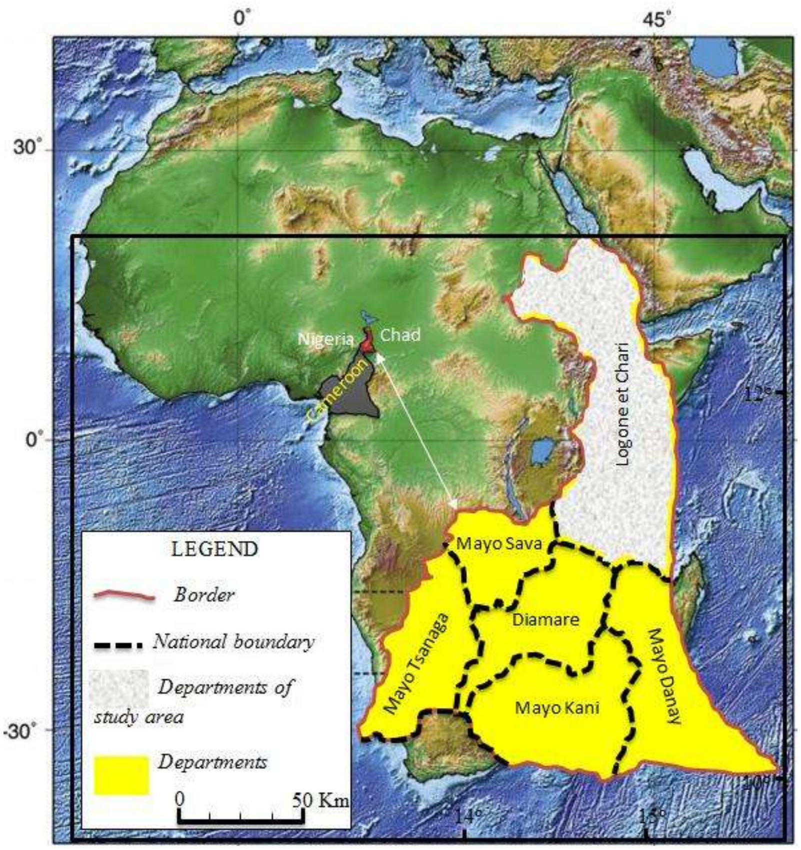


Fig. 2. Localization of study area.

2.2. Geological setting

The study area lies at the southern edge of the Quaternary deposits in the Lake Chad Basin, as shown in Fig. 3. The Quaternary period is characterized by significant volcanic activity in Tibesti and alternating deposits during the succeeding humid and arid periods. There were several cycles of expansion and regression of Lake Chad. The eolian and alluvial deposits of the Quaternary are limited to the depression of the current Lake, which they surround by a broad crown.

Fig.3. Hydrogeological map of our study area modified after Tillement, (1972) [7]

In this part of the basin, the thickness of Quaternary deposits generally varies between 50 m and 70 m (Biscaldi, 1970; Schneider, 1992). Like the rest of the Chadian basin, they cover a vast area of tertiary, quaternary and current alluvial sprays. The superficial deposits consist of alluvial deposits of Logone and mayos of the Mandara Mountains and lacustrine clays deposited during the extended periods of Lake Chad.

The Quaternary Aquifer is the most remarkable hydrogeological unit in the entire Chadian Basin. It is continuous from Yagoua to the edge of Lake Chad. It is heavily exploited for people's water needs. The Quaternary consists of a widely spread series of detrital sediments comprising interbedded layers of sands, silts and clays, fluviatile.

The results of BISCALDI (1970) [10] and Tillement (1970) have shown that the water table of our study area is a monolayer free generalized water table. Then, the acquisition of numerous data, including correlations of the lithological logs of boreholes, interpretations of welltests, chemical analyses during village hydraulic projects, geological and hydrogeological characteristics of Quaternary aquifers were specified. The results of Ngounou Ngatcha (1993) show that three types of aquifer exist. Those are perched aquifers, the superficial aquifers and the deep aquifers. The schematic diagram of the Quaternary aquifer in the Yaérés plain is given as follows in figure 4.

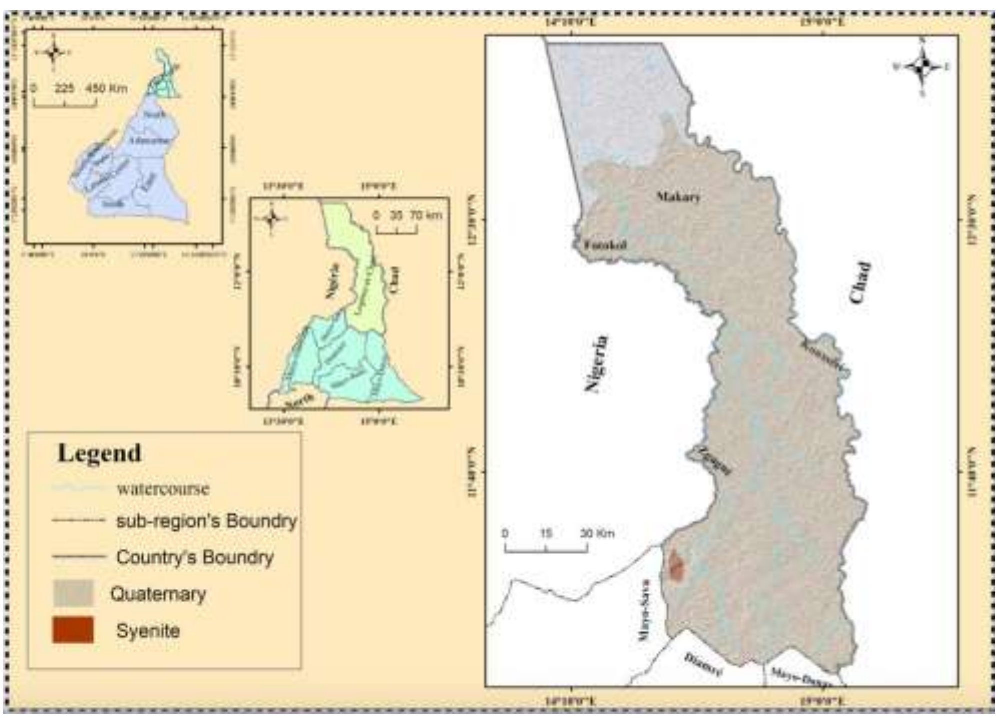


Fig. 4. Geological setting map modified after Vicat (1998) [13]

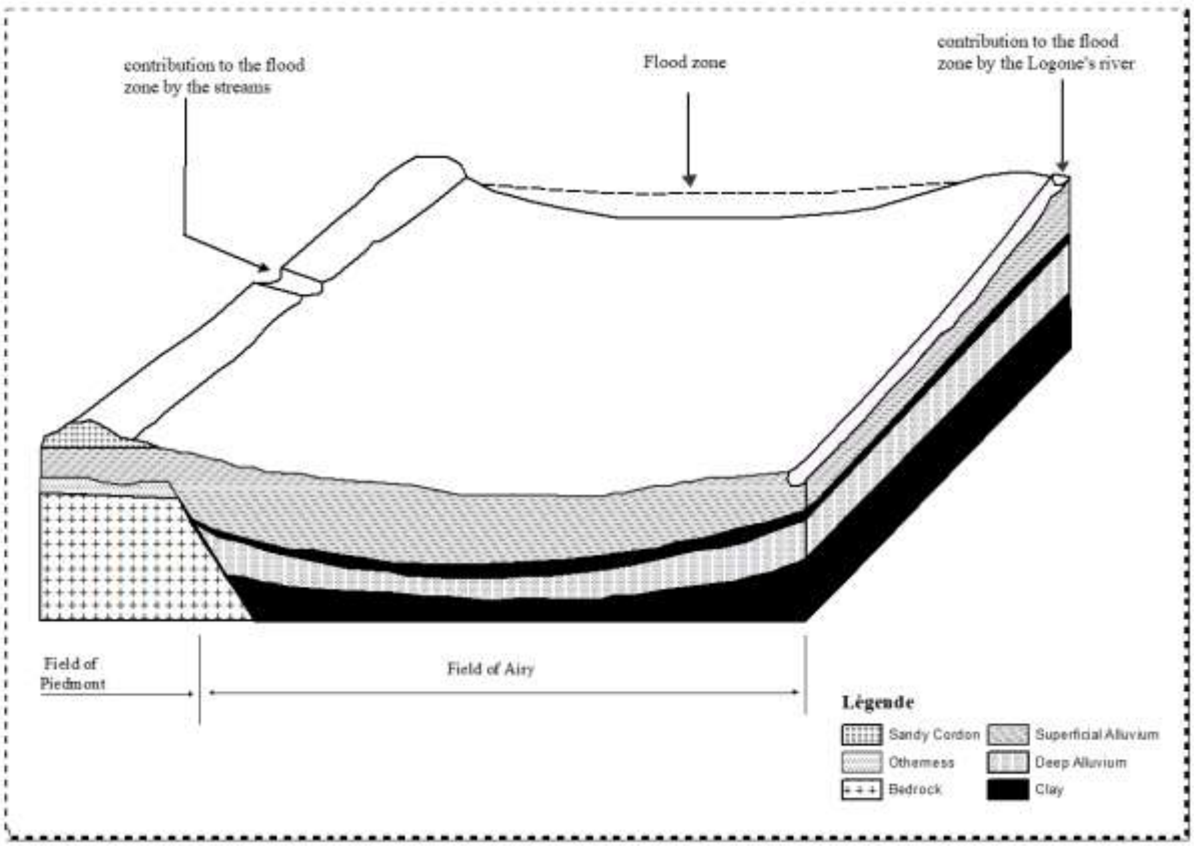


Fig.5. Schematic diagram of the Quaternary aquifer in the Yaérés plain (From Ngounou Ngatcha, 1993).

3. Materials and methods

3.1. Vertical electrical sounding

Eighty-four Schlumberger Vertical electrical sounding (VES), with a maximum current electrode spacing AB ranging from 3 to 240 m, were conducted in the study area in order to collect resistivity data. The apparent resistivities were be recorded with the SYSCAL PRO IRIS Equipment (Fig. 5). The measurement of the electrical earth resistivity consists of supplying an electrical current into the ground and then to measure the resulting potentials created in the earth.

Fig.6. Vertical electrical sounding instrument SYSCAL PRO IRIS

Since the current is known and the potential can be measured, an apparent resistivity can be calculated. For Schlumberger soundings, the apparent resistivity values are plotted versus half current electrode separation AB/2 on a log-log graph and a smooth curve is drawn for each of the soundings. The sounding curves are then interpreted to determine the true resistivities and thicknesses of the subsurface layers. Qualitative interpretation of the sub-surface resistivity distribution can be performed by observing the shape of the field curve. In the curve matching method, a curve is drawn by plotting apparent resistivity against electrode spacing, and this is interpreted by matching the field curve with the master curve. The resistivities of the subsurface material observed are a function of the magnitude of current, recorded voltage difference, and the geometry of the electrodes. The field curves were interpreted by the wellknown method of curves matching with the aid of the software IP2WIN (Bobatchev, 1992 ; Bobatchev, 2001). This method has been used in this work for lithogical prediction.

3.2. Drilling works

The ground geological configuration is commonly investigated in situ by drilling works. Eighty-four drilling with the average deep of forty-seven meters were made. The VES position is the location of well. The drilling consists of the down-hole hammer in which and bit are operating in the bottom of the borehole. The locations of drilling wells are shown in figure 9

3.3. Thermo-physical properties

Thermo-physical properties of geological materials are essential information to estimate heat transfer of GHE in the subsurface. With small scale GSHP systems (e.g. air-conditional power less than 30 kW), the thermophysical properties of the ground are useful for estimating heat transfer rate of BHEs directly due to the economic infeasible to perform field TRT tests (China Machinery, 2012). Briefly, geological materials can be categorized into two groups: soil and rock (VDI-4640, 2001 ; Huang, 1971). Parameters such as texture, bulk density and water content of soil are essential factors to thermal conductivity (TC) (Abu-Hamdeh, 2001). The various reliable TC estimations originate from direct laboratory determinations. If core samples are not available, indirect methods are used to calculate TC from petrophysical properties, including porosity, a parameter provided through well logging (Balling, 1981 ; Goss, 1976 ; Goutorbe, 2006 ; Hartmann, 2005). Another indirect approach of TC determination uses the abundance and composition of the rock-forming minerals and the porosity as a multi-component system (Brailsford, 1964 ; Brigaud, 1990 ; Demongodin, 1991; Vasseur, 1995) . All these indirect methods have their shortcomings and restrictions.

Numerous laboratory techniques for the estimation of TC are available comprising steadystate techniques (e.g., divided bar technique, needle probe) and transient techniques (e.g., line-source methods, ring-source methods, optical scanning). General reviews on these techniques are provided by Kappelmeyer and Haenel (1974), Beck (1988), Blackwell and Steele (1989), and Somerton (1992).

In this study, TC in dry condition was assigned in situ with the following equations for unconsolidated material (Eqs. (1) and (2)) to of: For sand percentages >50%

$$\lambda = 0.1442 \times (0.7 \times (lg\frac{PSD}{\rho_{BD}}) + 0.4) \times 10^{0.6243\times\rho_{BD}} \qquad (1)$$

For sand percentages < 50%

$$\lambda = 0.1442 \times (0.9 \times \left(lg\frac{PSD}{\rho_{BD}}\right) - 0.2) \times 10^{0.6243\times\rho_{BD}} \qquad (2)$$

where λ is thermal conductivity (W/m K), PSD is the pore size distribution (%) and assigned with the ratio of an unsaturated and saturated sample of core drilling operation, and ρ_{BD} is the bulk density (g/m^3) (Bertermann, 2004). The sand percentage was assigned only with the field sample observation of petrography

3.4. Field pump test

Commonly, hydraulic properties of an aquifer such as transmissivity and hydraulic conductivity are measured by field pumping/slug tests (Domenico, 1990). Pumping tests have been proved to be one of the most effective ways to obtain such parameters (Driscoll, 1986). The principle of pumping test is to pump water from a well and measure the discharge in the pumping well and the drawdown in the adjacent wells by piezometers at known distances. Neuman (1972) developed a new method concerning delayed water-table response that is based on well-defined physical parameters of the unconfined aquifer, as shown in Fig.7. Besides, the aquifer is considered to be a compressible system, and the water-table is treated as a moving material boundary. Neuman's drawdown equation (Neuman, 1975) describes the first segment of the time-drawdown curve given as:

$$s = \frac{w}{4\pi KD} W(\mu_A, \mu_B, \beta) \quad (3)$$

where s is the water drawdown (m), μ_A is the well function that equals to $r^2 S_A/4KDt$ under early-time conditions, S_A is the volume of water instantaneously released from storage per unit surface (m3), μ_B is the well function that equals to $r^2S_Y/4KDt$ under late-time conditions, t is the time in days since pumping started, KD is Transmissivity (m^2/s), W is the pumping rate (m^3/s).

In this study, the pumping test has been done in each well (the eighty-four wells). The filters are located in the aquifer unit depth. The hydrogeological model of the area is shown in figure

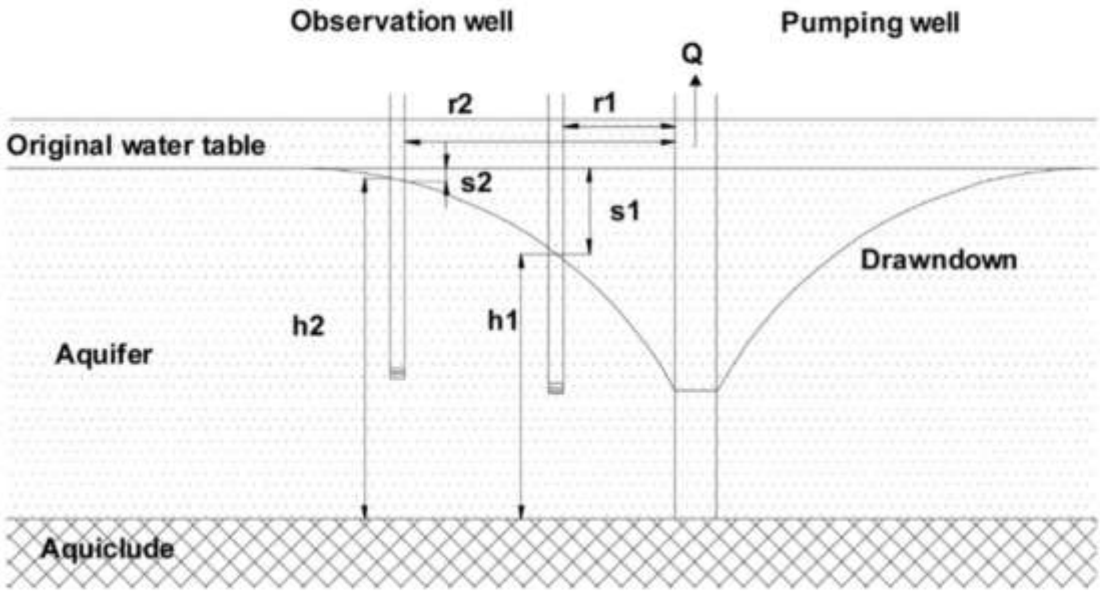


Fig. 7. Cross-section of pumping test in unconfined aquifer.

3.5. Ground water flow

3.5.1. Flow direction

Flow direction can be practically determined by many methods. In this study, we use a water table and topographic elevation map. It consists in plotting a water table elevation map of the study area and then, the flow direction can be easily determined according to the gravity principle.

3.6. Groundwater properties

Hydrochemical properties of the groundwater used in this study are from BGR-CBLT project (Seeber, 2014). During 27 days of fieldwork, a total of 83 water samples were collected, 49 in Chad and 34 in Cameroon. The samples were examined at the BGR workroom in Germany for complete species of anions and cations, trace elements and stable deuterium (2H) and oxygen-18 (18O) isotopes. Parameters such as water temperature, pH and electrical conductivity (EC) are estimated in situ using multiple digital sensor arrays (3430 WTWMulti).

4. Results and Discussion

In principle, any underground space may be used thermally. However, the choice of a specific technical system, that is, the installation of borehole heat exchangers (BHEs) or pumping and reinjection of groundwater with heat extraction, strongly depends on the local hydrological and hydrogeological conditions. For the design of geothermal systems, the knowledge of subsurface characteristics is crucial, even more for open geothermal systems (Banks, 2008). GSHP systems can be used from small, residential houses to a significant individual or public buildings (offices, hotels, school, and shopping). In the residential sector, typically heat pumps produced in more extensive series and standard heating capacities from about 5-20 W are used. For the commercial sector, all the installation (heat pumps, manifolds) tends to be much larger than for residential houses. Heat pumps with capacity from 50 kW upwards usually are constructed individually or in smaller numbers, adapted to the specific site conditions. Ground source heat pump plants of every size have been realized with borehole heat exchangers, ranging from small houses with just one borehole to the large building, requiring whole fields of borehole heat exchangers (Tong, 2018).

4.1. Vertical electrical sounding results

The vertical electrical sounding technique was used in this study, to know the successful location of the drilling a well. To be able to find an aquifer, it is necessary to use an indirect method. On the 84 soundings, the values of resistivities encountered are generally low (1- 122 ohm.m), meaning the presence of sedimentary basin, as mentioned in the literature review. Fig.8 is an example of VES performed in Makary. Values of resistivity obtained from data processing range from 4.9 to 44.7 ohm.m. These resistivity values are associated more to sedimentary formations such as clay, sand, and marl. The drilling results will allow us to know in an absolute way, the lithology and other hydro-geophysical parameters of the study area.

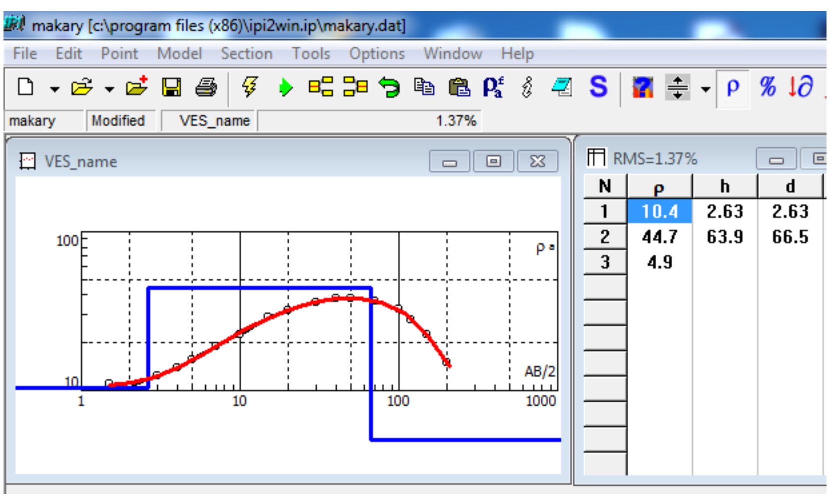


Fig. 8. Geoelectric layer at Makary with thickness h and depth d

4.2. Well drilling observation

Drilling was conducted at a depth of ranging from 23 to 101 m for an average of 47 m. The variation of the depth is due to the presence of an aquifer. Fig. 9. shows the distribution of wells in the study area.

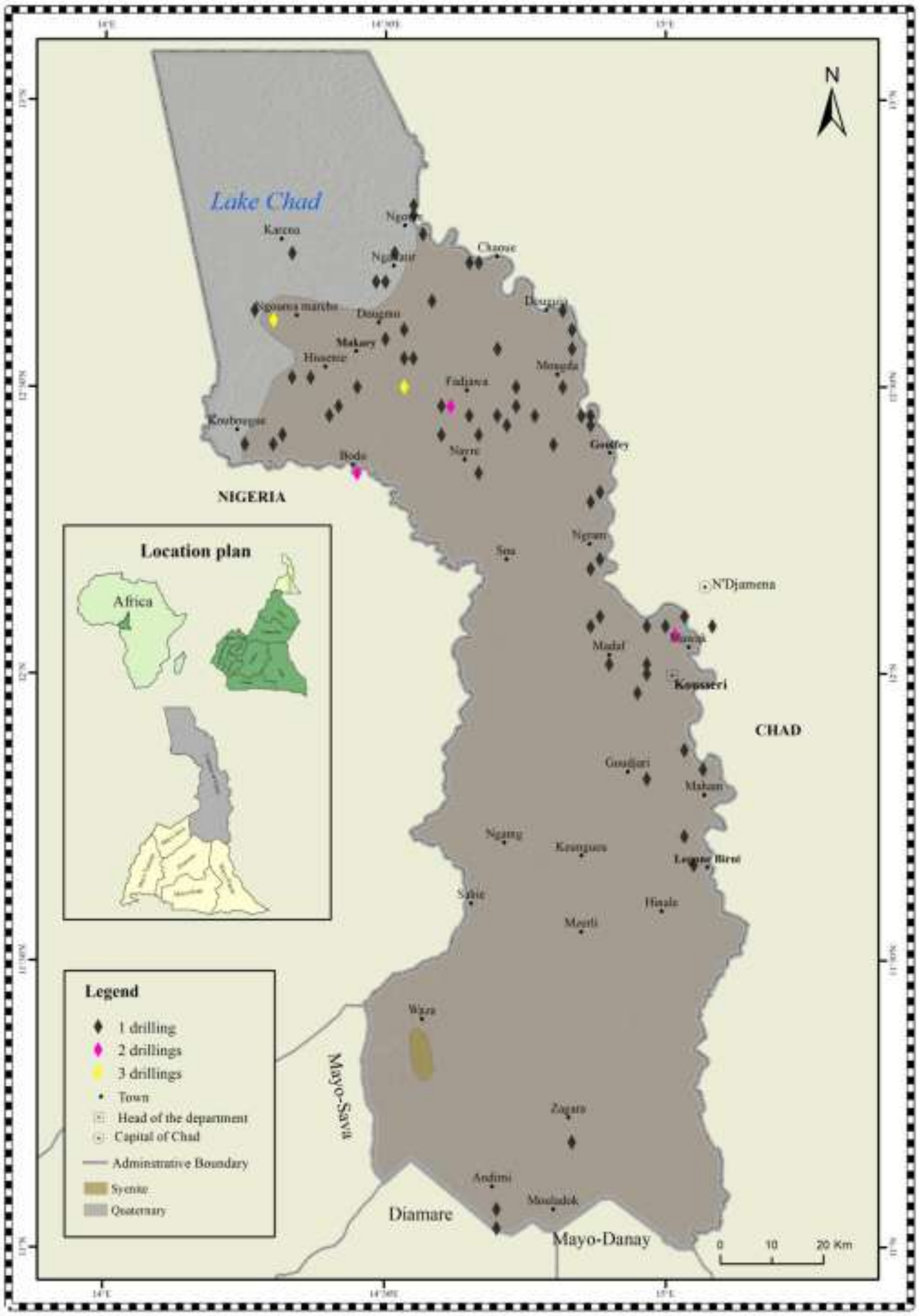


Figure 9. Well localization in the study area

Well N ° LE199K, located in Kousseri shows a lithology made up respectively of sandy clay (thickness 5m), fine sand (thickness of 17m), sandy clay (thickness of 6m), fine sand (thickness of 8m) and finally sandy clay (5 m thick) as shown in Fig.10.

In the locality of GOULFEY, the well N ° LE255G of the village DJAMOUS presents the following lithology: marl clay (thickness 5m), clayey sand (12 m), and fine sand (35 m) as shown in Fig.10.

Fig. 10. A geological profile (with layers thichness) for borehole field of a GSHP system in Kousseri and Goulfey

The well N° LE039M of Digam village in the locality of Makary gives the following layers: clayey sand (thickness 9m), fine sand (thickness 12 m), clayey sand (thickness 3 m), and fine sand (thickness 29m) as shown in Fig. 11.

The well N° LE317L in the locality of Logone Birni, the village of Zagara exhibit the following layers: silt (thickness 2m), fine sandy clay (thickness 15m), coarse sandy (thickness 35m), clayey sand (thickness 27m), fine sand (thickness 21 m) as shown in Fig.11

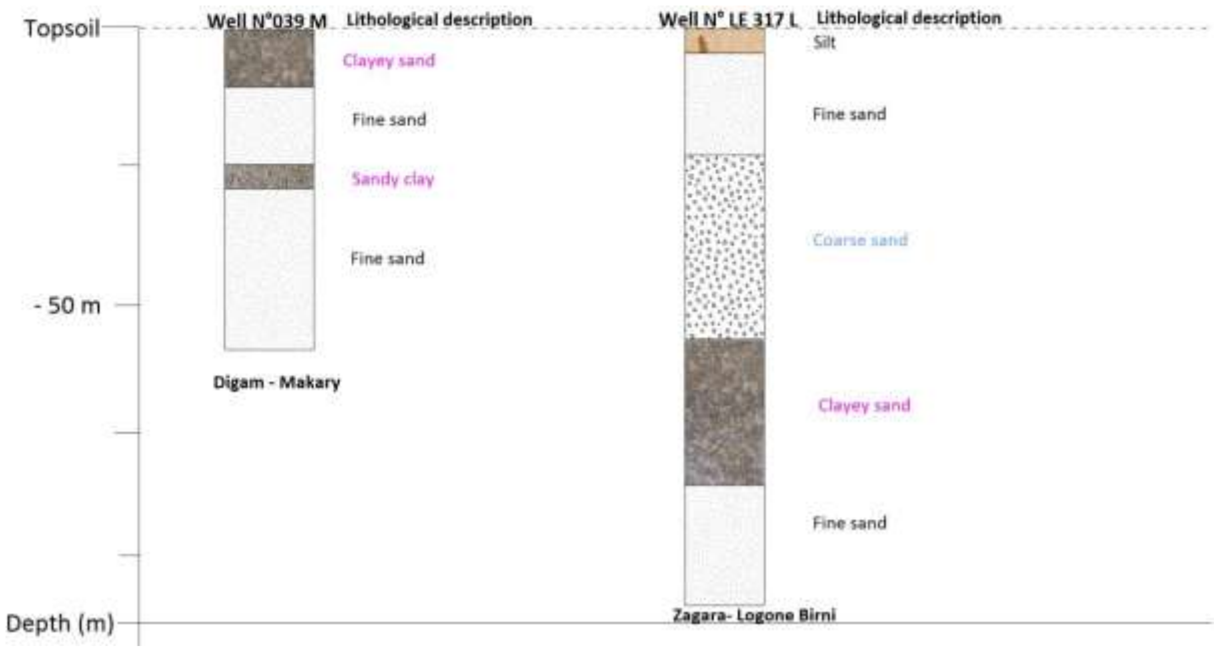


Fig. 11. A geological profile (with layers thickness) for borehole field of a GSHP system in Makary and Logone Birni

In general, the lithology consists of marly, clay, fine sand, sand, clayey and sand. The aquifer is sometimes overlaying and none, and usually in a fine sand reservoir. All these results are contained in Table 1 and could be used to estimate the heat energy transfer of vertical borehole heat exchanger of our study area.

4.2.1. Thermo-physical result

To estimate the thermal performance of BHE, knowledge of thermal properties of the ground is needed. The aquifer is in a geological formation of fine sand, porosity 35% and density 1.6 g / cm3. Using the formula number 2, we obtain the value of 1.45 W/m K of thermal conductivity in the dry conditions. It is observed that the measured thermal conductivities in the dry conditions range from 0.59W/ (m K) to 2.34W/ (m K), as shown in Table 2. Changes observed in various measured thermal conductivities are due to the geological structure of the layers. Obviously, average, the measured thermal conductivity in the dry conditions has a mean value of 1.53W/ (m K). The thermal conductivities are calculated in the dry condition, and the porosities are calculated by the ratio of an unsaturated and saturated sample of the core drilling operation ASHRAE table was used to estimate the thermal conductivity in the well conditions (ASHRAE, 1999). According to in situ measurements of ground thermal conductivity: A Dutch Perspective

(Witte, 2002 ; Jin, 2016), we estimate our thermal conductivity in the well conditions as follows in Table 1. Is it noted that the aquifer is located more in a fine sand condition with 2-4 W/ (m K) thermal conductivity. Many aquifers have been identified with different depths.

Table 1. Lithological material obtained by well and it estimated the thermal conductivity

Well N°	Longitude (m)	Latitude (m)	Depth (m)	Lithology/stratigraphy	λ (W/ (m K)
LE289M	595554	361109,8	47,83	Fine sand	2-4
LE033M	598887,3	363332	47,8	Fine sand	2-4
LE197K	666665	377776,4	41,8	Marl+clay/Fine sand/sand	1-2 ; 2-4
LE306G	608887,3	359998,6	48,3	Marl+clay/sand	1-2 ; 2-4
LE125L	602220,6	255554,3	94,9	Fine sand/marl+clay/clayey sand/coarse sand 0.15-2 ; 0.18-1.8 ; 2-3 ; 2-4	
LE146G	613331,7	362220,9	41,8	Fine sand	2-4
LE172G	594442,9	376665,3	47,8	Clayey sand	2-4
LE082M	575554	359998,6	47,9	Fine sand	2-4
LE052M	586665,1	357776,4	47,9	Fine sand	2-4
LE052M2	586665,1	357776,4	47,93	Sand	2-4
LE144G	619998,4	353332	44,8	Silt/fine sand/clayey sand	1-2 ; 1- 2 ; 2-4
LE268G	668887,2	279998,7	41,8	Fine sand	2-4
LE176G	611109,5	374443,1	41,8	Fine sand/sand/clayey sand	1-2 ; 1- 2, 2-4
LE159G	599998,4	381109,7	41,8	Fine sand/clayey sand	1-2 ; 2-4
LE039M	604442,8	366665,3	53	Clayey sand/fine sand/sandy clay/fine sand 1-2 ; 2-4 ; 1-3 ; 2-4	
LE034M	595554	364443,1	47,5	Clayey sand, fine sand	1-2 ; 2-4
LE307M	576665,1	362220,9	47,9	Fine sand	2-4
LE198K	672221	338887,5	41,7	Marl clay/clayey sand/sand	1-2 ; 2-3 ; 2-4
LE255K	602220,6	363332	53,2	Marl clay/clayey sand/fine sand 3 ; 2-4	1-2 ; 2-
LE308L	619998,4	344443,1	46,3	Marl clay/sand	1-2 ; 2-4
LE142G	614442,8	349998,7	39,4	Silt/fine sand/sand	0.18-2 ; 2-4
LE16M	583331,8	364443,1	45,8	Marl clay/clayey sand	1-2 ; 2-4
LE163G	592220,6	386665,3	47	Fine sand	2-4
LE004M	588887,3	372220,9	45,7	Fine sand	2-4
LE309G	609998,4	375554,2	41,9	Clay/clayey sand/fine sand	1-2 ; 1-3 ;2-4
LE143G	615553,9	351109,8	37,2	Clayey sand/fine sand/sand	1-2 ; 2-3 ; 2-4

LE310L	618887,3	333332	48,3	Clayey sand/sand	1-2 ; 2-4
LE001M	492220,7	369998,6	49,9	Fine sand	2-4
LE040M	611109,5	363332	23,2	Clayey sand/sand	1-2 ; 2-4
LE199K	672220,2	338887,6	41,8	Clayey sand/fine sand/clayey sand/fine sand/clayey sand	1-2 ; 2-4 ;1-2 ;2-4 ; 1-3
LE311L	619998,4	276665,4	48,4	Clayey sand/ sand	1-2 ; 2-4
LE148G	612220,6	363332	40,8	Marl/clayey sand/sand	0.18-1 ; 1 -2 ; 2-4
LE028M	584442,9	366665,3	45,8	Clayey/sand	2-4
LE019M	579998,4	367776,4	47,8	Clayey sand	2-4
LE312M	577776,2	382220,8		Clayey sand	2-4
LE161G	593331,7	384443,1	45	Clayey fine sand	2-4
LE177G	606665,1	363332	39	Marl clay/fine sand	1-2 ; 2-4
LE298	572220,7	135554,4	47,9	Clayey fine sand	2-4
LE115	618887,3	286665,4	48,3	Marl clay/fine sand	1-2 ; 2-4
LE200K	666665	388887,5	41,8	Clayey sand/fine sand	1-2, 2-4
LE313G	602220,6	362220,9	48,3	Marl clay/fine sand	1-2 ; 2-4
LE003M	592220,6	369998,6	45,5	Clayey sand	2-4
LE102L	699998,3	277776,5	41,8	Clayey sand/fine sand/sand	0.18- 2 ; 1-3 ; 2-4
LE195K	666665	377776,4	41,8	Marl clay/fine sand	1-2 ; 2-4
LE195K2	666665	377776,4	41,8	Marl clay/fine sand	1-2 ; 2-4
LE318M	599998,4	361109,8	47,4	Clayey sand/fine sand	1-2 ; 2-4
LE047M	602220,6	371109,7	47,4	Clayey sand/fine sand	1-2 ; 2-4
LE145G	615553,9	354443,1	41,8	Marl clay/clayey sand/fine sand/coarse sand 0.18-1 ; 1-2 ; 1-3 ; 2-4	
LE314G	609998,4	365554,2	48,3	Marl clay/fine sand	1-2 ; 2-4
LE147G	613331,7	363332	39	Marl clay/fine sand	1-2 ; 2-4
LE152G	611109,5	373332	41	Clay/clayey sand/fine sand	0.18-2 ; 1-2 ; 2-4
LE041M	609998,4	371109,7	41,8	Marl clay/sand/clayey sand/fine sand 0.18-1 ; 1-2 ; 1-3 ; 2-4	
LE315M	599998,4	357776,4	47,9	Fine sand	2-4
LE046M	591109,5	366665,3	47,9	Fine sand	2-4
LE046M2	591109,5	366665,3	47,9	Fine sand	2-4
LE046M3	591109,5	366665,3	47,9	Fine sand	2-4
LE171G	591109,5	382220,8	47,7	Fine sand	2-4
LE299M	588887,3	378887,5	48	Fine sand	2-4
LE111M	668887,2	283332,1	41,8	Clayey sand/sand	1-3 ; 2-4

LE164G	592220,6	387776,4	39,4	Fine sand	2-4
LE023M	575554	374443,1		Fine sand	2-4
LE023M2	575554	374443,1	39,3	Fine sand	2-4
LE023M3	575554	374443,1	45,5	Fine sand	2-4
LE141G	612220,6	347776,4	38,5	Clayey sand/fine sand/sand	1-2 ; 1-3, 2-4
LE123L	602220,6	244443,2	73,1	Topsoil/clayey sand/marl clay/fine sand 0.18-1 ; 1-2 ; 1-2 ; 2-4	
LE124L	601109,5	244443,2	87	Clay/sand 1-3 ; 2-4	
LE124L2	601109,5	244443,2		marl clay/clayey sand/sand	1-2 ; 1-2 ; 2-4
LE175G	603331,7	245554,3	46	marl clay/sand/clayey/sand	1-2 ; 1-3 ; 2-4
LE275L	668887,2	269998,7	48,3	Clayey sand/fine sand	1-2 ; 2-4
LE202KK	582220,6	388887,5	41,8	Marl clay/sand/fine sand	1-2 ; 1-3 ; 2-4
LE017M	591109,5	363332	47,9	Fine sand	2-4
LE160G	598887,3	377776,4	47,8	Fine sand	2-4
LE005M	591109,5	373332	44,8	Fine sand	2-4
LE006M	591109,5	373332	44,7	Fine sand	2-4
LE088M	577776,2	367776,4	47,9	Fine sand	2-4
LE117L	615553,9	367776,4	48,3	Clayey sand/marl clay/sand	1-2 ; 1-2 ; 2-4
LE021	573331,8	375554,2	45,7	Fine sand	2-4
LE316	604442,8	366665,3		Marl clay/sand	1-2 ; 2-4
LE300	587776,2	378887,5	47,8	Fine sand	2-4
LE032	596665,1	364443,1	48,3	Clayey sand/fine sand	1-2 ; 2-4
LE032M2	596665,1	364443,1	47,5	Clayey sand/fine sand	1-2 ; 2-4
LE317L	611109,5	234443,2	102,1	Silt/fine sand/coarse sand/clayey sand 0.18-1 ; 1-2 ; 1-3 ; 2-4	
LE135L	670109,4	266665,4	46,1	Clayey sand/sand	1-2 ; 2-4

Table 2. Thermal conductivity calculated on dry condition of materials obtained

Materials	Thermal conductivity (W/mK)
Clayey sand	0.59
Coarse sand	1.76
Marly clay	1.19
Sand	1.75
Silt	2.34

4.2.2. Field pumping test parameter

4.2.2.1. Drawdown and pumping flow

The drawdown measurement represents a major input to the solution of equations related to the interpretation of pumping tests.

High drawdown areas may be due to the low permeability of the aquifer at this location. Hence the non-interconnection between the pores, which explains why water does not circulate well at this location.

The drawdown map shows the type of aquifer because drawdowns can spread a few hundred meters from a well in a captive aquifer, while they rarely propagate more than one hundred meters from a well in the free-ground aquifer (Soro, 2002).

However, we also note that the specific flow is used to explain the productivity of a well. It makes it feasible to assess the quality of a structure because it takes into account the productivity of the water table (Sinan, 2003). The higher it is, the more the folding cone extends. The search for a very productive flow (Soro, 2002), can have a strong impact in long-term exploitation. Table 3 shows the results of selected pumping specific flow in the four localities of the study area.

The statistical analysis of the specific flows obtained in the study area shows us the minimum value of 0.2 m3/h/m and maximum value of 19.5 m3/h/m with an average of 7 m3/h/m.

Out of the 84 boreholes, 60 have a specific flow rate greater than 6 m3/h/m. These localities may be considered productive and could be accommodated to the installation of a GSHP.

Table 3. Pumping specific flow test of four selected well

Number of well	LE039M	LE199K	LE255K	LE135L
Pumping test N	1; 2; 3	1; 2; 3	1; 2; 3	1; 2; 3
Time (h)	2; 1; 1	2; 1; 1	2; 1; 1	2; 1; 1
Flow (m3/h)	0.65 ; 2.5 ; 5	0.86 ; 4.6 ; 9	0.74 ; 2.2 ; 4.4	0.95 ; 5.4 ; 11.3
Drawdown (m)	0.65 ; 1.58 ; 3.08	0.68 ; 2.01 ; 3.86	0.65 ; 1.49 ;2.64	0.69 ; 1.71 ; 3.23

4.2.2.2. Transmissivity

Transmissivity and hydraulic conductivity are two important hydraulic properties of aquifers since they represent their ability to circulate or "transmit" water flowing through the porous medium. These hydraulic properties were determined from pumping tests. For optimal designs of aquifer thermal storage systems (ATES), more detailed knowledge of the spatial distribution of the hydraulic conductivity or transmissivity in the aquifer might be necessary.

The geological model consistent with the depth of the planned GSHP in a residential of our study area is given in figure 12

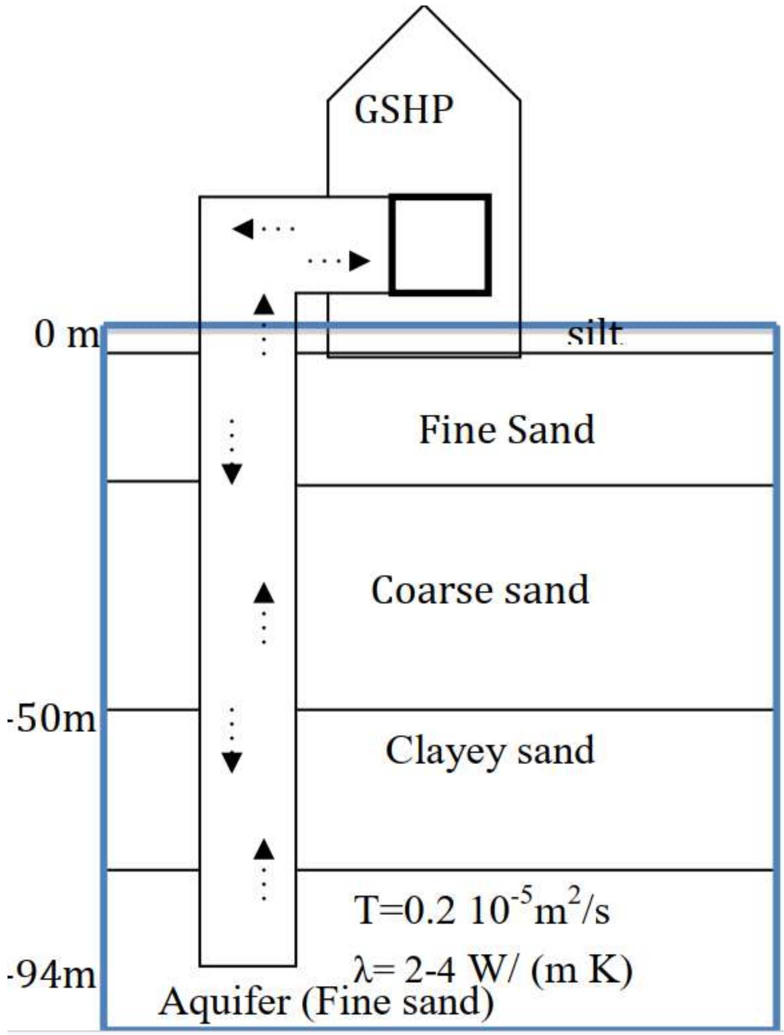
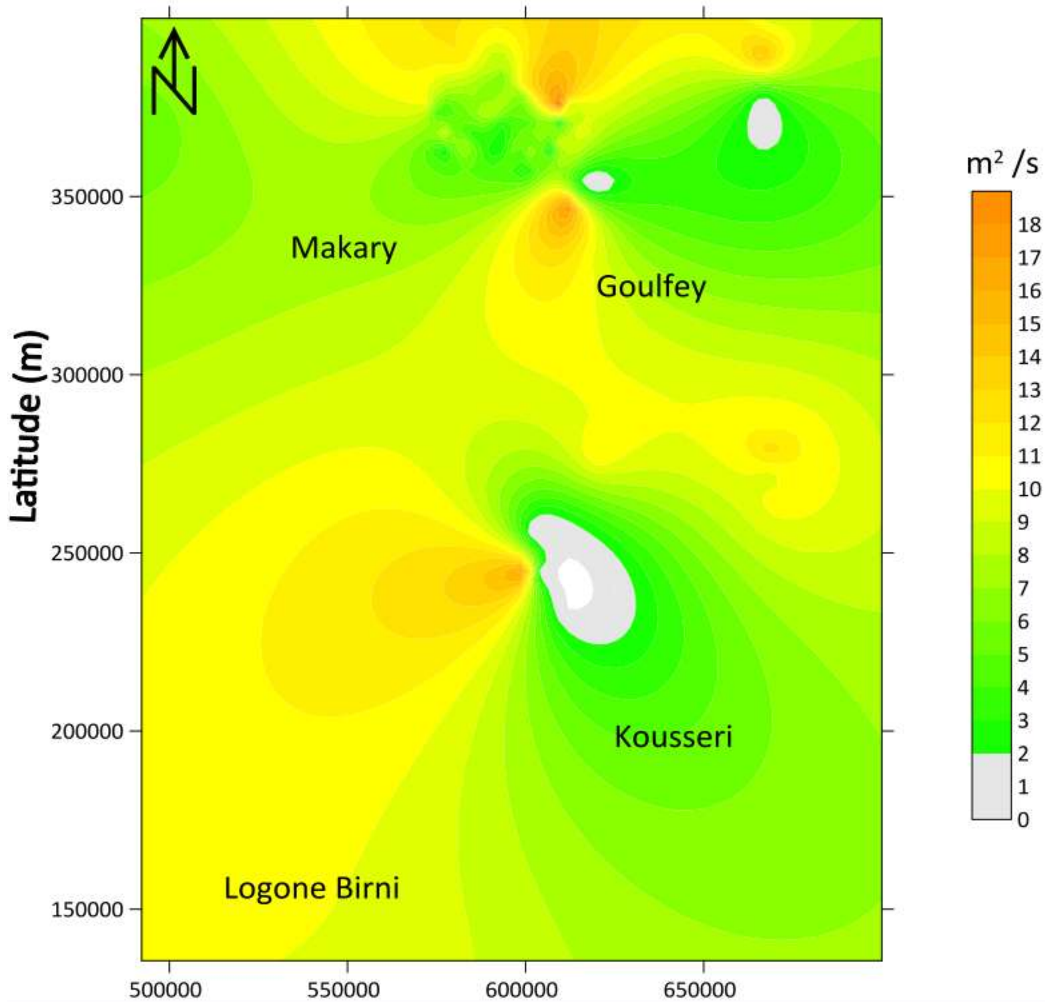


Fig 12. Geological model consistent with the depth of the planned GSHP in well N LE317L.

Eighty-four data were recorded, the values of transmissivity vary from 2 10-6 to 1.8 10-3 m2/s.

Fig. 13 show the low and large values in the study area. The golden surfer software was used to draw the isotransmissivity map by kriging method.



4.2.3. Ground water flow result

To evaluate the advection effects of groundwater on BHE heat transfer, it is necessary to determine flow direction and velocity of groundwater flow (Klinkenberg, 1994; Cook, 2003). The flow direction of groundwater plays a vital role in the layout of BHE due to the thermal plume induced by BHE upstream that can affect the performance of its adjacent BHE in the downstream direction (Cook, 2003).

Fig. 14 shows the water table to the sea level of our study area. Zones with a low water table elevation could constitute drainage zones for aquifers, and these places have the advantage of being always fed. The localities marked by high values of water table elevation could be explained recharge zones.

The map also shows the flow direction of the water table. The flow takes place from high to low water table elevation value.

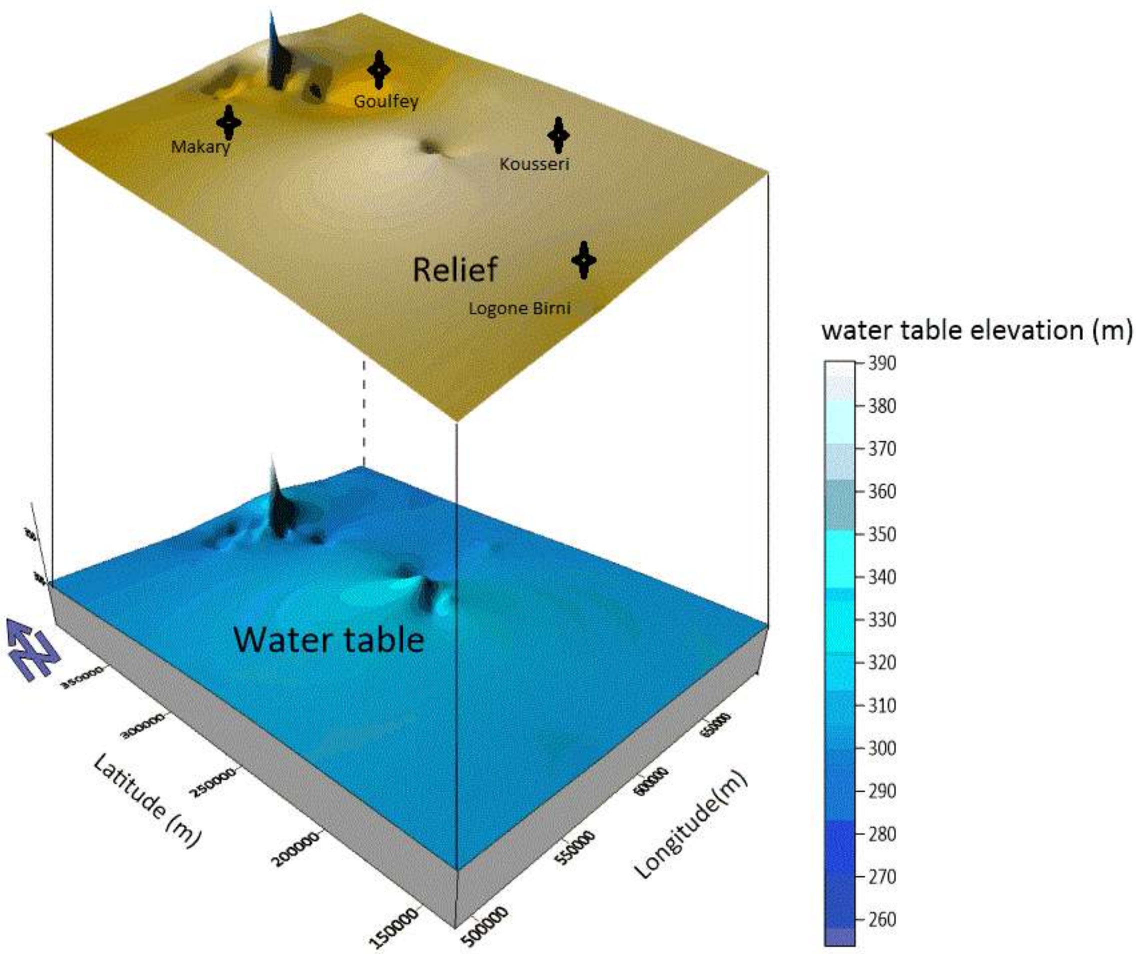


Fig. 14. Water table model of our study area

4.2.4. *Groundwater properties*

Sent by Copilot:

If open-loop systems are installed, issues such as clogging and corrosion can arise. Poor water quality can exacerbate these problems. Therefore, it is essential to investigate the chemistry and biology of wastewater to prevent these undesirable phenomena.

According to the BGR-CBLT project (Jin, 2016), the pH values of water range from 6.5 to 8.5, and the electrical conductivity varies from 110 to 3800 μS/cm, as shown in Figure 14. This suggests the presence of groundwater flow in some areas. The temperature of the groundwater ranges from 27 to 32°C, which helps analyze the implications of energy exchange in the layered subsurface.

Isotope analysis indicates that most of the groundwater in the study area is recharged by surface water at least three months after the rainy season (Jin, 2016). Additionally, the Quaternary groundwater is of good quality. Therefore, the water quality in our study area is generally suitable for GSHP installation. Table 4 presents the hydrochemical parameters.

Table 4. Hydrochemical parameters obtained by BGR-CBLT project(Jin, 2016)

Parameters	Min	Max	Average	Unit	Oms Limit
pH	6.5	8.5			>6.5<8.5
EC	110	3800		μS/cm	1500
T	27.3	32.7	30.4	C	-
SO_4	0.0	448.0	18.1	mg/l	500
Mg	0.5	32.2	8.4	mg/l	-
Cu	00	0.1	00	mg/l	0.2
F	0.1	7.8	0.5	mg/l	1.5
Pb	00	00	00	mg/l	0.01

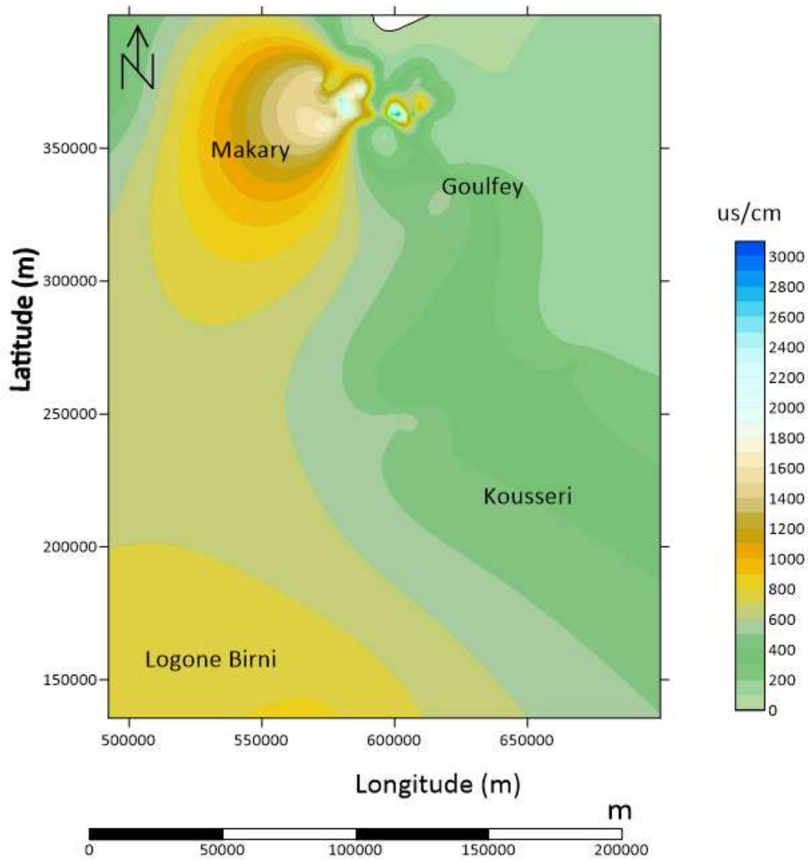


Fig. 14. Iso electrical conductivity map obtained

Conclusion

This paper examines hydro-geophysical investigation for ground source heat pump system installation in Cameroun. The study was conducted in four localities of the Far North region: Kousseri, Goulfey, Logone Birni, and Makary. Geological layers, pumping test parameters, Thermal properties, and hydrochemical parameters have been investigated. Results obtained from those investigations have been analyzed and discussed.

Main findings of this study include:

Vertical electrical soundings are implemented to investigate the subsurface layers of the ground. The resistivities values obtained are mostly associated with sedimentary formations such as clay, sand, and marl.

The drilling data confirm the presence of sandy clay, marly clay, fine sand, coarse sand, sand and silt.

The thermal conductivities estimated in dry conditions various material are clayey sand (0.59 W/mK), coarse sand (1.76 W/mK), marly clay (1.19 W/mK), Sand (1.75 W/mK), silt (2.34 W/mK). Thermal conductivities of common material in the well conditions are also estimated using the ASHRAE table. The temperature of aquifer varies from 27 to 32 C. These results would allow us to estimate the heat transfer rate of BHE per meter, Thermal diffusivity and volumetric heat capacity.

Hydraulic properties of the aquifers in the layered subsurface are investigated by pumping tests. Transmissivities, drawbacks and flow parameters were being plotted to understand the characteristics of the aquifer better.

Hydrochemical investigation of groundwater reveals a good quality of water. The groundwater temperature is also investigated to study the implication of thermal exchange in the layered subsurface.

Acknowledgements

Authors would like to express their deepest and sincere thanks to the Regional Delegation of Water and Energy of Maroua for the facilities provided during the data acquisition for this work. Sincere thanks to the anonymous reviewers for the deep review and constructive comments that have helped to improve this paper.

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