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Geological and Hydrogeological Structure of the Aquifer of the City of N'djamena, Chad

Moussa Abderamane, Mahamat Nour Abdallah, Abderamane Hamit and Abdel-Aziz Abdrahamane Yassine
Departement de Géologie, Université de N'Djaména, Laboratoire HydroGéosciences et Reservoirs, N'Djaména, Tchad

Correspondence
Moussa Abderamane, Departement de Géologie, Université de N'Djaména, Laboratoire HydroGéosciences et Reservoirs, N'Djaména, Tchad
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Abstract

The study of the geological and hydrogeological structure of the aquifer of the city of N'Djamena aims to improve our knowledge for sustainable and prudent management of the groundwater resource. For this study, a methodology combining the geological and hydrogeological structure was adopted. It consists of two steps, the first of which is based on the realization and analysis of lithological sections of different boreholes capturing Quaternary aquifers and the second consists in the realization of the hydrogeological structure of the Quaternary aquifer. The results of the different sections of the boreholes revealed different lithological facies with varying thicknesses (both vertically and laterally). The different Quaternary sections carried out are made up of alternating layers of clay and sand. The deposits are predominantly sandy. The slick is lodged in the sandy formations, whose thickness is more or less constant, which is of the order of 50 to 63 m. The hydrogeological structure allowed us to determine the roof, the wall, the thickness of the Quaternary aquifer as well as its wetted thickness, which averages 44 m. These new data allowed us to realize the 3D architecture of the Quaternary Aquifer of the city of N'Djamena for a better efficient and sustainable management.

Keywords: Aquifer, Chad, lithostratigraphy, N'Djamena, quaternary

INTRODUCTION

Groundwater is an essential and strategic resource whose sustainability depends on enlightened management (IGE, 2015). Indeed, N'Djamena has considerable groundwater resources (Schneider and Wolf, 1992) without, however, having delineated its main aquifers or estimated their resources. The lack of knowledge of the depth to be drilled concerning the water table to be captured still poses problems (Kadjangaba, 2007). It is, therefore, necessary to implement, in parallel with the exploitation of these aquifers, global studies for the recognition of water resources for sustainable management (Abderamane *et al.*, 2013). Previous work carried out in this city (Bonnet and Meurville, 1995; Djoret, 2000; Massuel, 2001; Leblanc, 2002; Abderamane *et al.*, 2013; Kadjangaba *et al.*, 2018) showed that the current state of knowledge on the Chari Baguirmi (N'Djamena) aquifer system is limited. Because of all these current and future

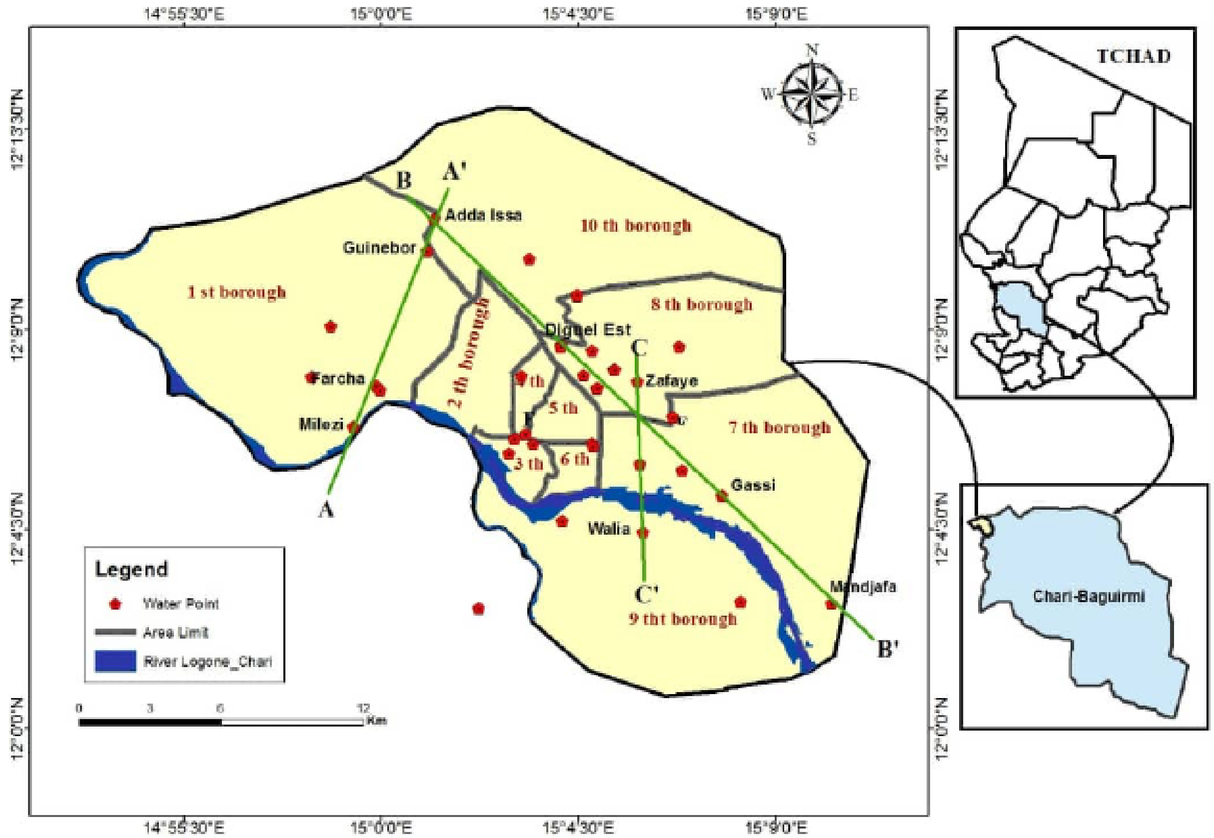

Fig. 1: Location map of the study area

problems, in-depth studies are needed to improve the understanding of the aquifer system of the city of N'Djamena, where basic data on geology and hydrogeology are still insufficient and very fragmentary. From a lithological point of view, the sedimentary series are very heterogeneous (Moussa *et al*., 2016). Despite the importance of the Pliocene and Quaternary sedimentary series present at the scale of the Chad Basin, they are still poorly known and little studied (Massuel, 2001), particularly due to the lack of a robust chronological framework (Bouchez *et al*., 2016) and especially their particular conditions of outcrops (Moussa, 2010). Previous studies have reported the presence of three groundwater tables at the level of N'Djamena, namely: Quaternary, Pliocene and Continental terminal (BRGM, 1988; Schneider and Wolf, 1992). It should be remembered that the aquifers of the Quaternary formations provide most of the city's water supply (Kadjangaba, 2007). The stratigraphic boundary between the Pliocene and the Quaternary is rather poorly defined (Louis, 1970; Schneider and Wolf, 1992). However, the Quaternary corresponds to the end of the Pliocene clay sedimentation (aquifer bedrock). The Quaternary is made up of two aquifers, the first of which is free at a depth of about 10 m and is mainly exploited by traditional wells, while the second aquifer, located at a depth of about 60 m, is exploited by drilling (Kadjangaba, 2007; Djoret, 2000). These two aquifers are separated by an impermeable to semi-impermeable layer in places (Schneider and Wolff, 1992). A few rare scientific studies have been carried out on the different aquifers (Pliocene and Quaternary), explaining the complexity of this hydro system on different levels: climatic, geological, hydrological, environmental and sedimentary (Djoret, 2000; Le Coz, 2010; Kadjangaba, 2007; Moussa, 2010; Abderamane, 2012; Bouchez *et al*., 2016; Mahamat Nour, 2019).

Indeed, previous work has been carried out on conventional quaternary aquifer areas. The main objective of this study is to contribute to the knowledge of the geometry of the aquifer and the lithology of the various geological formations crossed by the structures.

Location and physical setting of the study area: The city of N'Djamena ex Fort Lamy is located on the border with Cameroon along the Chari River and more precisely at the confluence of the Logone and Chari Rivers on the eastern bank of the latter, at 12°8' North latitude and 15°2' East longitude (Fig. 1). It is subject to a Sahelian-type climate, characterized by a short period of rain and then a long dry period.

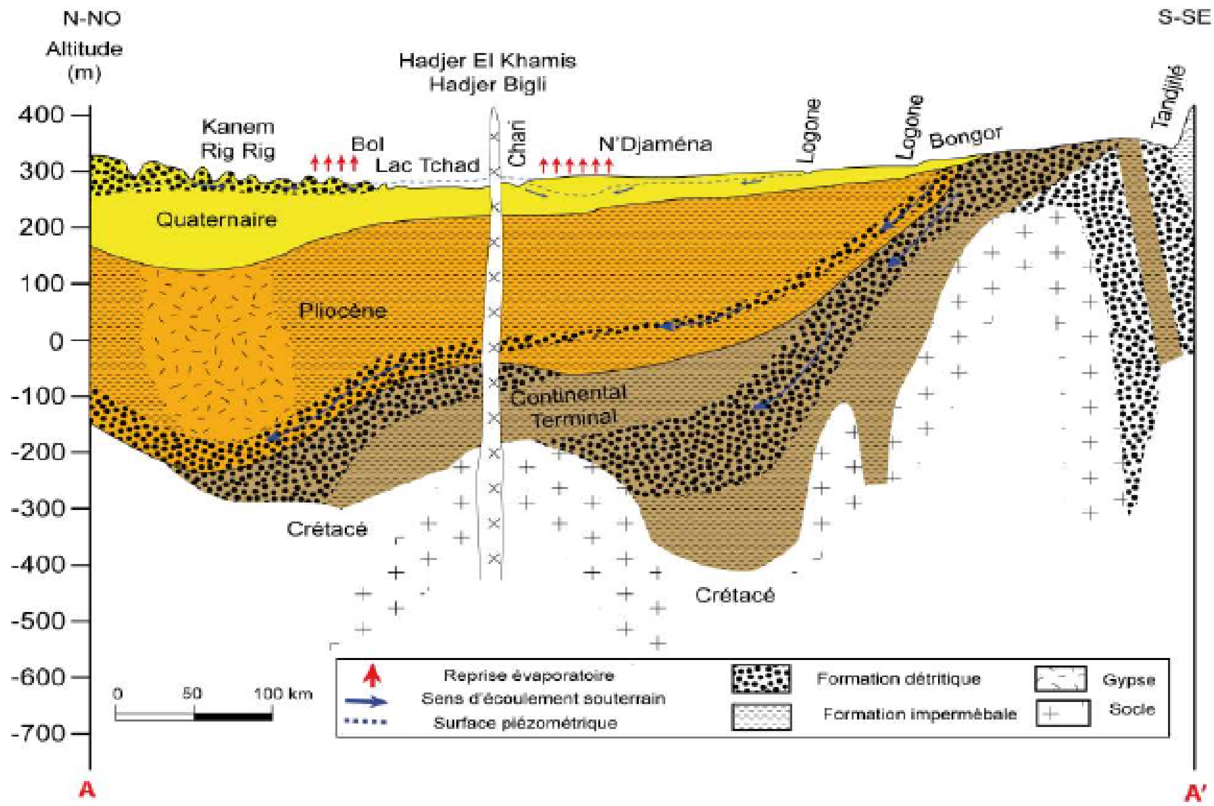

Fig. 2: N-NW and S-SE geological section showing the different aquifers present in the Chari-Logone basin and their thicknesses. It also shows the recharge zone and the evaporation recovery zone
Schematic section of Lake Chad-Goré carried out by Schneider and Wolf (1992) modified and simplified by Mahamat Nour (2019)

The study area is part of the Lake Chad basin, which has the same lithology as that already described for the entire basin (BRGM, 1988; Louis, 1970; Kusnir and Schneider, 1993; Djoret, 2000; Schuster *et al*., 2005).

The hydrogeological section of the Lake Chad basin (Fig. 2) prepared by Schneider and Wolf (1992) and modified by Mahamat Nour (2019) is still used as a reference in the description of the aquifer systems of the Chari-Logone basin. Oriented N-NW and S-SE, this section passes through Lake Chad, the Chari, the Logone up to Tandjilé.

The visual section at the basin scale illustrates the succession of layers encountered at N'Djamena (Fig. 2). The depth of the crystalline basement could not be precisely determined in the vicinity of the city of N'Djamena. However, a depth of 550 m was estimated from seismic investigations (BRGM, 1988). The oldest sedimentary deposits that must have been preserved in basement depressions are not known precisely and the section made at the scale of the basin (PNUD-UNESCO-CBLT, 1970; Moussa *et al*., 2016) highlights the inexistence of Primary and Secondary although some authors think that the Cretaceous would be present in this zone (BRGM, 1988) that we observe on this map in Fig. 2.

Thus, the main hydrogeological units known in the Lake Chad basin are distinguished from the bottom to the top:

- **The continental terminal (cenozoic):** By their extent, the Continental Terminal formations, which are discordant on the basement, constitute one of the main geological units in the basin. They are rather aquifers disconnected from the surface formations (Schneider and Wolf, 1992). It is artesian around Lake Chad over an area of about 60,000 km^2 and is exploited in Niger and Nigeria by several artesian boreholes (Djoret and Favreau, 2014).
- **The lower pliocene:** The Lower Pliocene aquifer is located between 250 and 300 m below the ground surface. There is no clear boundary between this aquifer and that of the Continental Terminal. The impermeable clayey sedimentation of the Pliocene, the wall of the phreatic aquifer, marks the boundary between the Continental Terminal - Quaternary and

the beginning of essentially sandy sedimentation (Servant, 1973; Schneider and Wolf, 1992).

- **The quaternary:** The geological history of the central basin can be summarised by a succession of regressions and lake transgressions, caused during the Quaternary by alternating arid and wet periods (Servant, 1973). These Quaternary formations are of continental origin (Schneider, 1989). The deposits are essentially sandy with clayey intercalations (Roche, 1980). The Quaternary aquifer is located between 50 and 180 m. The depths relative to the ground of the static levels vary from 5 m at the edge of the Chari and to 80 m in the centre of the piezometric trough of the Chari Baguirmi aquifer (Djoret, 2000; Abderamane, 2012; Bouchez, 2015), the main piezometric depression of the zone. At the local scale, the formations are certainly marked by strong lithological and granulometric, horizontal and lateral heterogeneities, but at the basin scale, they appear largely homogeneous and continuous, forming a productive aquifer known as the Quaternary aquifer (Massuel, 2001; Schneider and Thiéry, 2001).

METHODOLOGY

For this study, we proceeded by collecting available data: drilling data (data relating to the stratigraphic logs of the drillings) and fieldwork (piezometric) which took place during the recession period and concerned the 10 districts of the city of N'Djamena. It should be noted that these fieldworks allowed us to determine the static levels of the boreholes in the Quaternary aquifer.

To achieve our objectives, a methodology combining geological; hydrogeological and 3D architecture approaches are developed for:

- Allow to present the mapping of the piezometric surface of the aquifer to identify the geological context in which the study was carried out
- Identify the geometry of the aquifer using GIS software from precise and coherent data

Profiles of litho-stratigraphic correlations: The litho-stratigraphic correlations are performed according to three profiles with different orientations (Fig. 1). The first section (profile AA') passes through 4 structures and is oriented NNE-SSW. The second cut (profile BB'), passes through five structures, it is oriented NNW-SSE, the third cut (profile CC'), oriented N-S, passes through 3 structures.

Method for determining aquifer geometry parameters: We were previously georeferenced in a projection system (WGS 84) the map of the Lower Pleistocene sand wall (Massuel, 2001; BRGM, 1988) which seemed the most relevant for the determination of

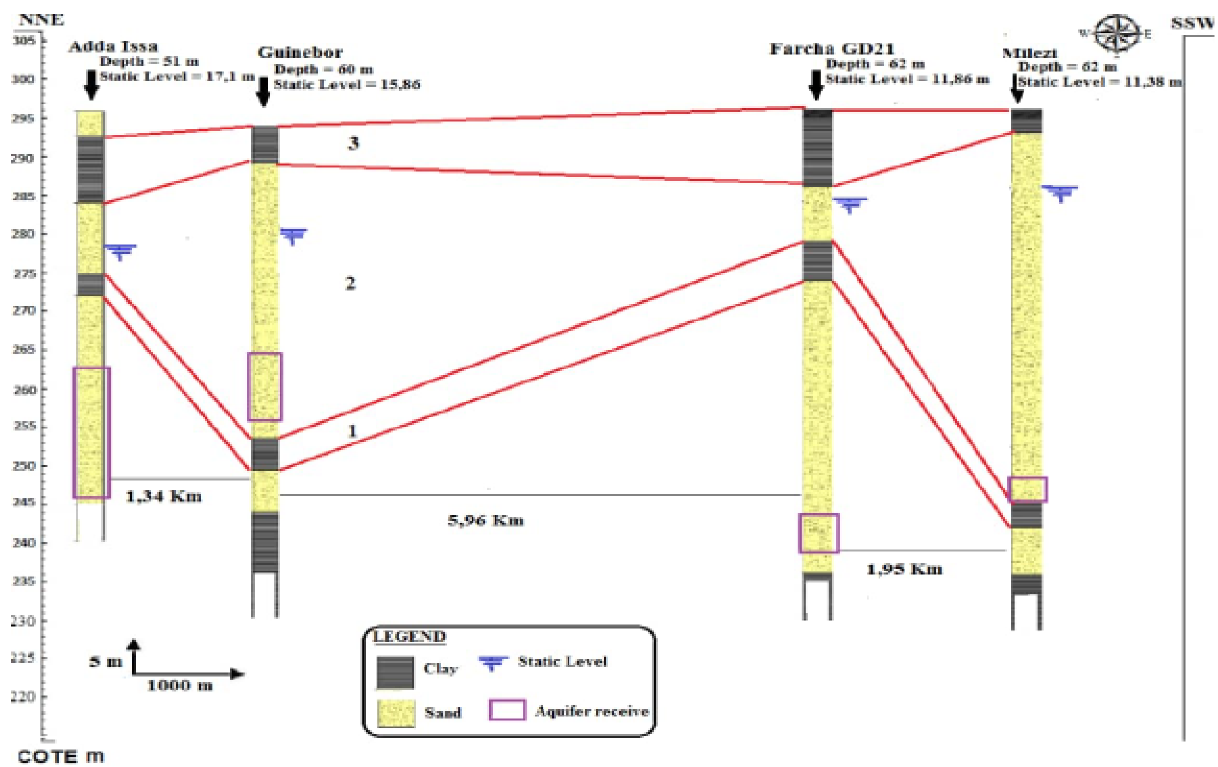

Fig. 3: Litho-stratigraphic section of the axis (Adda Issa-Milezi)

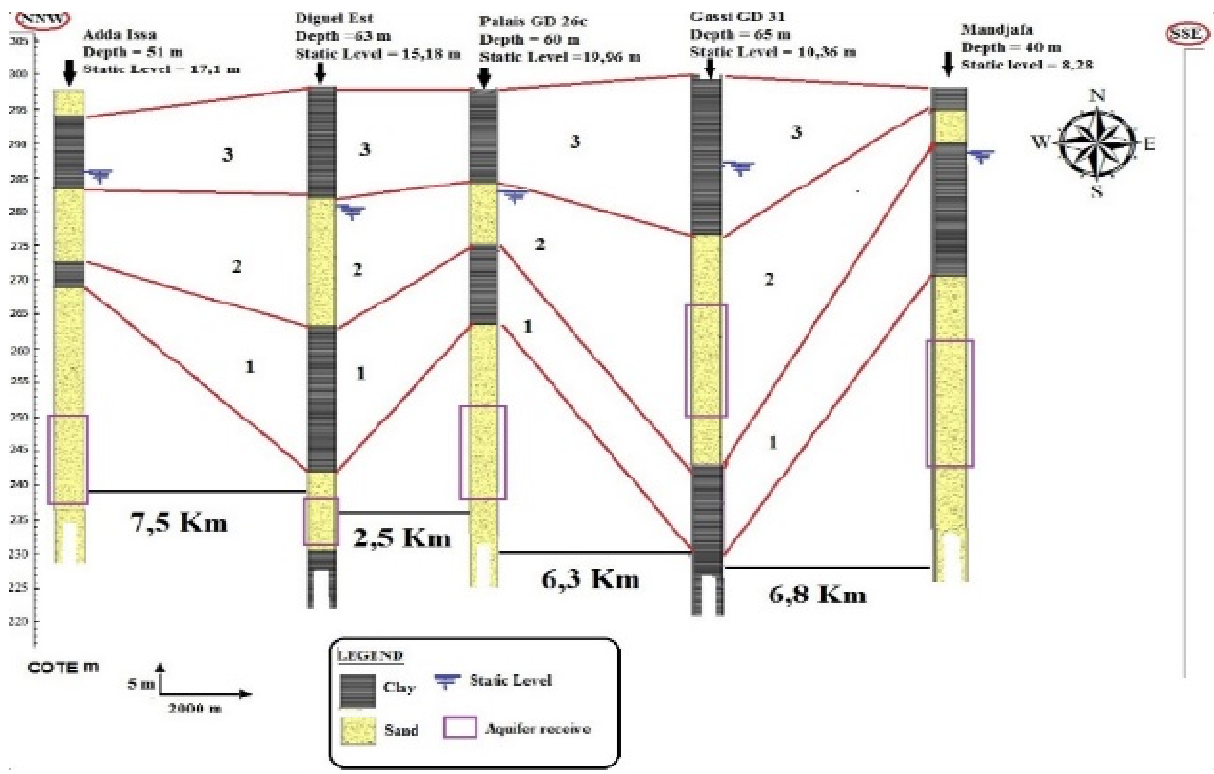

Fig. 4: Litho-stratigraphic section of the axis (Adda Issa-Mandjafa)

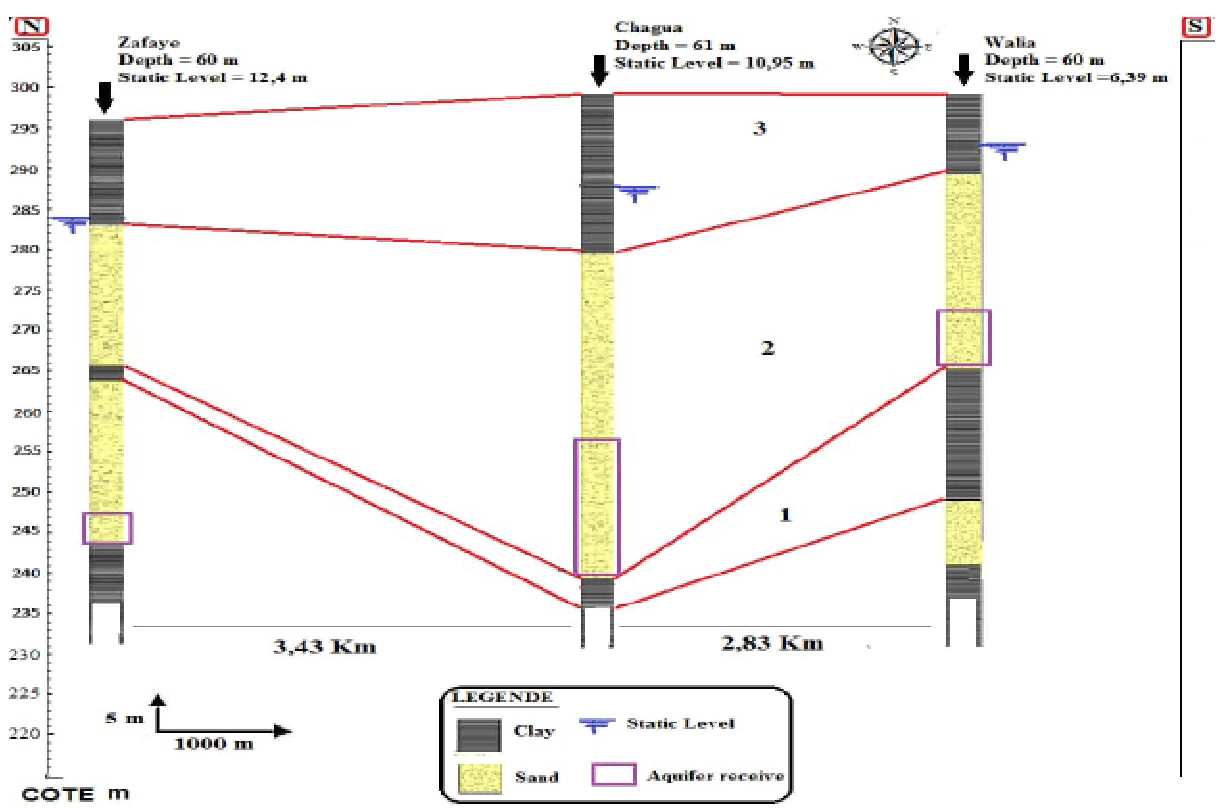

Fig. 5: Litho-stratigraphic section of the axis (Zafaye-Walia)

the wall of the Quaternary formations. The wall was established following a large amount of information from the interpretation of logs (gamma-ray and resistivity) and cores, published by Schneider and Wolf (1992). Boreholes from the 7th EDF also made it possible to specify certain areas and to estimate a maximum altitude of the wall. Borehole sections from studies by Servant (1973) and Schneider and Wolf (1992) were used to validate this step.

We totalled 45 points, spread over the entire study area and estimated the absolute elevation with a precision of <5 m, given the uncertainty in the ground elevation. Kriging interpolation with Surfer3D software (Golden Software Inc.) was performed for the values.

In the same way, all the dimensions of the measuring points on the bedrock are calculated.

RESULTS

Litho-stratigraphic correlations: The various lith-stratigraphic correlations carried out show us on average the lithology of the first 59 m. The different geological formations are: sands, clay-sandy clays. The thicknesses of the layers are variable according to the localities. The lithology presents lateral and vertical variations of facies which makes it difficult to correlate the layers. From top to bottom in the majority of localities, we find clay formations on the surface but sometimes sand and at the base of the clay. The different litho-stratigraphic correlations are as follows:

- **Section AA' (Adda Issa-Milezi axis):** The litho-stratigraphic section shows us 3 types of layers (Fig. 3): Clay, sand, clay. The piezometric levels are between 277 and 285 m.
- **BB cup' (Adda Issa-Mandjafa axis):** The litho-stratigraphic section shows us 4 types of layers with interlayers: clayey and sandy. Specifically, in different localities, the layers have variable thicknesses (Fig. 4).
- **CC' section (Zafaye-Walia axis):** The litho-stratigraphic section shows us 3 types of layers: Clayey, sandy, clayey. Specifically, in different localities, the layers have varying thicknesses (Fig. 5).

The depth of the structures, as well as the static level, vary along the axes:

- On the axis (Adda Issa-Milezi), the drilled depth varies between 51 and 62 m and the static level is between 11.38 and 17.1 m.
- On the axis (Zafaye-Walia), the drilled depth varies between 60 and 61 m and the static level is between 6.39 and 12.4 m.

Structure of the quaternary aquifer:

The roof of the aquifer: Despite the relative frequency of silty levels near the surface, it seems unlikely that they could play a significant hydraulic role. The first slick encountered is considered free over the entire study area. The roof, therefore, corresponds to ground level (Gear and Schroeter, 1973; Schneider and Wolf, 1992; Abderamane *et al*., 2013). The average altitude varies between 292 and 301 m for topographic slopes varying between 1 and 2.5%.

Aquifer wall: The strength of the Quaternary aquifer is assessed from deep borehole cuts through the entire surface formations and reaching or even exceeding (millet market drilling) the clay layer that separates them from the overlying Pliocene aquifer. We attempted to reconstruct the general morphology of the wall of impermeable Pliocene clay layer to estimate the thickness of the Quaternary aquifer. The top of the powerful Pliocene clay series, marking a strong discontinuity with the overlying sandy-clay series, was chosen as the most likely lithological level to represent the bedrock of the aquifer. The wall is the apex of this clay layer, generally identifiable by its thickness (which exceeds <63 m in most profiles). The terrain encountered from the surface to this layer is considered Quaternary and the underlying clay series and deep aquifer are considered Pliocene. This approximation is largely sufficient for a hydrogeological study of the region. Indeed, the continental origin of the Plio-Quaternary formations leads to numerous facies variations between a clayey pole and a sandy pole, both lateral and vertical, which do not facilitate the determination of the thickness of the Quaternary aquifer.

The general morphology of the wall of the Quaternary aquifer thus reconstructed makes it possible to show an altitudinal variation of the wall between 237 and 240 m for an average of 238 m. The lithological descriptions are often quite detailed in the sections of the boreholes above. However, it is not always easy to define a precise depth of the transition from the Quaternary formations to the Pliocene impermeable.

Total thickness and wet thickness of the aquifer: The thickness of the aquifer is obtained by making the difference between the elevations of the roof and the elevations of the wall.

To determine the wet thickness of the aquifer we proceeded by calculating the difference between the thickness of the aquifer and the static level.

Piezometry: The interpolation of the piezometric levels calculated using ArcGis allowed us to obtain the reference piezometric map (Fig. 6). The map thus obtained corresponds to the piezometric map of the low waters, since the measurements are made in the month of flooding. This map presents a similarity with old

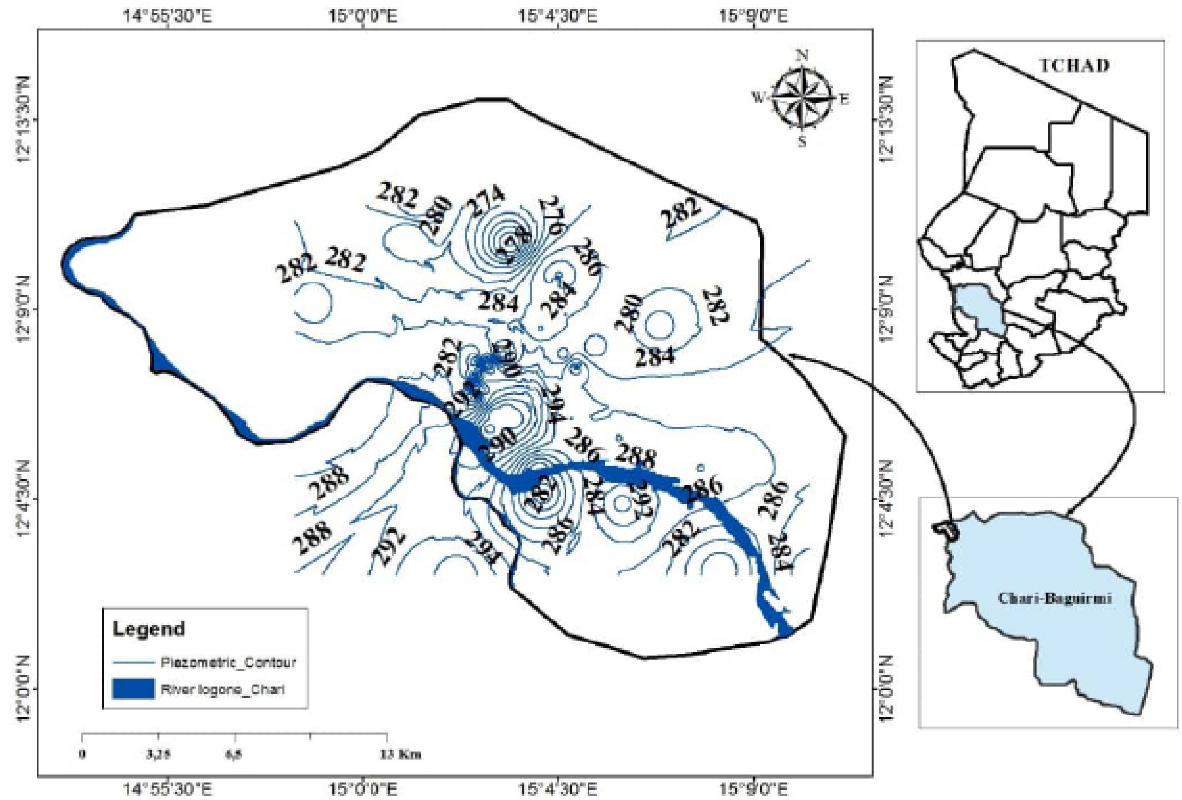

Fig. 6: Piezometric map in recession period (April 2018)

piezometric maps carried out in the region by Bonnet and Meurville (1995), Massuel (2001), Abderamane (2012), Djoret (2000) and Abderamane *et al*. (2013). Their representation shows piezometric domes and depressions, highlighting the direction of groundwater flow.

DISCUSSION

Litho-stratigraphic correlations: The various lith-stratigraphic correlations are located in the detrital levels of the Quaternary, which are essentially formed of alternating clay and sand, the thickness of which varies according to the locality.

The lithology presents lateral and vertical variations in facies that make it difficult to correlate the layers. The lithology of the boreholes in our study area is similar to that described for the entire Lac-Tchad basin (Louis, 1970; BRGM, 1988; Kusnir and Schneider, 1993; Schuster *et al*., 2005; Moussa *et al*., 2013).

The sections carried out to confirm the heterogeneity and allow us to extend this character to the entire study area (Ngounou Ngatcha *et al*., 2007; Zaïri, 2008; Schuster *et al*., 2009). The formations encountered would have been deposited during the transgression and regression of various episodes of the Mega-lake (Maley and Maley, 1981; Leblanc *et al*., 2006; Moussa *et al*., 2013; Lemoalle *et al*., 2014). The alternation and succession of sand and clay deposits show that the filling or sedimentation conditions were different (Maley and Maley, 1981; Maley, 2000; Ghienne *et al*., 2002; Lemoalle *et al*., 2012). These sedimentations could be related to the climatic oscillations that the region experienced (Servant, 1973; Sylvestre, 2014; Maley and Vernet, 2015; Moussa *et al*., 2016).

As a result, the first metres of the profiles are dominated by clay formations in most of the structures (except Adda Issa), followed by sands and the last metres by clay formations or sometimes sands. The presence of sands in the first few metres (Adda Issa) suggests that this structure is located on the ancient meanders of the Chari (Moussa, 2010).

In the Chari-Baguirmi in general and the city of N'Djamena in particular, the roof of the Quaternary aquifer is confused with the topographic surface. The few clayey levels encountered in the cross-sections of the structures do not have sufficient lateral extension to give a captive character to the aquifer of the Quaternary aquifer (Gear and Schroeter, 1973). This aquifer is considered free throughout the study area and is located in sandy formations.

The thickness of this Quaternary aquifer is more or less constant, in the order of 50 to 63 m, with average layer thicknesses varying according to the formations.

The deposits are predominantly sandy (Schneider and Wolf, 1992). The average static level is 13 m.

Because of the results obtained, the study area is covered by Quaternary deposits. Below the Quaternary deposits, at a depth of approximately 61 m, appear the Pliocene clays, which have an average thickness of 200 m. The next meters are the lower Pliocene sands. These sands would constitute the Lower Pliocene aquifer on which the water table is located. The thick layer of clay makes the water table everywhere captive and often artesian.

Aquifer geometry and hydrodynamic functioning: The piezometric measurement of the water table in N'Djamena shows that the groundwater table is shallower, the depth of the static level varies from 7 to 9 m in the vicinity of the river, from 11 to 13 m in the city centre and reaches 15 to 19 m or even further north of the town. That is to say, the further away from the river, the deeper the groundwater level becomes and this justifies the observation of Djoret (2000), Kadjangaba (2007) and Abderamane *et al.* (2013), that the groundwater is essentially fed by the Chari River, rainwater and water from ponds can also participate (Abderamane *et al.*, 2013; Bouchez, 2015).

The piezometric map shows isopeze curves with an altitude varying between 264 and 294 m (Fig. 5). The isopiezes are narrowed in the centre-west, south and north-northwest. They are widened in the northeast and southeast.

The top of the aquifer in the study area corresponds to the topographic surface. Indeed, the first Quaternary aquifer is considered as a free water table over its entire surface (Gear and Schroeter, 1973; Schneider, 1989; Ngounou Ngatcha *et al.*, 2007), or semi-captive under a few metres of clayey levels, also known as the water table (Kadjangaba, 2007; Abderamane *et al.*, 2013). It appears to be continuous despite the lenticular character of the sand formations captured (Schneider and Wolf, 1992; Bouchez, 2015), as this is predominant and it is assumed that there would be very good communication between the sandy levels. It provides good flow rates when the captured thickness is sufficient (Djoret and Favreau, 2014) and is of interest to the most productive levels of the vertical section crossed (Schneider and Wolf, 1992). The roof, therefore, corresponds to ground level. The average altitude varies between 292 and 301 m for topographic slopes varying between 1 and 2.5%.

The Quaternary wall constitutes the roof of the Pliocene and is made of impermeable clay layer

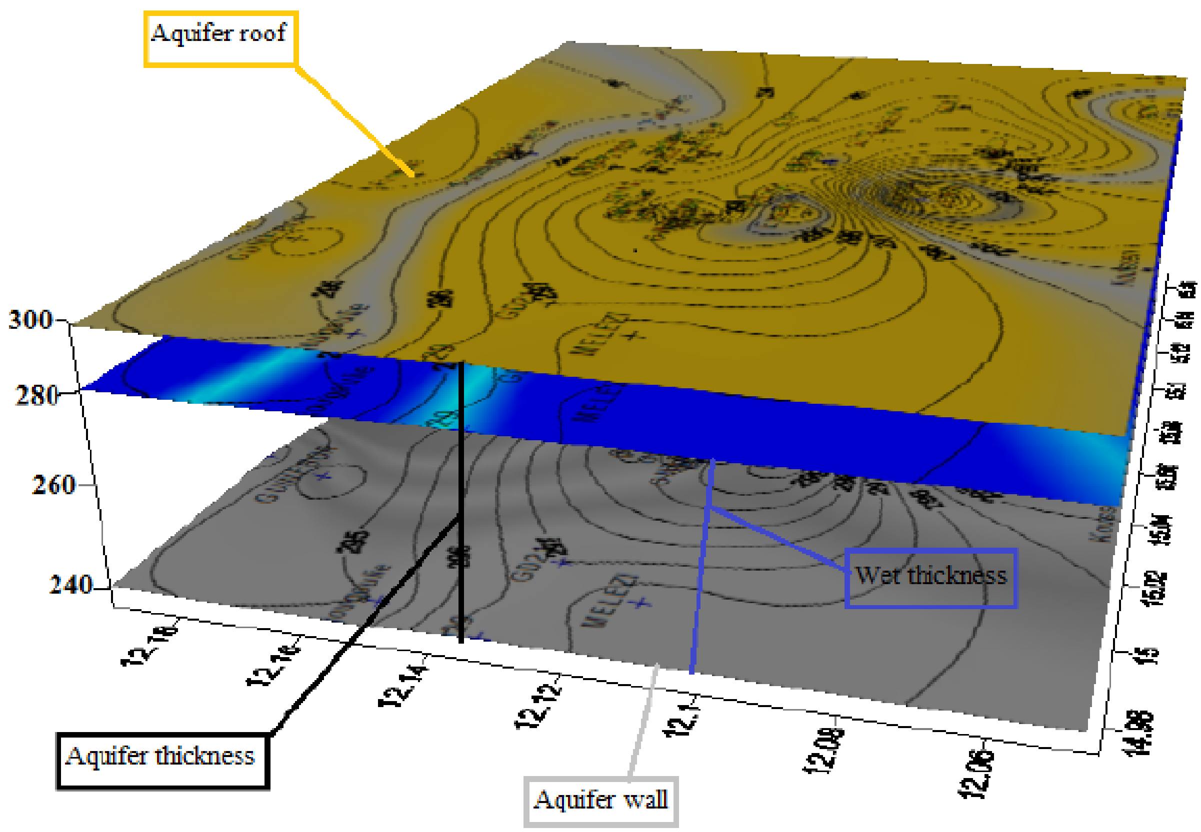

Fig. 7: Schematic cross-section of the aquifer geometry of the study area

(Schneider and Wolf, 1992) (Fig. 2). The terrain encountered from the surface to this layer is considered Quaternary and the underlying clay series and deep aquifer are considered Pliocene. The total thickness of the Quaternary sedimentation is approximately constant, in the order of 50 to 63 m and the contact with the underlying clays is clear. Our observations are similar to those of Bonnet and Meurville (1995), Massuel (2001), Zaïri (2008) and Mahamat Nour *et al*. (2017) who state that the thickness of the Quaternary aquifer exceeds <70 m in the Chari Baguirmi region. Small differences depend on the accuracy of the data. Bedrock data showed an altitudinal variation between 237 and 240 m (Fig. 7). The wetted thickness is about 44 m on average.

The block diagram (Fig. 7) shows the structure of the Quaternary aquifer around N'Djamena.

CONCLUSION

At the end of this study whose objective is the understanding of the geological and hydrogeological structure of the aquifer of the city of N'Djamena. It emerges that.

The analysis of the lithological sections shows us that in the Quaternary, the thickness of the layers is variable. The lithology presents lateral and vertical variations of facies which makes it difficult to correlate between layers. From top to bottom in the majority of localities, we find clay formations on the surface but sometimes sand and at the base of the clay. The water table could be lodged in either sandy or sandy-clay formations. The average static level is 13 m.

The hydrogeological structure of the aquifer system in the study area was facilitated through a methodology by shimming the Lower Pleistocene sand wall map, which allowed the determination of the roof and wall, whose roof is generally confused with the topographic surface and that the Quaternary water table is considered to be an open water table over its entire area. The Quaternary wall constitutes the roof of the Pliocene and is made up of impermeable layers of clay. The total thickness of the Quaternary sedimentation is approximately constant, of the order of 50 to 63 m.

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