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# Structure, geometry and piezometry of the Turonian-Coniacian aquifer captured in the Benin-Togo Coastal Sedimentary Basin

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**Abstract**

The Kéta Basin in Benin and Togo is located in the tropical zone between the equator and the Tropic of Cancer, between parallels 6° 10' and 7° 75' north latitude and meridians 1° 0' and 2° 48' east longitude. The study area occupies the southern tip of the two countries, with the Mono River forming the border. The Turonian-Coniacian aquifer, the oldest aquifer unit in the coastal sedimentary basin, is the subject of this study. This study aims to determine the structure, geometry and piezometry of this aquifer. Three cross-sections were created (Benin and Togo) using the traditional method, combining topographical maps, graph paper and Qgis 2.18.15. Piezometry was then carried out in three stages: determining the altitudes of the measurement points, calculating the piezometric levels and interpolating the calculated piezometric levels. The piezometric map was produced using Excel, Surfer 11 and Qgis 2.18.15 in succession. All these methods indicate that the Coniacian Turonian aquifer outcrops to the north of the northern plateaus of the Benin-Togo Coastal Sedimentary Basin. As the flow direction is mainly north-south, it can be deduced that the aquifer is fed by rainwater infiltration at its outcrop areas.

**Keywords:** Piezometric survey, Keta basin, hydrogeology

## Introduction

Globally, the issue of water supply is becoming increasingly worrying (in Okoundé, 2010). Although water remains abundant, it is unevenly distributed across the Earth's surface and underground. As a result, some countries suffer from a significant lack of water to meet the basic needs of their populations, while others no longer know how to control the chronic excess water that is gradually invading arable land and displacing entire population flows (Pet it, 2004; Idder et al., 2013). Our planet is experiencing a demographic boom that will lead to an explosion in water consumption and, inevitably, a deterioration in its quality. The coastal cities of Africa are currently experiencing this with the rapid and uncontrolled growth of their populations and demographics.

Benin and Togo mainly use groundwater to supply drinking water to their populations, as it is generally of better quality than surface water. However, limited knowledge of the hydrogeological characteristics of the land could seriously jeopardise the preservation of these water resources for future generations (Orou-Pété et al., 2021). The Turonian-Coniacian is one of the four major aquifer units in the Coastal Sedimentary Basin (BSC) and is the deepest. It is tapped in the north of the BSC (where it outcrops) with large-diameter wells; in the Lama depression, it is artesian in nature, and in the south of the BSC. With the uncontrolled spread of urban populations linked to demographic growth, it is urgent to control the reservoir in order to manage it efficiently. The objective is to ensure sustainable management of the resource. The management of this deep aquifer inevitably requires hydrogeological characterisation.

The hydrogeology of coastal sedimentary aquifers has been studied for some thirty years (Gallo, 1979); (Akiti, 1980); (Dray et al., 1989); (Olga, 1998); (Njitchoua et al., 1999). Today, the deterioration in water quality is forcing a re-examination of the hydrodynamics of the entire system (Akouvi et al., 2005).

The objective of the work is to clarify the structure, geometry, and piezometry of the Turonian-Coniacian aquifer. Specifically, it concerns:

- Produce hydrogeological cross-sections
- Define the geometry of the aquifer

Make a piezometric map of the Turonian-Coniacian aquifer

## Study area

### Location, Climate, Vegetation, and Soils

The Kéta Basin in Benin and Togo is located in the tropical zone between the equator and the Tropic of Cancer, between parallels 6° 10' and 7° 75' north latitude and meridians 1° 0' and 2° 48' east longitude. The study area occupies the southern tip of the two countries, with the Mono River forming the border. Known in Togo as the Togolese Coastal Sedimentary Basin, it covers an area of approximately 3,300 km2, or 6% of the national territory (Gnazou et al., 2015). In Benin, it is known as the Benin Coastal Sedimentary Basin and covers an area of approximately 11,476 km2, or 10% of the national territory (Glodji et al., 2019). The Benin-Togo Coastal Sedimentary Basin (BSCB-T) covers a total area of approximately 14,776 km2 and is bounded to the north by the outcrops of its substrate (Panafrican crystalline basement) and extends southwards into the offshore portion under the Atlantic Ocean, widening from west to east, from the border between Ghana and Togo to that between Benin and Nigeria.

The Turonian-Coniacian aquifer that is the subject of our study outcrops north of the BSC Benin and Togo on the four northern plateaus of Benin (Kétou, Zagnanado, Abomey and Aplahoué) and the three in Togo (Kouvé, Tchévié and Fogbé).

The region, which has a subequatorial climate, is characterised by two distinct rainy seasons linked to the movement of the Intertropical Front (a longer rainy season from mid-March to July and a shorter rainy season from mid-September to November) and two dry seasons from August to mid-September and from December to mid-March, respectively (Achidi et al., 2012).

The average annual rainfall recorded at the Bohicon weather station in Benin (from 1922 to 2009) is 1,197 mm, with potential evapotranspiration of approximately 1,500 mm/year (Achidi et al., 2012; Amoussou, 2005) cited by (Kpegli et al., 2018).

Rainfall across the basin is not uniform; it decreases significantly from the northeast (1,445 mm in Tabligbo) to the southwest (864 mm in Lomé). The average monthly temperature varies between 25 and 29 °C in Lomé (Gnazou, 2008). Similarly, rainfall gradients vary from west to east between 900 and 1450 mm in southern Benin (Alassane, 2004). Relative humidity is high, ranging between 65% and the average annual temperature is 27°C but can reach 38°C in the dry season and drop to 19°C in the rainy season (Kpegli et al., 2018).

The original vegetation of the study area (in Benin) is characterised by a mosaic of forests and savannahs, but has been largely replaced by secondary grasslands or savannahs due to human intervention. However, isolated tropical forests (original vegetation), most of which are protected for religious reasons, still exist (Adjakidje, 1984); (Adjanohoun, 1989; Houndagba, 2015) cited by (Kpegli et al., 2018). In Togo, it is mostly covered by wooded savannah (Alassane, 2004). The Togolese portion of the study area extends over an ecological zone characterised by Guinean humid savannahs with patches of humid forests.

According to (Volkoff, 1970) and (Lamouroux, 1966), cited respectively by (Alassane, 2004) and (Gnazou 2008), the soils of the entire Benin-Togo coastal sedimentary basin include ferralitic soils. These are either ferruginous sesquioxide soils or leached soils with concretions on clayey-sandy or sandy-clayey sediments, or vertisols on clayey sediments. The coastal and alluvial zone is covered with either hydromorphic soils, halomorphic soils leached with alkalis, or poorly developed soils on coastal or alluvial sands. They also include tropical ferruginous soils leached at shallow depths.

The population of the Togo Sedimentary Basin (BSCT) is approximately 1,164,500 inhabitants, according to data from the National Institute of Statistics and Economic and Demographic Studies (INSEED) on the 2010 general population and housing census. The population of the Benin Sedimentary Basin (BSCB) is estimated based on the populations of the various districts covered by the basin. According to the National Institute of Statistics and Economic Analysis (INSAE), it is approximately 5,271,802 inhabitants, RGPH4-2013. The population of the Benin-Togo Coastal Sedimentary Basin (BSCB-T) is around 6,436,300 inhabitants. Economic activities in the basin are dominated by rain-fed agriculture, crafts and trade. Food crops such as maize and cassava are widely grown. Irrigated rice cultivation is also practised in the Kovié, Mission-Tové, Hon, Yovotonou and Ouinhi areas. The BSCB-T is mainly populated by the Evé, Ouatchi, Fon, Goun, Kotafon, Aïzo, Adja, Mina and Xwla peoples, as well as the Honli, and a few minority groups such as the Yoruba, Hausa and Nago.

Geomorphologically, the Benin-Togo coastal sedimentary basin is organised on either side of the Lama depression, which runs north-northeast to south-southwest, into a series of sloping plateaus cut by river valleys. This basin is drained by the main rivers of the Zio, Haho, Mono, Couffo, Zou and Ouémé.

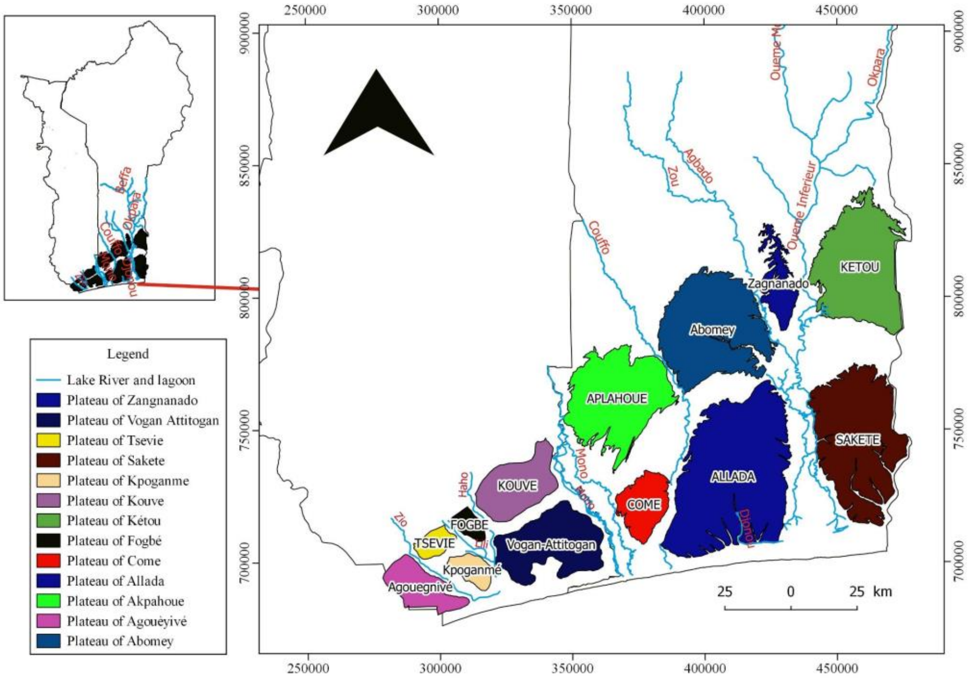


**Figure 1:** Location of the study area

## Geology and hydrogeology of the Benin and Togo Coastal Sedimentary Basin

From a geological point of view, according to the synthesis of previous studies on the stratigraphy and geology of this basin, reconstructed using seismic, lithological, structural and sedimentological data, as well as numerous hydraulic and petroleum surveys and mineral deposits (Monciardini et al., 1986); (Sylvain et al., 1986); (Johnson, 1987); (Breda, 1987); (Kaki et al., 2001); (Da Costa, 2005) and (Oyédé et al., 2006)), the Kéta Basin, which covers Benin and Togo, comprises sedimentary formations (sand, gravel, sandy clay, clay, marl, limestone) dating from the Cretaceous to the Quaternary periods, which have a monoclinal appearance characterised by differential subsidence, increasing towards the south-southeast (Slansky, 1962); (Gnazou, 2015). The sedimentary aquifers of the coastal basin (Kéta Basin) are multi-layer aquifers, which generally have high productivity (Boukari et al., 1994); (Boukari, 1998).

From a hydrogeological perspective, the Coastal Sedimentary Basin contains four aquifers separated by thick aquicludes with low permeability. These are the Quaternary sand aquifer, the Miocene-Pliocene sand aquifer, the Palaeocene limestone aquifer and the Upper Cretaceous (Turonian-Coniacian) sand aquifer. The Quaternary and Miocene-Pliocene aquifers are shallow and can be tapped with large-diameter wells. The Palaeocene and Upper Cretaceous aquifers are deep, but the Upper Cretaceous aquifer (the subject of our study) has the particularity of outcropping in the northern part of the Coastal Sedimentary Basin, where it is recharged.

The Upper Cretaceous aquifer layer resting on the bedrock, fragmented by longitudinal and transverse faults represented by alternating sandy layers of varying thickness, is free-flowing north of the Lama depression (on the northern plateaus) and confined to the south. Its thickness gradually increases from 50 to 60 m in the north to more than 800 m near the coast (Maliki, 1993, cited by Alassane, 2004). In Togo, its thickness varies between 5 and 25 m and is clayey or sandy-clayey in nature. The depth varies between 50 and 120 m in places (Gnazou, 2008).

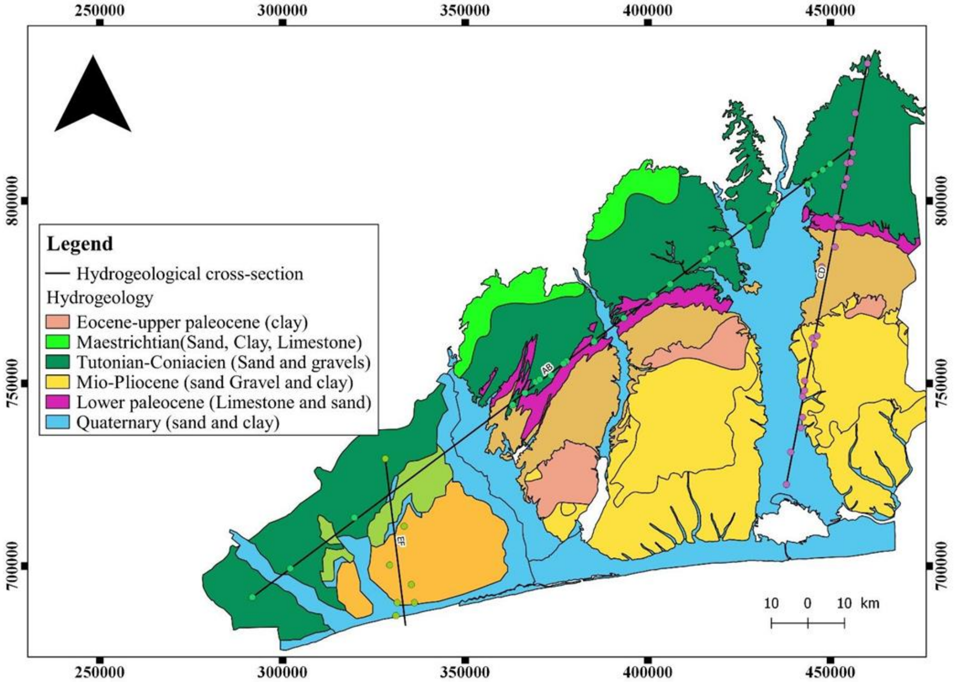


**Figure 2:** Geology of the Benin-Togo Sedimentary Basin showing the sections to be cut

## Materials and methods

### Data collected and materials used

The data collected initially concerned stratigraphic logs (from boreholes and piezometers), from which those used to produce hydrogeological cross-sections were selected. We then collected field maps; these are :

- Topographic maps of Klouékanmè, Abomey, Zagnanado, Kétou Pobè, Grand-Popo, Lokossa, Allada Adjohoun, Sakété (2018) 1/50,000 in Benin at the National Geographic Institute (IGN) of Benin and the sheets Lomé, Tsévié, Hahotoé, Ahépé, Tabligbo (2013) 1/50,000 in Togo at the General Directorate of Cartography (DGC);
- digital terrain model (30*30 resolution) downloaded in 2024 from https://ers.cr.usgs.gov/;
- We then carried out a field campaign consisting of measuring static levels in 60 large-diameter wells during the high water period (July 2023) and 15 wells in Togo during the low water period (March 2023). This piezometric study campaign was carried out over a one-week period to ensure that groundwater levels were comparable. These static levels were used to produce the piezometric map of the aquifer system, which is presented and analysed below.

The following equipment is used during our fieldwork:

- A Garmin Global Positioning System (GPS) device for recording geographical coordinates in the field,
- a piezometric sonde for measuring static levels,
- Excel software for data processing, QGIS 2.18.15 for arranging scanned images of lithostratigraphic correlations and hydrogeological cross-sections produced on graph paper, and QGIS and Surfer 11 for producing maps,
- Digital camera for instant photography.

## Méthods

### Hydrogeological cross-sections

To determine the structure and geometry of the aquifer captured by the exploitation works, we first carried out a geological identification by creating three (03) cross-sections. These are the Benin-Togo (AB) cross-sections, the Kouvé-Attitogan (EF) cross-sections and the Kétou Sakété (CD) cross-sections (NNE-SSW direction). To produce these sections, the stratigraphic logs of the boreholes were projected in QGIS 2.8.15. Then, the topographic profiles and lithostratigraphic correlations between the different stratigraphic logs of the boreholes were produced on graph paper using the topographic maps mentioned above. the static levels (measured during drilling) were then transferred to the vicinity of the boreholes and, finally, these levels were correlated to obtain the piezometric line of the captured horizon; the sections obtained were scanned, arranged and digitised in QGIS 2.8.15 to be exported as images.

**Piezometric surveys**

Statistical levels (NS) were measured in approximately sixty (60) wells (large diameter) by first measuring the depth of the water relative to the well rim using a piezometric probe, then subtracting the height of the rim. Next, the geographical coordinates (X and Y) were recorded at each well using a GPS device.

The piezometric maps were created in three stages: determining the altitudes of the measurement points, calculating the piezometric levels, and interpolating the calculated piezometric levels. We began by determining the altitudes of the measurement points.

The piezometric level is the static level relative to mean sea level (0). As we were unable to level all our measurement points and could not rely on the low accuracy of the Z altitudes recorded by GPS in the field, we determined them using an equation (3) that was established through a correlation between the altitude values of the IGN Benin geodetic markers located within and near the study area, and the altitude values of these geodetic benchmarks extracted from a global 1-arc second SRTM Digital Terrain Model (DTM) (DTM with a spatial resolution of 30m x 30m, downloaded from the website https://ers.cr.usgs.gov/ already mentioned above).

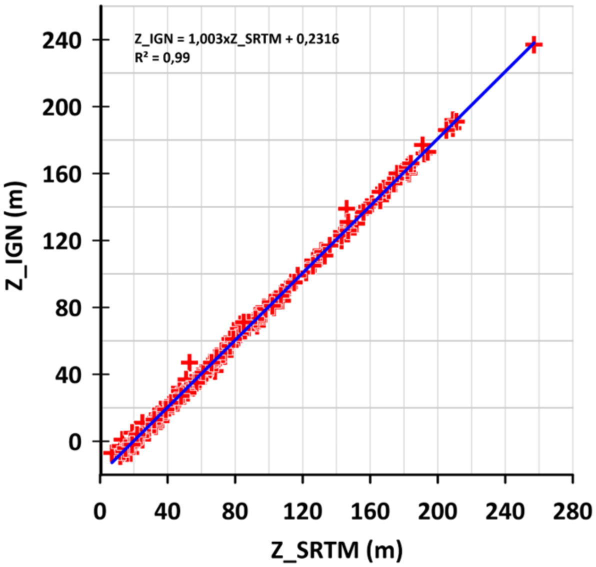


**Figure 3:** Correlation line between IGN altitudes and SRTM altitudes

We then calculated the piezometric levels (Np) using the formula Np= Z-Ns/sol. Replacing Z with its value in equation (1), we obtained:

**Np= (1.003*Z_MNT+0.2346) –Ns/sol**

With NP (m): the piezometric level, Z: the estimated altitude of the measurement point; Z_MNT: the altitude of the point from the SRTM 1Arc global DTM source at https://ers.cr.usgs.gov/ and NS: the static level measured relative to the ground.

**Tableau 1:** Values of parameters for comparing measured piezometric levels and those estimated from the DTM

| MNT | NSE | RSR | $R^2$ | Perfomance |
|---|---|---|---|---|
| SRTM | **0.9978** | **0.046** | **0.9982** | Très bon |

For plotting the iso-value curves, the interpolation method chosen is kriging, as the results can be checked using distance variograms. (Orou pété et al., 2021) According to Matheron (1965), cited in Orou pété et al. (2021, the theoretical variogram is only representative of the empirical variogram in the vicinity of the origin. The power model is the one that best fits our piezometric level values.

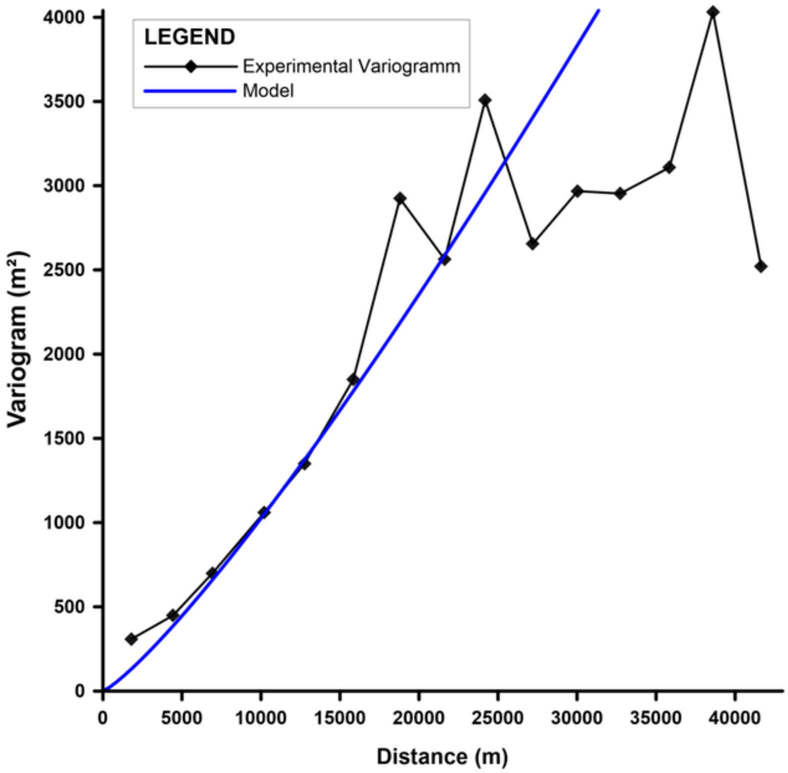


**Figure 4:** Adjusted distance variograms for piezometric levels

The formula for the power adjustment model is as follows:

$$\gamma(h) = 1{,}5 + bh^{1{,}99}$$ **with b: the slope of the straight line.**

## Results and discussions

### Geological and hydrogeological identification of the aquifer being exploited

Based on the lithological cross-sections collected from boreholes, three hydrogeological cross-sections were produced in the following directions: South-West to North-East (Togo-Benin); North-North-West to South-South-East (Kouvé-Atitogan); NN East–SS West (Kétou-Sakété). The hydrogeological sections obtained are shown in Figures 5, 6 and 7.

Five (05) more or less continuous layers, differing in lithology, are traversed by the correlated boreholes. These consist of a surface layer of laterite, a clayey layer dating from the Maastrichtian, sandy layers, a clayey-sandy layer and limestone. The sandy layer (which appears to have two levels in Togo) is a Turonian-Coniacian formation (Cretaceous sand), while the limestone layer between the thick clay layers is a Palaeocene formation.(Monciardini et al., 1986). The sandy layer has a section that outcrops (and is therefore unconfined) to the north of the plateaus and gradually sinks towards the south until it disappears completely under the thick clay layers, making the aquifer confined. The Palaeocene limestone aquifer is confined from south to north of the Coastal Sedimentary Basin.

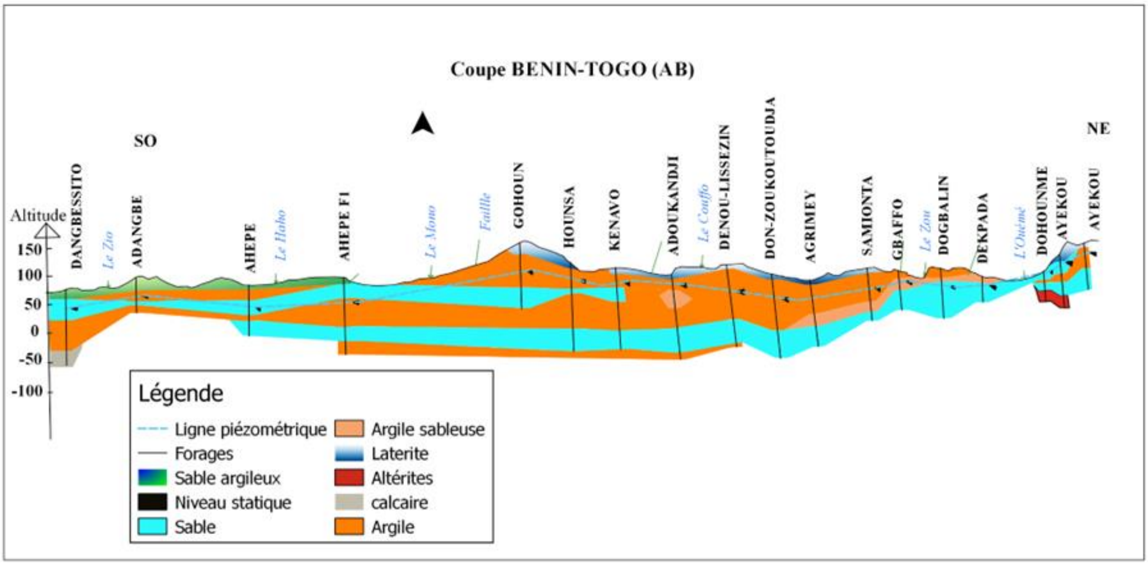


**Figure 5:** Hydrogeological cross-section of Benin-Togo

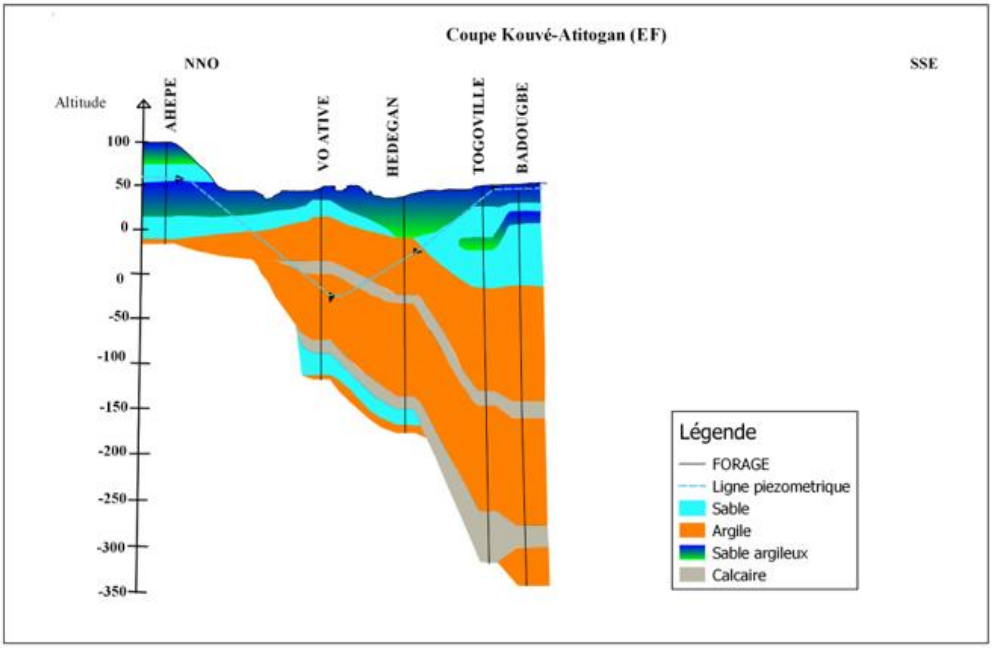


**Figure 6:** Hydrogeological cross-section of Kouvé-Atitogan

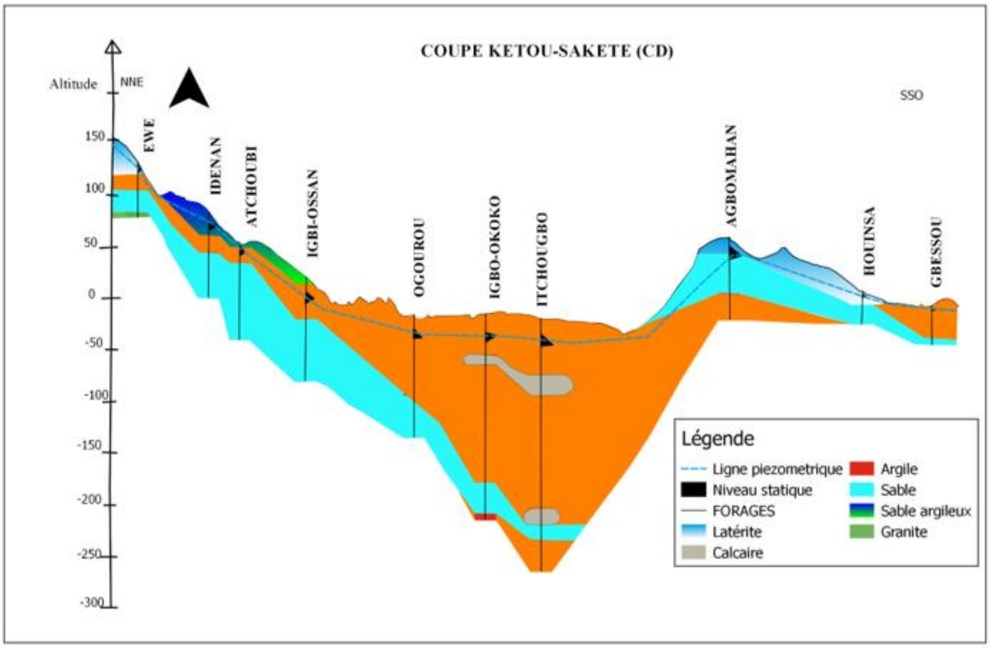


**Figure 7:** Hydrogeological cross-section of Kétou-Sakété

## Piezometry

The piezometric surveys of the aquifer (Figure 8) was only possible for the Beninese part, given the unrepresentative nature of the wells due to their virtual absence in our study area in Togo. The flow directions are multidirectional and differ from one plateau to another. We have a first recharge zone located north of the study area (north of the Kétou plateau) and a second recharge zone located in the Zagnanado plateau, from where groundwater flows mainly southwards. Observing the direction of flow, groundwater diverges locally on this central plateau towards the Zou River and the Ouémé River valleys. A recharge zone located northwest of the northern Abomey plateau, from which groundwater generally flows towards the southeast. The fourth recharge zone is located northeast on the Aplahoué plateau (Kpégli et al.,2018).

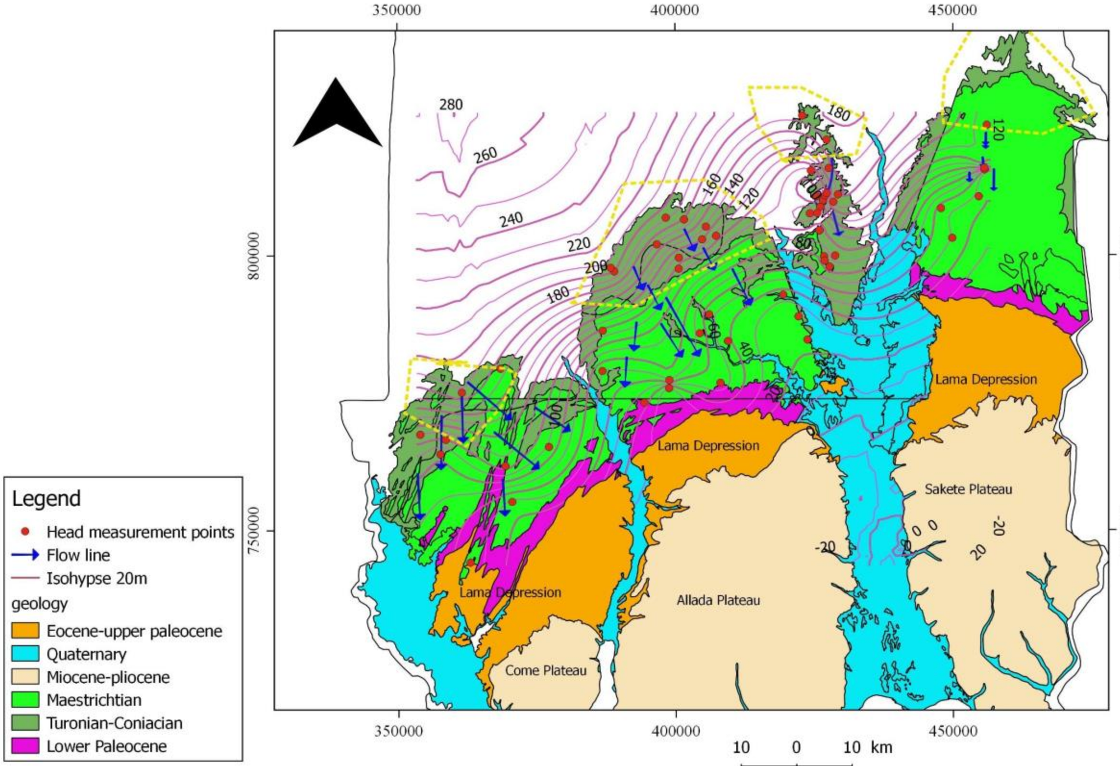


**Figure 8:** Carte piézométrique du Turonien Coniacien au Bénin

## Conclusion

In order to identify and better understand the Turonian-Coniacian aquifer captured in the Benin-Togo Coastal Sedimentary Basin, we have determined the structure, geometry, and piezometry of this aquifer. Thus, we obtained several lithologies from boreholes distributed across the plateaus of the Coastal Sedimentary Basin and conducted a field campaign to measure static levels in about sixty wells in Benin. This allowed us to create three hydrogeological sections on the scale of the Basin and to produce the piezometric map of the aquifer on the scale of Benin. The captured aquifer horizon is the Upper Cretaceous, which is a formation of the Turonian-Coniacian covered by a thick impermeable clay layer, which is a Maastrichtian formation. This very deep aquifer is tapped by large-diameter wells, thus requiring no significant effort for its extraction. It happens to be free in the North of the Northern plateaus of the Coastal Sedimentary Basin.

**Conflict of Interest:** The authors reported no conflict of interest.

**Data Availability:** All data are included in the content of the paper.

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