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Full Length Research Paper

Hydrodynamic characterization of the Paleocene aquifer in the coastal sedimentary basin of Togo

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The intense exploitation of shallow aquifers in the coastal basin of Togo provokes a rapid depletion of these reservoirs. The confined paleocene aquifer represents potential reserves that are yet little exploited. This paper presents the hydrodynamic characterization of this aquifer. Piezometric data established from 80 wells fluctuate between 1.17 and 3.42 m; and demonstrate the effect of pumping on groundwater level with a depression located in South-West of the study area. Major fluctuations higher than 2 m, are observed in some wells located in the North of the basin. These are a result of the recharging of the Paleocene by the shallow aquifer of the Continental terminal in the North of the basin where the two aquifers are in contact.

Key words: Water table, aquifer, Paleocene, fluctuations, Togo.

INTRODUCTION

The Paleocene carbonate rocks found in the sedimentary series in the coastal basin of Togo constitute a thick aquifer of great importance. Unfortunately, this aquifer is little known. The few studies carried out (PNUD, 1975; PNUD, 1982) have been prospective in character. The partial knowledge of this deep aquifer is attributed to the high cost of prospection, and shallow aquifers are most exploited. The extraction of groundwater in Togo has increased in these past years due to the growth in worldwide demand for water and also to the move away from exploitation of surface to ground water. The coastal basin supports one third of the national population in a 3450 km² area, which is about 6% of the total area of the country (Bourgeois, 1981). It is an area with major economic activities and the location of nascent industry. This concentration of population and industries in such a small area, leads to major local disequilibria between the supply and demand for water. Many factors aggravate this disequilibrium, including among others, the absence of the very productive unconfined aquifer of the Continental terminal in the central part of the basin (the Lama depression, the open pit phosphate mine), the threat of contamination by marine and the anthropic pollution (Honyiglo, 1969) of shallow aquifers (marine sands and the Continental terminal), which until then were exploited for divers uses. To these two factors should be added the feeble recharging of the aquifers because of their configuration (great thickness of the unsaturated zone), and to a rainfall deficit (Hubert et al., 1989).

All these constraints, resulting from the exploitation of the shallow aquifers have consequently redirected hydraulic projects toward deep aquifers such as the Paleocene. With the increasing withdrawal of water from the Paleocene, it seems appropriate to characterize the hydrodynamic behaviour of this aquifer. This characterization allows one to ensure the conservation and the durability of this resource. The aims of this paper are to describe the spatial state of the water table of the Paleocene aquifer and to discuss the hydrodynamic fluctuations within it.

METHODS

The study area

The study area is the coastal sedimentary basin of Togo. It is bounded in North by the crystalline basement. Its width increases from the Ghana border in the West toward the Mono river which forms the border with the Republic of Benin in the East.

Geomorphologically, the coastal sedimentary basin appears as a collection of inclined plateaus separated by river valleys, and located on both sides of a median depression oriented NNE - SSW,

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known as the “Lama depression”. On the coastal plain, is a lagoonal system composed of small lagoons of which Lake Togo is the most important among all.

The basin has a subequatorial climate characterized by two distinct rainy seasons related to the movement of the Intertropical Front. Rainfall in the basin is not uniform; it diminishes markedly from the North-East (1445 mm at Tabligbo) to the South-West (864 mm at Lomé) (Gnazou, 2008). The average monthly temperature varies between 25 and 30°C on the whole of the basin.

The stratigraphy of the basin was established following the drilling of numerous water and petroleum boreholes, by geophysical studies and by mining surveys (Sylvain et al., 1986). The post-paleozoic sedimentary serie starts with the Maastrchtian and ends with the Quaternary series [8; 9] (Figure 1). In these coastal basin formations, there are four aquiferous horizons (PNUD, 1975; PNUD, 1982) that are subject to widespread exploitation. These aquiferous levels are the upper Cretaceous, the Paleocene, the Continental terminal and recent coastal sands all separated by thick aquicludes.

PIEZOMETRIC READINGS

Well selection

The data on the location of water wells that tap the Paleocene were collected from the data bank of the Hydraulics Department of Togo; we selected a lot of data on the locations of water wells that tap the Paleocene. In order to obtain an optimal number of wells that would allow the establishment of an accurate piezometric map, mainly village wells (the latter are exploited and can therefore serve as water table observation wells), were sampled during field work done in march 2005.

Piezometric readings

A network of almost eighty water wells (Figure 2) was the object of static or dynamic water level readings using a BFK150 type piezometric probe fitted with a sound or visual light signal. Apart from this campaign which included all the wells that tap the Paleocene, seven other wells have been the object of periodic water table readings (once every month). The accuracy of the readings is in the order of the centimeter.

DATA PROCESSING

Data are subjected to a statistical analysis with Xlstat program (Fahmy, 2006). The coefficient of variation (CV expressed in %) is used as test of homogeneity of our results. The coefficient of variation obtained by eliminating aberrant values is equal to 29.7%.

$$CV = \frac{\sigma}{\bar{x}} \times 100$$

σ Standard déviation

$\bar{x}$ Arithmetic mean

When (Ossey et al., 2008):
CV < 2%, measures are very homogeneous,
2% < CV < 30%, measures are homogeneous,

CV > 30% measures are heterogeneous and are less representative of the area.

The measures of water depth in the wells only provide raw data that are not generally useable in this state and it is necessary to decode and analyze them before their using. The piezometric level (H), being the altitude of water level in natural equilibrium in the well, it is calculated based on the difference between ground elevation (reference at the well) Z, and the depth of water Hp, in the well (Castany, 1982).

$$H = Z - Hp.$$

We used Golden Software's Surfer and Microsoft's Excel softwares for processing the spatial state and the temporal evolution respectively of the water table.

RESULTS AND DISCUSSION

Spatial state of water table

An analysis of the piezometric map shows the presence. (Figure 3)

- of concentric curves in the west of the basin, in the area including Lome and its environs
- of more or less closed curves in the North-East between Tabligbo and the Mono river and
- of parallel and uniformly spaced isopiestic lines in the rest of the basin.

The anomalies observed in the piezometric curves indicate a depression in the South-West, and a dome in the North-East. In the depression, flows occur from the North-West toward the South-East, and from the North-East toward the South-West in the direction of the pumping areas. On the other hand, at the dome, the flows are divergent toward the East in Mono river direction, and toward the South according to the slope of the substratum.

The depression observed in the West of the area is reflecting the intensive pumping carried out in this area for diverse purposes in the town of Lomé and its environs. Losses through evapotranspiration are assumed to be negligible given the depth of the aquifer (OMS, 1972), which exceeds 50 m. It is thus noted that:

In the North of this western part, in the Tonoukouti area, Paleocene wells are exploited for agricultural land irrigation but also for supplying the riverine populations (Woeledji et al., 1996). This is the case of well F2 which yields a flow rate of 40 m^3/h, but also consistent for the village wells.

To the South of Tonoukouti, in the Toglekope area, the catchment area of the Togo Water Authority, where three wells are sunk and exploited to supply the town of Lome with drinking water, flow rates lie between 43 and 80 m^3/h.

In the extreme South, one finds the town of Lome where the Paleocene aquifer is under intense pressure. This intense exploitation gives rise to isopiestic curves that close up more and more. Thus, in the town of Lome, if the wells of private operators have not been inventoried it is known that there is high demand for the Paleocene

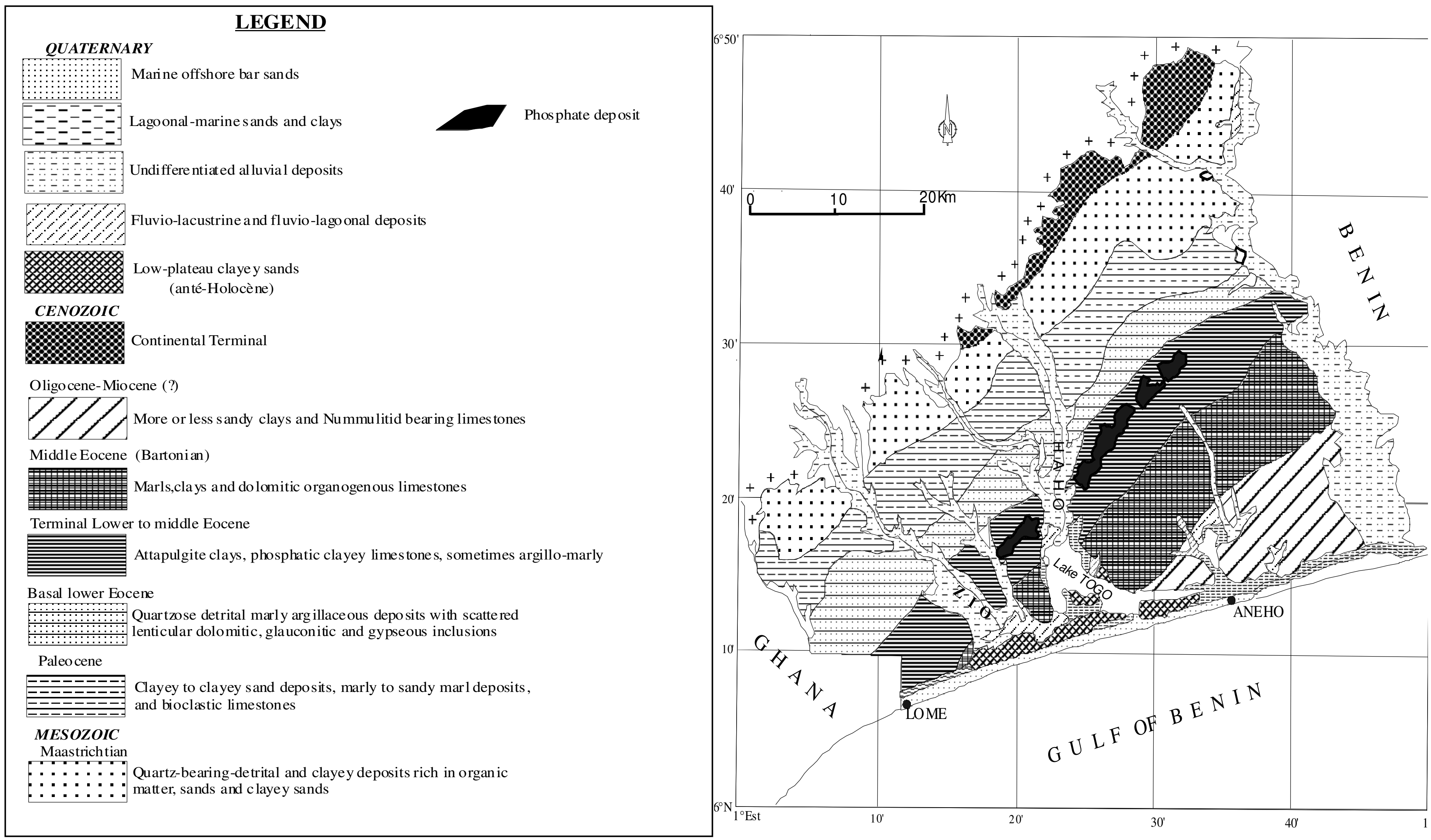

Figure 1. Geological map of coastal sedimentary basin of Togo (Sylvain et al. (1986).

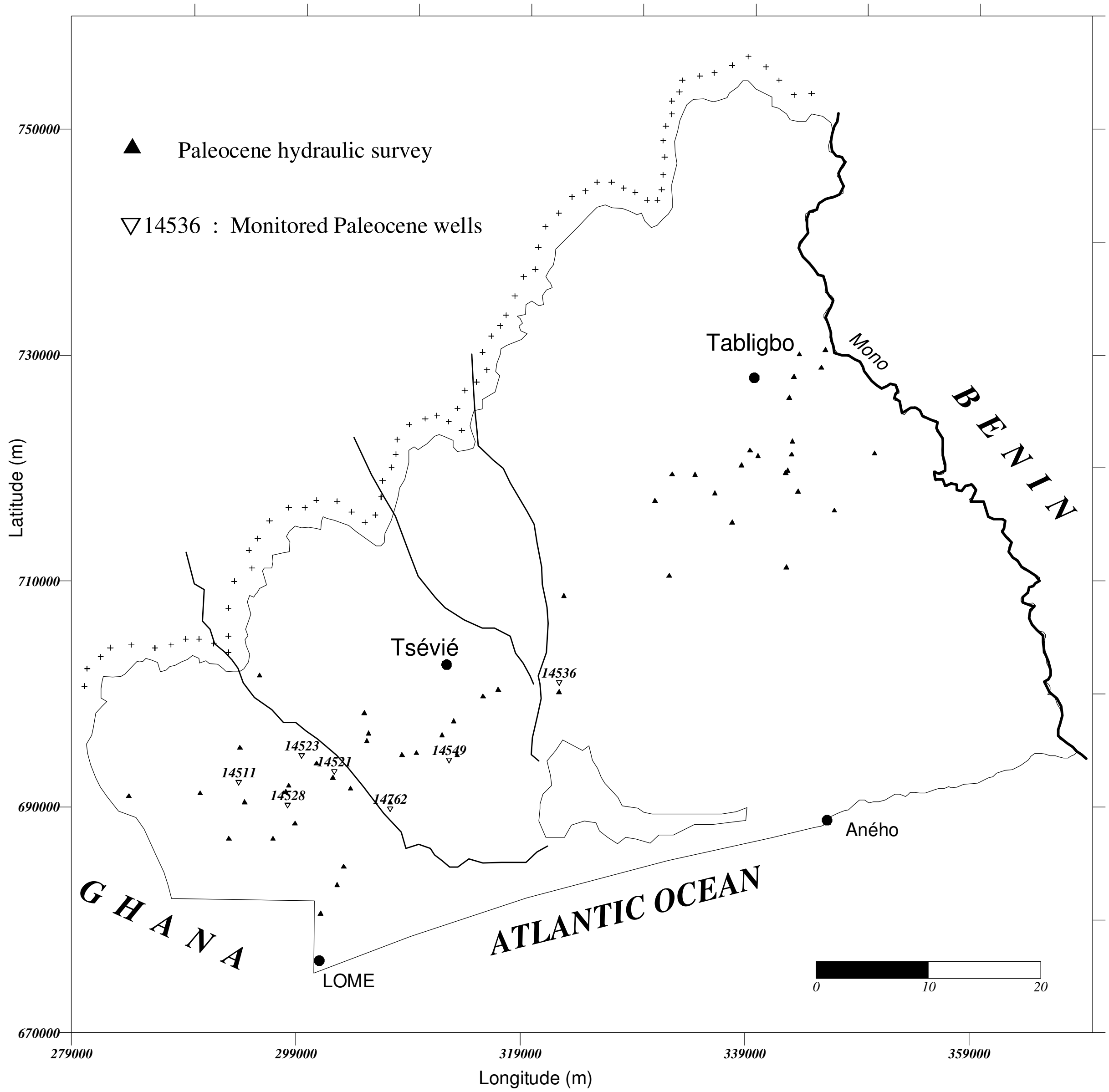

Figure 2. Piezometric network in the Paleocene aquifer.

aquifer by many public departments and industries for diverse uses. These include the wells serving the new presidential residence, the libyan embassy in Togo, the Social Security Office (CNSS), the Lome Airport Authority (SALT), the West African Advanced School of Theology (ESTAO), the Hospital at Tokoin (CHU) and the Amina factory.

The presence of the dome further North-East, with divergent flows could be the result of a catchment area with a shallow aquifer, but also because of the thinness of the clayey hanging wall. The effect of pumping in the eastern part of the study area is not noticeable due to the lack of intensive pumping in the Paleocene, since withdrawal by the TdE for supplying the drinking water to the urban centers at Tabligbo and Vogan is done from the continental terminal.

Apart from these two anomalies in the piezometric surface, (piezometric depression and dome) the water table in the rest of the basin is flat. Water flows here are from the North toward the South and are considered to be specific to the aquifer, because of the morphology of the substratum which plunges in the direction of the Atlantic Ocean.

The hydraulic gradients calculated from the flow lines (Table 1) in different parts of the basin are very low and vary slightly, thus indicating a homogeneous permeability in the white organogenous limestone.

These gradients are of the same order of magnitude as those obtained in the west of the basin (1 /1500) (Fahy and Honyiglo, 1974).

Table 1. Values of hydraulic gradients in the Paleocene aquifer

Sectors	Equipotentials	Gradient values
West of piezometric depression	11.5 à -4.1	1 ‰
East of piezometric depression	7.6 à 0.2	0.6‰
East of basin near Mono	12.8 à 7.6	0.3‰

Temporal evolution of the water table

We monitored monthly the evolution of the water table of the Paleocene aquifer, in order to better understand the changes in, and the main characteristics of its hydrodynamic operation.

Seven wells located in the West and in the center of the basin have been examined from May, 2004 to August, 2006 according to two hydrologic cycles.

Annual evolution of the water table

The observation period starts from the beginning of the rainy season in April and ends during the dry season in March.

The level of Paleocene ground waters generally varies during the year, and also from one year to the other. However, all the wells do not show the same variation (Table 2).

Fluctuations in the water table lie between 2.83 m (Agoè) and 0.66 m (Klobatemé) for the period 2003 - 2004. For the year 2004 - 2005, they vary from 0.66 m (Zéglé) to 2.5 m (Agoè). The variances for these periods are respectively 0.7 and 0.3. These values show that variations in the level of water table for whole aquifer are not spread out because of its confinement.

The wells that show high fluctuations are those located in the Northern part of the study area while the wells located more to the south fluctuate less.

Interannual evolution of the water table

We consider variations in the level of the water table over a two year period. Just as the seasonal variation in water table, one notes an interannual fluctuation in the water table. The heights of the water table fell from 3.45 to 1.17 m (Table 3). The highest amplitudes in water table variation are observed in the wells located in the northern part of the study area (wells 1-4528, 1-4511, 1-4521 and 1-4523). Be it the seasonal evolution or the interannual evolution, the water table variations observed could either be attributed to the draining of the shallow aquifers, or to the pumping carried out within the Paleocene aquifer itself. In both cases, the movements are largely superior to those observed in previous studies (BCEOM/BRGM, 1983) which estimate them to be hardly superior to 50 cm.

To understand these fluctuations observed in the Paleocene aquifer, we analyzed the existing relations between water table and effective rainfall; which is the quantity of water provided by rainfall and which remains available, on the ground surface after subtraction of losses by evapotranspiration (Castany, 1982).

The examination of the graph of the relation between effective rainfall and water table (Figure 4) provides the following remarks.

- There is no direct relationship between these two parameters in all the wells monitored.
- The graph of fluctuation in water table allows the distinction of two types of well: wells with a constant and stable water table over time, and those having very big water table variations.
- A continuous decrease in the resource in the wells located in the north of the study area. These remarks lead to the following interpretations:
- The absence of correlation between effective rainfall and water table shows that there is no direct recharging of the aquifer by rain;
- The rise in the water table in some wells can be explained by the abundance of effective rainfall recorded between May, 2004 and June, 2005;
- The wells with large fluctuations are located in the North of the study area while those with small fluctuations are located in the southern part. If the latter are located in a totally confined area with no relation with other aquifers, it is not true for the former.
- In those wells, where no relationship exists between water table and rainfall, an increase in the level of the water table probably results from charging by adjacent aquifers. On the other hand, a lowering of the water table could be the result either of withdrawal from the Paleocene itself or of variations occurring in the continental terminal. Thus, a lowering of the level of the water table in the Continental terminal could trigger the same in the Paleocene, while a rise could provoke a similar reaction.
- This method of recharging the Paleocene aquifer shows that it is composed of two parts:
  - a northern semi-confined part which is connected to an unconfined upper aquifer of the continental terminal that charges the former; this hypothesis was proposed in studies carried out in Ghana (Akiti, 1980).
  - a totally confined part in the south that is isolated from the continental terminal.

Conclusion

A spatial water table study has clearly shown the effect of pumping on ground water level in the town of Lomé and

Table 2. Seasonal evolution in water table.

Wells	14523 Alinka	14549 Zéglé	14528 Anonkui	14536 Akodesséwa	14762 Klobatémé	14521 Zongo	14511 Madjikpéto	Min	Max	Variance
amplitudes 2003 - 2004 (m)	1.97	1.00	2.77	0.94	0.66	2.83	1.95	0.7	2.8	0.7
amplitudes 2004 - 2005	1.00	0.62	1.22	0.90	1.15	2.50	1.09	0.6	2.5	0.3

Table 3. Interannual fluctuations in water table.

Wells	14523 Alinka	14549 Zéglé	14528 Anonkui	14536 Akodesséwa	14762 Klobatémé	14521 Zongo	14511 Madjikpéto	Min	Max	Variance
Annual amplitudes (m)	2.41	1.56	3.45	1.17	2.22	3.41	2.80	1.17	3.42	0.7

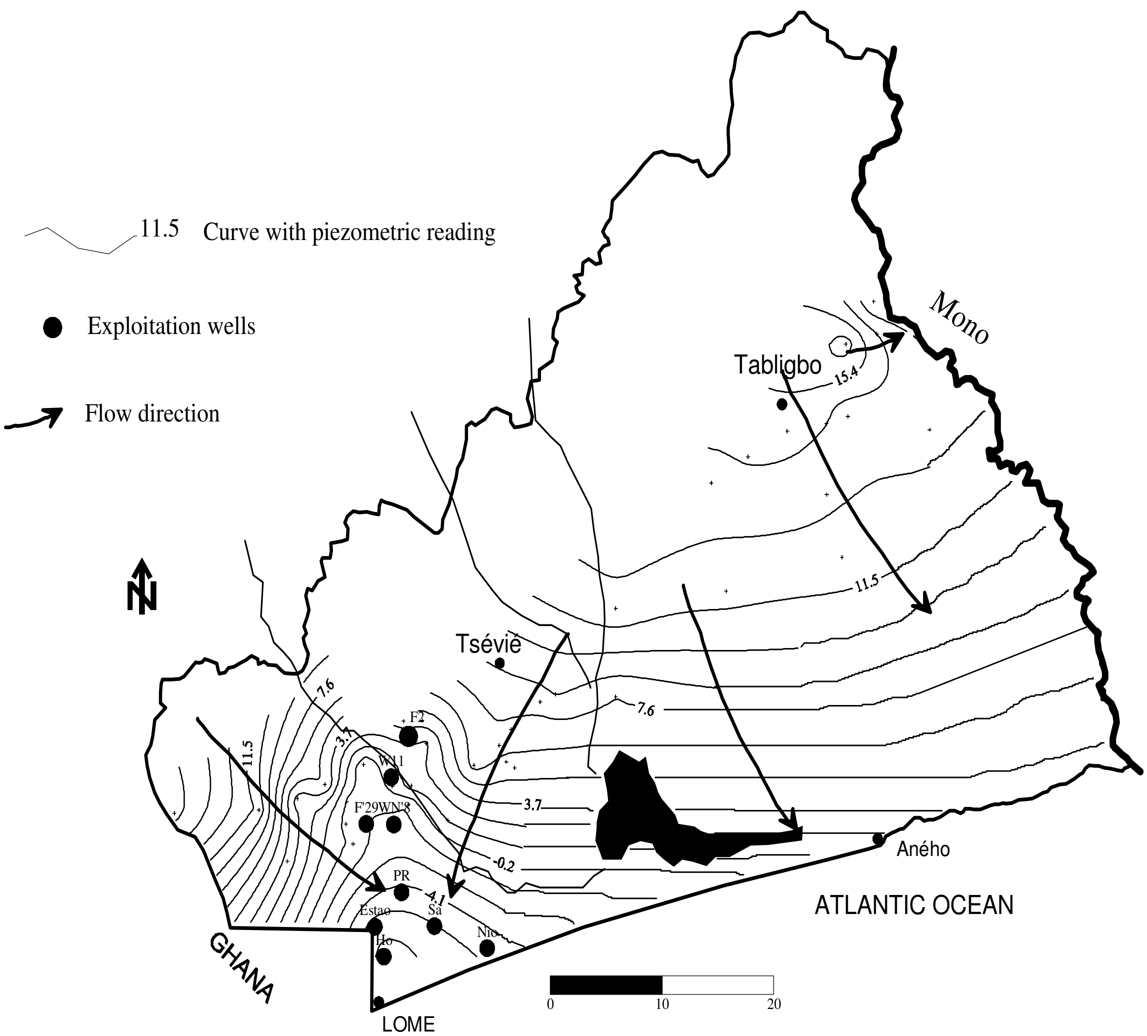

Figure 3. Piezometric Map For March 2005

its environs. In the rest of the basin, water flows occur in the direction of the sea which constitutes a natural outlet for the aquifer. The low hydraulic gradients indicate a high permeability. The graphs showing the relationship

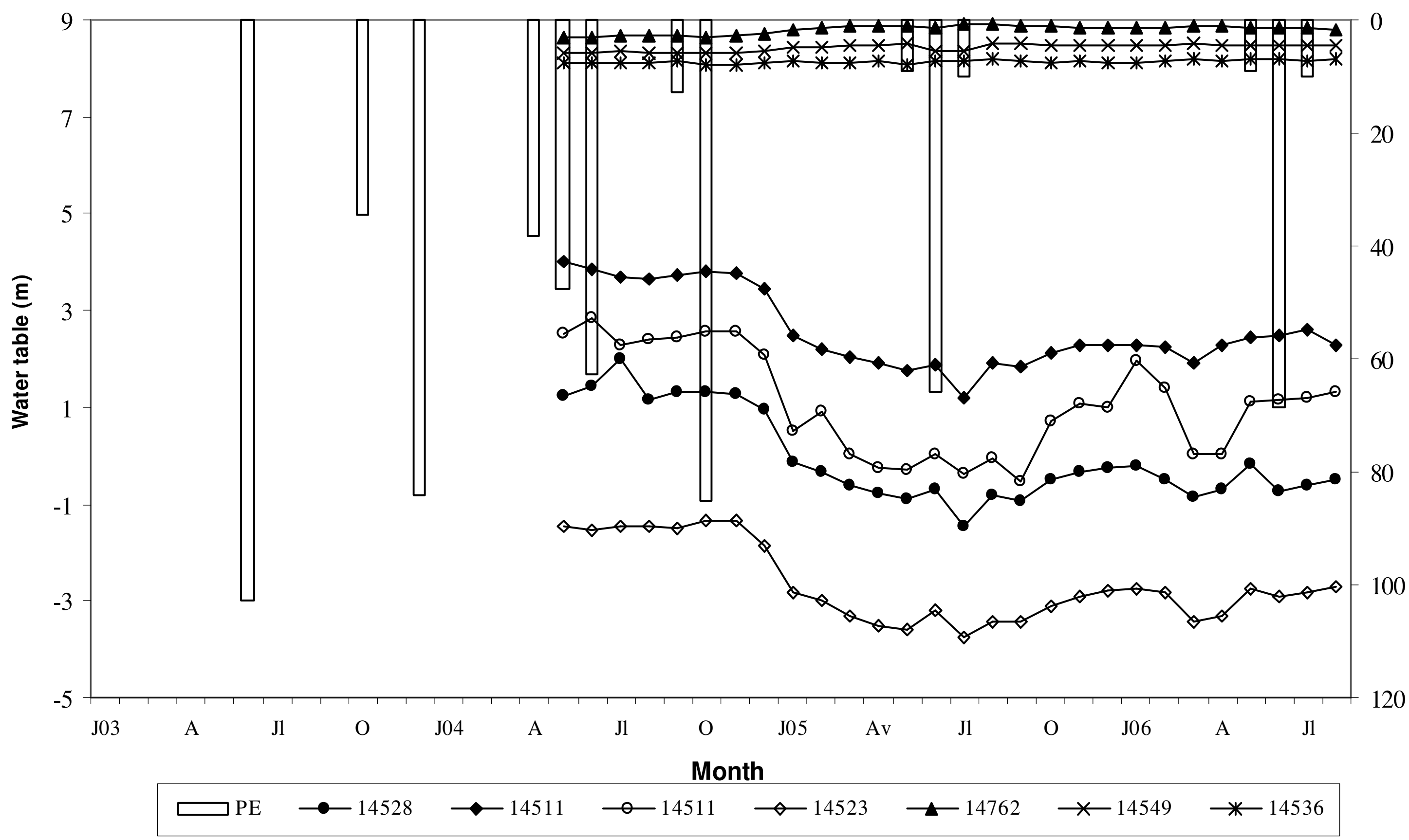

Figure 4. Relationship between

between water table and rainfall show that the aquifer is not directly charged by rainfall but by adjacent aquifers. The temporal observation of the water table during these last two years shows a continuous decrease in the resource in the North-West of the basin.

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