Available online www.jsaer.com

***Journal of Scientific and Engineering Research*, 2019, 6(10):173-184**

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

Impact of the Seasonal Variability of the Rains on the Hydrodynamic Operation of the Aquifer Major of the Plateau of Mbe in Pool-Nord in Republic of Congo Brazzaville

H. Obami-Ondon[1*], U. Gampio Mbilou[2], Raymond Gentil Elenga[4], Médard Ngouala Mabonzo[3], D. Nkounkou Tomodiatounga[1], B. Mabiala[1]

[1]Laboratoire Mécanique, Energétique et Ingénierie, Ecole Nationale Supérieure Polytechnique, Université Marien Ngouabi, B.P. 69 Brazzaville, Rép. du Congo.
*harmelobami@gmail.com
[2]Département de géologie, Faculté des Sciences et Techniques, Université Marien Ngouabi, B.P. 69 Brazzaville, Rép. du Congo
[3]Département de géographie physique, Faculté des Sciences Sociales et des Arts, Université Marien Ngouabi, B.P. 69 Brazzaville, Rép. du Congo
[4]Département de physique, Faculté des Sciences et Techniques, Université Marien Ngouabi, B.P. 69 Brazzaville, Rép. du Congo

Abstract This study aims showing the existence of a seasonal variability on the level of the plateau of Mbe and at including/understanding its impact on the food of the aquifer deep of this area. With this intention, various data of precipitation of the synoptic stations of Brazzaville and Djambala of year 2017 and 2018 were used. The monthly piezometric follow-up campaigns during the water resource year, between September 2017 and August 2018 with a network of four (04) drillings, a well for subterranean water and three (03) rivers for the water levels were carried out. The harvest of these data, enabled us to see the fluctuation of the ground water compared to the rains. With the measured piezometric data and supplemented by that of the village hydraulic project. We made an interpolation with the software surfer 13, in order to establish a first piezometric chart of the area. This study also shows us, that the ground water is into perfect balances, drained (direction of flow) by the large rivers which notch this plate, in particular: Léfini in north, river-Congo in the east and the south and finally, Louna in the North-West and Maty-Djiri in south-west. This drainage ensures the perenniality of these rivers during all the water resource year. Lastly, the variation of precipitations does not affect in a visible way piezometry because the great thickness of the not-saturated zone which causes the effects delayed on the ground water. Precipitations on the area being considerable during the water resource year, makes it possible to guarantee the perenniality of the resource.

Keywords Seasonal variability, hydrodynamic operation, aquifer major, Plateau of Mbe, Pool-North-Congo

1. Introduction

For the man, the subterranean water constitutes a vital resource, in particular in the arid and semi-arid areas where the surface water is not always perennial and is vulnerable to pollution. The subterranean water is generally drinkable with the source and is available on the spot. So it is the most important source of drinking water for the rural communities. This report is made in African rural environment where the populations are supplied primarily starting from the pumps with human motricity (PMH) installed to equip drillings and of the traditional wells which are often temporary [1].

In Congo-Brazzaville, in the plateau of Mbe (fig. 1), water is major factor limiting, on the one hand, for agriculture, the breeding, industrial development, etc And on the other hand for the food of the populations which leave the districts of Brazzaville-North because of erosions, stranding and the floods to settle there [2]. The plateau of Mbe, in spite of the semi-arid climate conditioned by these permeable geological formations, the problem of water arises in terms of development. The scarcity of surface water and the non perenniality of this resource surface due to the geological conditions mentioned supported the use of the deep ground water like palliative to satisfy the requirements out of water for this population. The plateau of Mbe has an important aquiferous potential. This water tank is widespread in practically all plateaux [3]. This ground water is fed primarily by the infiltrations of rainwater in the ground. They accumulate in bateke sands, filling the least vacuum, saturating with moisture the basement, thus forming a deep subterranean water tank called aquifer of the plateau of Mbe. Unfortunately, this aquifer has never been the subject of a piezometric follow-up to see the influence of the rains on this deep ground water. The hydraulic system of the zone of study consists of several perched ground waters not very productive, the marshes and the deep aquifer.

The question of water about the Bateke plateaux was put for a long time on about the quantitative and qualitative plan being given the lack of water points surface, bad water quality in and many cases their draining in dry season [3]. Several reports/ratios review this situation: [4-9] and reports of some projects. But, there does not exist any study detailed on the impact of the variability of the rains on the deep aquifer of Mbe. It is thus advisable to know and follow the static level of this aquifer according to the seasons.

This present work aims to study the impact of the variability of the rains on the deep aquifer of the plateau of Mbe. With this intention, the campaigns of measurements of the static levels were undertaken during one hydrological year. These measured piezometric levels, were useful for: (I) establishment of the first piezometric chart of the plateau of Mbe and (II) a comparison between the variations of the static levels and the data of monthly average precipitations of the synoptic stations of Brazzaville and Djambala, in order to apprehend the impact of the rains on this deep aquifer.

2. Materials and Methods

2.1 Presentation of the zone of study

The department of the Pool is located in the southernmost part of the Republic of Congo.

It is limited to North by the Léfini river; in the East by the Congo river; in the South by the Congo river and the Democratic republic of Congo (RDC) through the watersheds of the plateaux of the cataracts. In the North-West by the river Bouenza (Lali); in the West by the river Ndouo (Niari).

Administratively, the department is limited to North by the Plateaux; in the East and the South by the Democratic Republic of Congo; in the North-West by the department of Lékoumou and in the west by the department of Bouenza.

The zone of study, which is not other than the plateau of Mbe (Fig. 1) lies within a broader geographical scope. It belongs to a whole of the plateaux which resemble each other enormously: the natural landscape is the same one except for nuances: [4-5]; the inhabitants all are of Batekes authentic. They are the Batekes plateaux. However the plateau of Djambala and that of Nsah are almost as deprived of inhabitants as that of Mbe. This triple correspondence seems to lead to a simple explanation of the deficit of settlement, feature common to the three plateaux. One immediately thinks of accusing, either the medium exploited by Batekes, or the techniques which they use. The first could not lend itself to a sufficiently productive farm for many men. One can suspect as well Batekes of exploiting their plateaux in a so ineffective way as it would result in a great wasteof surface. However, the lack of the water points (river) on this vast wide can also be a reason, because to build a village or a city one seeks before a whole point of water provision. But there exists a fourth plateau, the Koukouya plateau. Completely similar to the others, its reduced dimensions do not prevent it from carrying a population of more than 10.000 inhabitants that is a density of 20 hab /km^2 approximately, one of strongest of Congo. This aberrant fact shows that the things are more complex than it appeared at first sight [10].

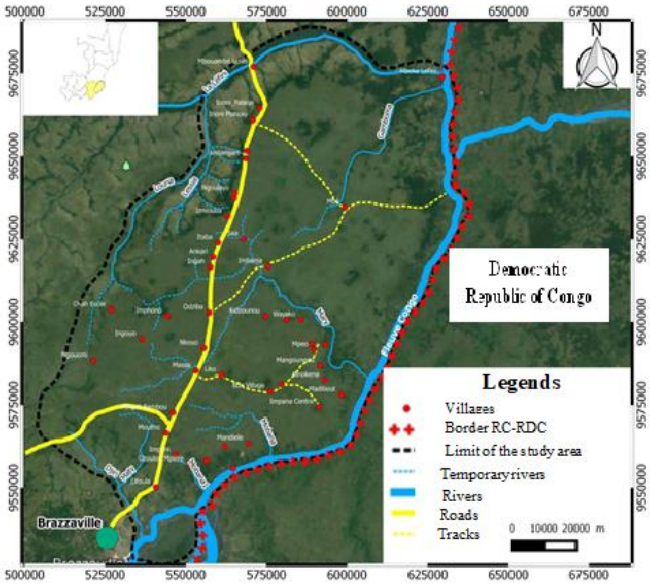


Figure 1: Presentation of the zone of study

2.2. Climatic framework

The local climate belongs to the southernmost Congolese sector of the Guinean subequatorial field, intermediary between the Guinean-forester field and the field soudano-Guinean [11]. It is characterized by:

• a relatively constant and low temperature due to altitude (annual average: 23°C);

• a high relative moisture (annual average: 78%) with a tension annual average of least low vapor of Congo.

One 3 months marked dry season, where the freshest temperatures of the year appear (of 13° with 16°), a rather strong pluviometry annual passing 1.500 mm (sector of Mbe) to 1.700 mm (sector of Odziba) and distributed over approximately 100 days [11].

2.3. Geological framework

The geology of the zone of study (fig. 2) belongs to the geological unit of Congo called: Batekes plateaux.

The Batekes Plateaux correspond to an immense plate reaching 700 m of altitude, which extends as far as RD-Congo [12, 13], subdivided in several small plateaux (Djambala, Koukouya, Mbe…) by deep rivers such as Alima, Mpama, Léfini, Nkéni… These deep rivers show a prevalent orientation parallel with taking down faults NE-SO.

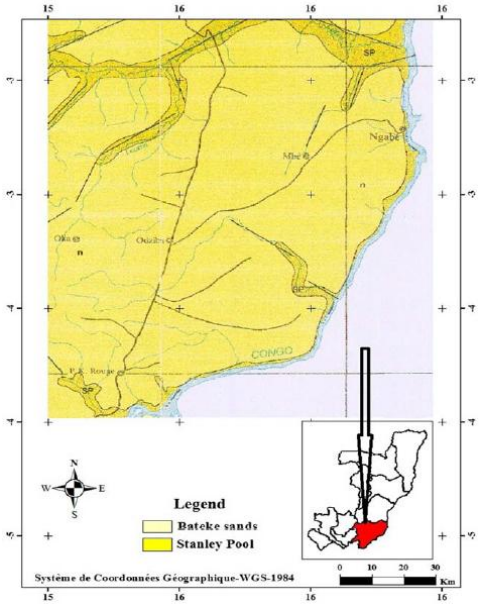


Figure 2: Geological map of the zone of study (H. Obami Ondon et al., 2018)

2.4. Framework hydrogeologic

Mass of the tender likings of the plateauxbateke form an important subterranean water tank. This tank is supplied by the vertical infiltrations which constitute a significant proportion of precipitations. As there does not exist any side trap, there is a continuous flow on the circumference of each plateau and their removed topographic positions make very difficult the use of stored water. The sector of the sources of Mary and Gamboma (fig. 1) is however privileged, but a full hydrogeologic study would be justified only within the framework of a project of development of there zone [3].

In his study on the model of sandstone, M. Minguet [14]; shows the staged provision of the water tables locked up inside the sandy layers by levels of less permeability. The circulation of water, from top to bottom, between these ground waters is done via the plan of dip and the diaclases. Only the higher ground waters are fed directly by precipitations. It results from it strong oscillations of their piezometric surface in areas at marked dry season, on the other hand, the deep ground waters have a practically permanent flow.

This assumption is confirmed by the drillings carried out on the Koukouya plateau (at the Tchoumou village). In their respective work, [9] and [3]; concluded on the existence of an important deep ground water at the base of the plateaux and small ground waters perched with a depth close to 50 Mr.

If not, in a general way, as mentioned in the introduction, the hydraulic system of the zone of study consists of several perched ground waters not very productive, the marshes and the deep aquifer.

2.5. Experimental method

The interest to carry out the series of measurements of the static level is to obtain piezometric charts and the variation of the static levels on the studied sector, in order to compare them with monthly average precipitations of these stations. The stations of Brazzaville and Djambala were chosen for lack of station synoptic on the zone of study. This choice was based on the points hereafter:

1) the station of Brazzaville, compared to the proximity with the zone of study and

2) the station of Djambala, because it is on a plateau which shows the same physical characteristics, geological and climatic of the zone of study.

Initially, the whole sector was subject of a census of forty seven (47) drillings of the project “Water For All”, entirely financed by the Congolese State and those of the private individuals for their small economic activities. From this census, we classified drillings by three (03) categories which are the following ones: (I) drillings in exploitation, (II) technique broken down drillings and (III) drillings without pumps, for reasons which we are unaware of. After this classification, we retained the category (III) for this study. In the category (III) of drillings without pumps, four (04) were retained like piezometers for the follow-up of the deep ground water during this study.

2.6. Network of measurement

It should be noted that prior to this study, no piezometric monitoring of the aquifer had ever been carried out due to the lack of significant number of structures that capture the deep aquifer. In addition, the depth of the rivers does not exceed 1 m. That did not have any importance in our work (Table 1). Because the water level should be observed starting from the limnimetric scales installed for this purpose.

Table 1: Geographical references of the works selected

District	Country	Longitude (decimal degree)	Latitude (decimal degree)	Altitude (m)	deep (m)
Ignie	Moutho (Drilling)	15.3950556	-3.92144444	720	347
Ignie	Yie (Drilling)	15.4065	-3.90080556	711	363
Ngabé	Inkaon (Drilling)	15.5281944	-3.43541667	697	206
Ngabé	Itaba (Drilling)	15.5393889	-3.40591667	683	217
Ignie	well (Ignie)	15.39438056	-3.98889166	715	3,40
Ignie	Maty (River)	15.33968056	-3.94544166	444	deep<1
Ngabé	Gamboma (River)	15.88034444	-3.28915	493	mwhere are
Ignie	Mary (River)	15.64360833	-3.22717222	528	placed the limnimetric scales.

As part of our work, a network was established starting from drillings selected of the village hydraulic project "Water For All" (Table 1; Figure 3), information of that project and a prospection campaign on the ground was carried out. For this study, four (04) drillings (fig. 4a), one (01) well and three (03) rivers for the water level were regularly monitored for 12 months (Table 1). The piezometers were selected on criteria of depth, lithological cut, use, design and accessibility [15]:

- Depth: the depth of the work must make it possible to remove any ambiguity on the aquifer reached. One avoids consequently works of depth intermediate (between 150 and 200 m) which cannot collect or cross correctly the deep ground water, or both following sectors.
- Lithological cut: In the best of the cases, one reaches a lithological cut of the survey. Its presence, its quality and its coherence with the geology of the sector can be regarded as pledges of quality of the other information collected on the structure.
- Use: the measurement of the level of water requires that the structure be seldom requested or for short pumpings, so that the measured level is close to the level at rest. In our case, for lack of piezometers, we had used the works without pumps, therefore drillings which are at rest since the realization.
- Design: the head of the structure must allow measurement, i.e. the passage of a piezometric probe. The selected structures answer this requirement.
- Accessibility: the agreement of the owner or the administrative organization is essential. On this point, we had requested and obtained the written authorization of exploitation of the structures and the data of the project "Water for All" from the ministry of major structure.

All the points of measurement were continuously monitored, the rivers and the well on a daily basis and drillings each month, with a sound luminous probe of 300 m (fig. 2.4c), the meter-ribbon for the well (fig. 2.4d) and the limnimetric scale of IRSEN for the rivers (fig. 2.4e). But concerning the Gamboma river, the limnimetric scale is filled by the sediments, we took as point of measurement the bridge (fig. 2.4b). The piezometric statements are all done in the opened well, drillings, river, at well defined hours of the day: very early in the morning, and morning-evening for the wells (between 8:00 - 10h and 17:00) before the exploitation of the aforesaid structure, that is between 08 hours and 10 hours for the rivers and drillings, period during which the structures are in static situation. It should also be noted that there is a heterogeneity in the space distribution of the points of measurements due quite simply to the geographical location of the various villages and river such as shows figure 3.

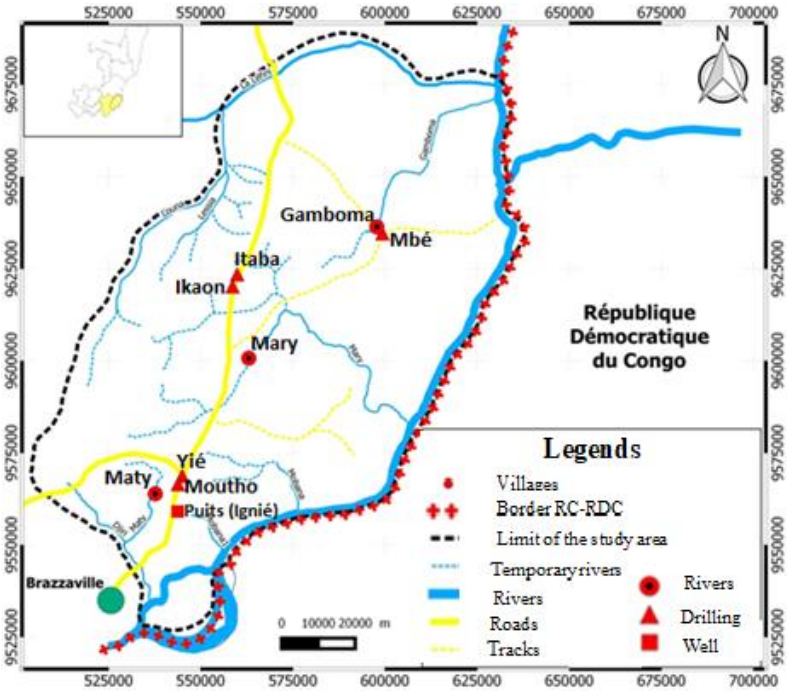
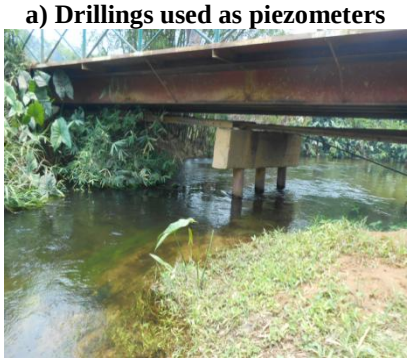


Figure 3: Chart of localization of the points of measurement

a) Drillings used as piezometers



b) Bridge on Gamboma

c) the sound luminous probe of 300 m

d) The decametre

e) The limnimetric scale

Figure 4: Materials used

3. Results and Discussions

During the hydrological year from September 2017 to August 2018, a measurement was taken each month, on the whole drillings of our network (Table 2). On the other hand rivers weekly and the well daily. After analyzing the daily data of the rivers, which we noticed the increase of the water level after the rain, that water returns to its initial level a few hours later. Since, the rivers do not know a variation in days; we have used the monthly average without introducing important skews. Then a monthly average was calculated to the measures of the

water level of each river in order to include/understand the fluctuation between season. After observation of the deep ground water, the annual minimal level is observed between August, July and September, and the maximum level is reached between October and March, (Figure 4 and Table 2). A low annual amplitude of 30 cm was recorded on the level of all the piezometers of our network, except for the drilling of the Inkaon village which has the annual total amplitude highest (60 cm). This fluctuation which is not very important, enables us to say that, the ground water is in balance during every season. It is also requested in the whole of the area of study.

Table 2: Piezometric variations (m) and precipitation (mm) monthly 2017-2018

Mois / Village	Sept.	Oct.	Nov.	Déc.	Jan.	Févr.	Mars	Avril	Mai	Juin	Juillet	Août
Moutho (m)	**-197.65**	-198	-198	-198	-197.8	-197.8	-197.8	-197.9	-197.9	-197.9	**-197.65**	**-197.65**
Yié (m)	**-170.3**	-170.6	-170.6	-170.6	-170.6	-170.6	-170.6	-170.55	-170.55	-170.55	**-170.3**	**-170.3**
Inkaon (m)	**-159.5**	-160.1	-160.1	-160.1	-160.1	-160.1	-160.1	-160	-160	-160	**-159.5**	**-159.5**
Itaba (m)	-168.15	**-168**	**-168**	**-168**	-168.2	-168.2	-168.2	-168.3	-168.3	-168.3	-168.15	-168.15
Station de B/V	31.7	153.9	272.3	193.2	154.7	137.6	187.7	162.4	127.1	17.9	12.2	12.0
Station de Dja.	109.5	257.9	284.2	217.7	176.6	184.5	228.6	249.7	181.8	38.6	14.1	38.1

Source of precipitations of the monthly averages: ANAC of Brazzaville

Analysis of the evolution of monthly piezometry (fig. 5 B; table 2) makes it possible to understand that, the refill could be done during the dry season between July and September. It is the months during which the water level in the piezometer of the Inkaon village seemed to increase. This logic indeed testifies the power to the geological formations which compose the plateauxbateke and to the processes of percolation from surface.

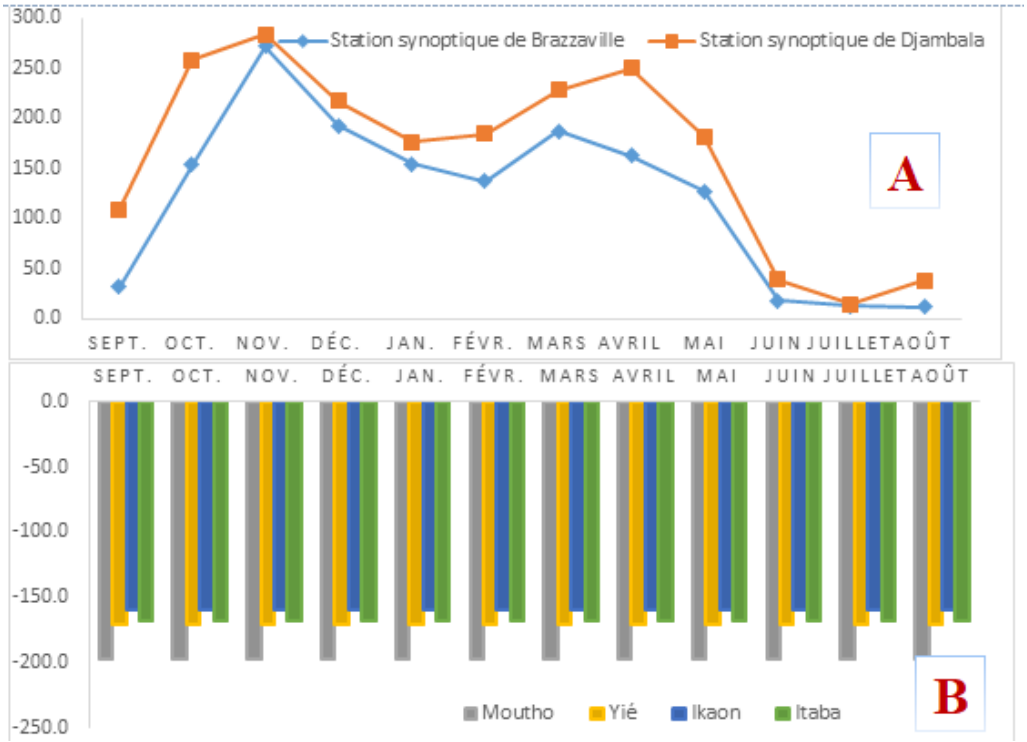


Figure 5: A-Monthly average Have-variations of precipitations (mm) and B-piezometric (m) of the ground water from Sept. 2017 in August 2018

It appears immediately that the amplitude of the variations of the piezometric level is low during the year, compared with the thickness of the aquiferous section which could be between 175 with 350m in the zone of study.

The structures of our network have stable levels during the year. Thus, by observing figure 5 has and B, we could think that, the variation of precipitations does not influence directly the deep ground water of the zone of

study, but this delayed effect would be due to the geological conditions which are essentially constituted of sands and of the intercalations of sand-argillaceous and of the sandy-clay. In a general way, a seasonal variation was observed clearly during the great dry season (July, August and September), that can be appreciated in table 2. This variation is marked by a small increase which starts before the season of the large rains, as of October. This strong buffer effect can be explained by the great thickness of the zone not-saturated at the roof of the aquifer, about 200 meters on average on this sector. This unsaturated zone allows the storage of water of the rains, without significant transfer to the zone saturated because of the less permeable intercalations of levels which induce the presence of the more or less temporary perched ground waters. Consequently, one can note that the piezometric level of the aquifer major of the plate of Mbe would be in balance (Fig.5 B). Moreover, the homogeneity of the piezometric variations in these two piezometers attests hydraulic continuity of the aquifer deep on a plateau scale.

It is noted finally, that the variation of precipitations do not affect in a visible way piezometry because of the great thickness of the not-saturated zone which causes the effects delayed on the ground water (Fig.5 B).

3.1 Comparison with the well of Ignie

In order to compare with the not very major and not protected structures, the well of Ignie (depth 3,40 m) was monitored in a daily basis (Table 3). The results made it possible to observe the seasonal variation of the level of this surface ground water (Table 2.3). This surface ground wateris not met on all the surface of the zone of study. It assure to the theory of [3], who thought that there exists a aquifer not very deep upstream of each river of the plateau of Mbe. As this assumption suggests it, downstream from this well, we have a river which takes source with a few km from there that one calls Mobana.

Table 3: Monthly variations of the level (in cm) of the well of Ignie

	Sept.	**Oct.**	**Nov.**	**Dec.**	**Jan.**	**Febr.**	**March**	**April**	**May**	**June**	**July**	**August**
Synoptic station of Brazzaville (mm)	31.7	153.9	272.3	193.2	154.7	137.6	187.7	162.4	127.1	17.9	12.2	12.0
Synoptic station of Djambala (mm)	109.5	257.9	284.2	217.7	176.6	184.5	228.6	249.7	181.8	38.6	14.1	38.1
Well 45 (cm)	-313	-192	-85	-96	-88	-82	-131	-118	-119	-187	-248	-281

Source of precipitations of the monthly averages: ANAC of Brazzaville

While, in the well of Ignie the level drops considerably between July, June, August and September (fig. 6; 7); the deep ground water could be reloaded or remain in balance. This report confirms the hydraulic independence of the two systems, at least on a seasonal variation scale. We can rather confirm that this ground water is fed directly by rainwater, such as testifies his variation according to the monthly averages to pluviometry on the two synoptic stations (figure 7 A). I.e., between October and May, the ground water is saturated (Fig.6a), on the other hand, when the rains cease falling, the water level decreases considerably in the well (Fig.6b).

The curve of the chronicle of the water level in the well, correlates well the curve of the variation of monthly average precipitations (fig. 7 A).

a) Countryside Nov. 2017 (great rain season)

b) Countryside August 2018 (great season dries)

Figure 6: The difference of the water level in the well between the two great seasons.

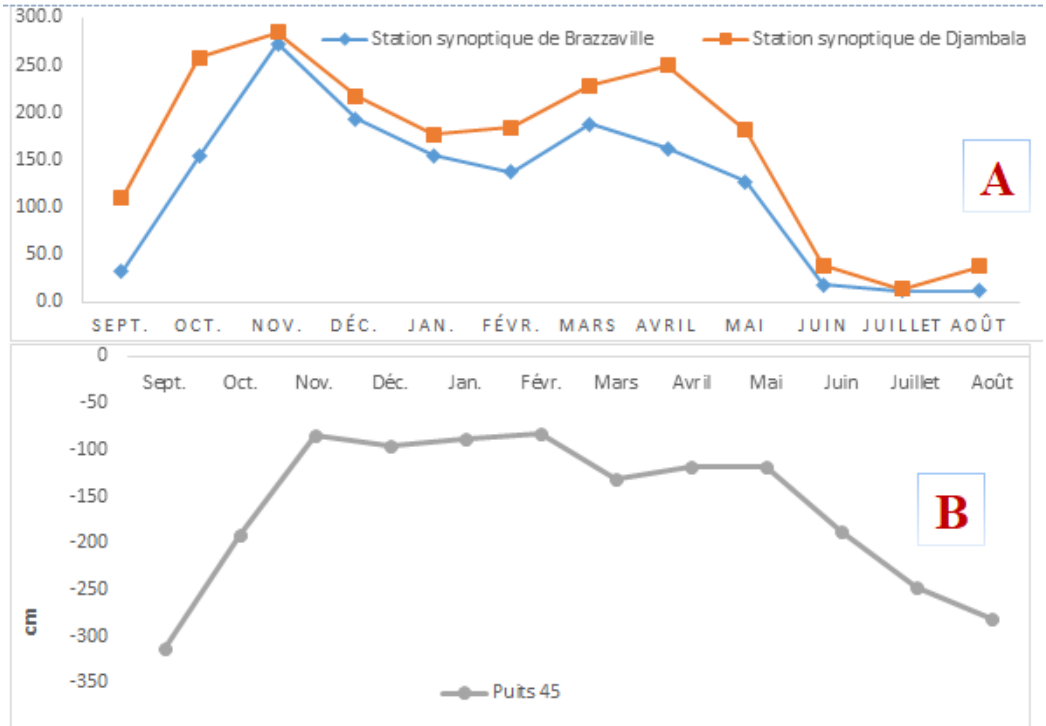


Figure 7: A-monthly average variations of the rains (sept.2017- August 2018).
B-Water level in the well (Seven 2017 in August 2018).

3.2. Variation of the water level in the rivers

Analysis of the annual events (that is to say four seasons between 2017 and 2018) shows that the average response time of the rivers following the rainy episodes is rather short; the water level starts to rise increase a few hours after the rain. Such an increase in the water level is more visible with the level of the daily data and a few hours afterwards, they find their regular levels. This buffer effect which almost does not have importance enabled us to work with the monthly averages for a good seasonal appreciation (Fig.8). Indeed, the increase by the rain is often masked on the level of the Gamboma river where the increase or the fall of the water level is forced by the arrivals of sands which come to fill the bed of the river, because at this point, we took as item zero the bridge (Fig.4b).

Table 4: Monthly variations of the level (cm) of water between 2017-2018

Names	Sept.	Oct.	Nov.	Dec.	Jan.	Febr.	March	April	May	June	July	August
MARY	60	60	61	61	61	60	62	66	70	68	64	59
MATY	69	70	70	72	70	70	69	69	70	69	69	68
NGAMBOMA	-148	-153	-186	-185	-140	-148	-134	-120	-132	-81	-129	-149

One realizes that Mary, Maty and Gamboma in spite of the filling of the bed by the sediments (sands) which come on both sides are remarkably regular and perennial all the year. Indeed, the average dimension on the scale oscillates between 60 and 70 cm and a lower average of 59 in August for Mary (Table 4). On the level of Maty, the average dimension is between 69 and 72 cm, of which the lowest average is observed in August. Lastly, Gamboma, does not present a clear situation, because of silting (fig. 8 B), but remains regular all the year like the others.

It should be noted that the three rivers followed on the zone of study are stable and regular during all the water resource year and the regularity of these rivers, confirms the study of [16]. We can also say as, the rain does not influence truly the water level in the rivers, but it causes a short rise of the water which immediately finds its level after the rain. The oscillatory movement of Gamboma is influenced by sands which fill the bed at the point of measurement (fig. 8B).

Concerning the flows of these rivers, we were satisfied with the results obtained by [16] between April and October for lack of material. These results reveal that the medium flow of Gamboma with Mbe oscillates between 3.90 and 4,41 m^3/s. On the other hand, Mary between 1.05 and 1.23 m^3/s. unfortunately, this study did not take into account Maty. But Maty could have well a flow more raised than the two others.

These values prove clearly that, these rivers do not experience the low water level. According to [16], these oscillations represent the variations of the level of the ground water and highlight the regular role of this one.

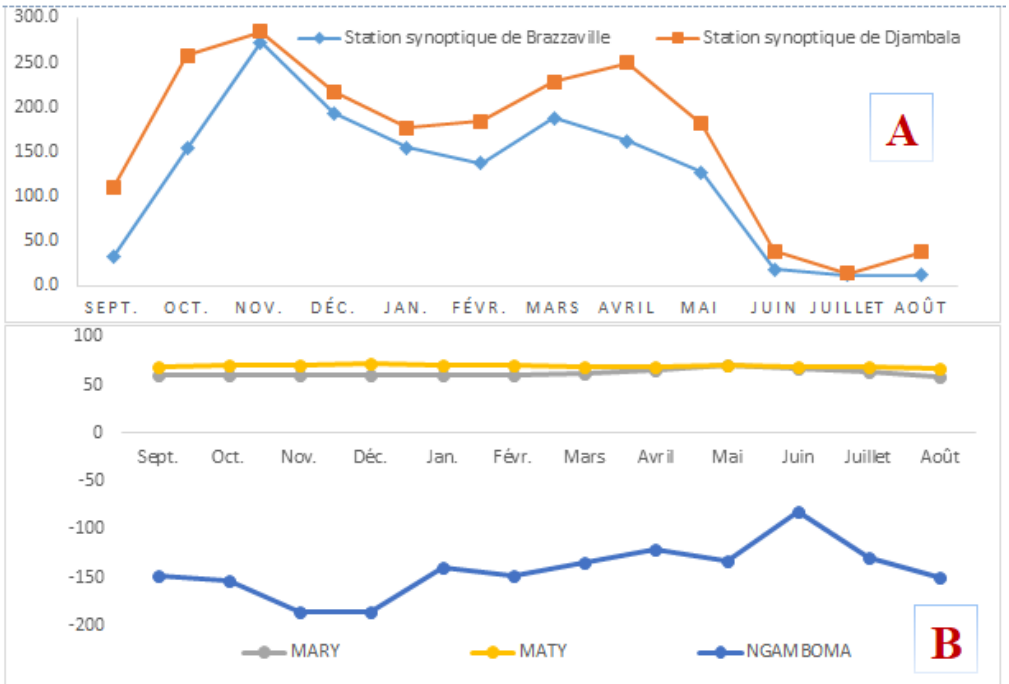


Figure 8: A- Monthly average variations of the rains (sept. 17- August 18).
B- Water level in the rivers (Seven 2017 in August 2018)

3.2. Piezometry

After the monitoring of the hydrological year, the ground water presents a weak variation, less than 60 cm. In comparison with the stability (weak variation) of the ground water (Table 2), we could establish only one piezometric chart, by supplementing the data with those measured during the year 2015-2016, during the realization campaign of drillings by the company ASPERBRAS-Congo (Water Project For All). This chart must be considered with precaution because of the nonhomogeneous distribution of the points of measurement on the zone of study. Figure 5 locates the dimensions of the zone of study between 550m at the center and the west, and 600m in the south of the zone of study.

The general flow of the ground water is done according to a radial direction, which goes from the center of the zone of study towards north-north, the North-East and the North-West, foreseeable gravitating flow taking into account the slope of the substratum certainly. This direction of the flow towards north, perhaps explained by the two following elements: the Léfini river and the Congo river which drain probably the ground water. In the southern zone, it would be drained by the Congo river and the Djiri river. Moreover, one transverse profile was traced which testifies to the convex shape of the ground water of the plateau of Mbe confirming thus the results of [3, 17-19] (fig. 5).

The monitoring of the levels of the deep aquifer confirms the hydraulic continuity of the aquifer on a plateau scale by showing a similar balance in all the points. In general the level varies little during the year (less than 1 m) and the main part of the seasonal variations would be related to water of the rains which infiltrate on all surface. This evolution is particularly marked in the north of the plateau of Mbe (Inkaon village), in the sectors of weak exploitation. The levels in other sectors are more stable. The aquifer is in perpetual stability and does not undergo quasi any pumping.

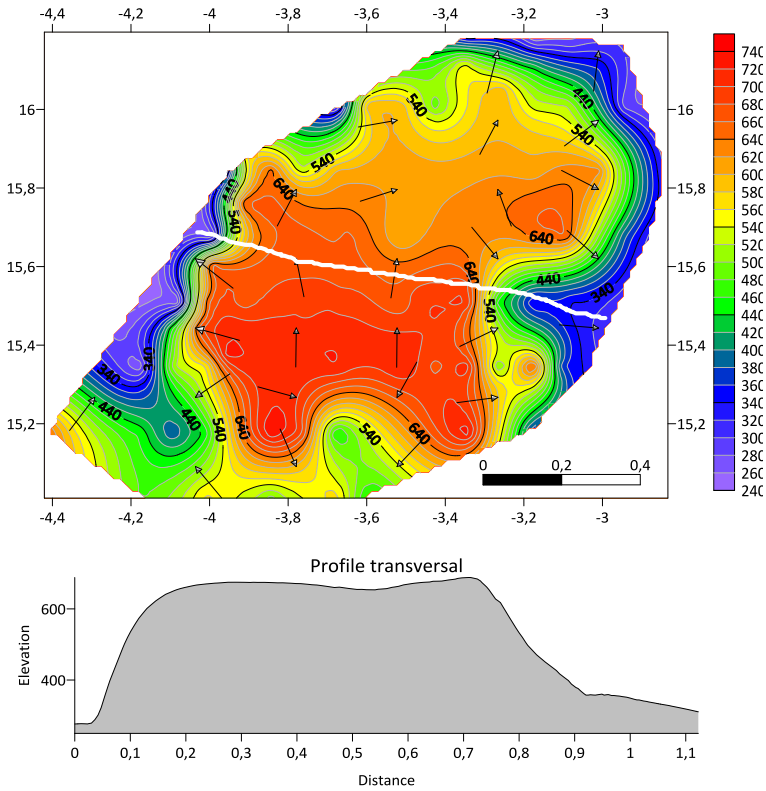


Figure 5: Piezometric chart and transverse profile of the zone of study

4. Conclusion

The piezometric level is the only accessible variable, characteristic of the hydrodynamic state of the deep aquifer of the plateau of Mbe. This one, enabled us to establish a piezometric chart of the zone.

Initially, the seasonal monitoring during the water resource year between September 2017 and August 2018, was carried out starting from a network of four (04) drillings, and of a well for subterranean water, and of three (03) rivers for surface water. This study made it possible to have a general idea on the roof of the ground water which has a convex form, then the comparison of the piezometric levels of the deep aquifer of the plateau of Mbe and the bringing together of the data of literature, with the current data bring arguments on certain aspects of the hydrodynamics of the aquifer of the plate of Mbe. Moreover, the study also shows that, the rivers are all regular during all the year and seems to drain the ground water. The power of this ground water and the regularity of the rivers which would be fed by the ground water, are characterized by the rains which infiltrate in the basement for nine (09) months. Consequently, we can note that the piezometric level of the aquifer major of the plate of Mbe would be in balance. The variation of precipitations does not affect in a visible way piezometry because the great thickness of the not-saturated zone which causes the effects delayed on the ground water. Precipitations on the area being considerable during the water resource year, make it possible to guarantee the perenniality of the resource.

Acknowledgements

We would like to thank Mr. Jacques NGOULOU for his remarks and observations.

References

[1]. Pavelic P, Giordano M, Keraita B, Rao T, Ramesh V. (2012). Groundwater availability and use in Sub-Saharan Africa.A review of 15 countries. Eds. Sri Lanka: International Water Management Institute (IWMI).

[2]. Harmel Obami Ondon, Urbain Gampio Mbilou, Dominique Nkounkou Tomodiatounga, Médard Ngouala Mabonzo, Raymond Gentil Elenga, Bernard Mabiala, (2018). Physicochemical Characterization of Water of the Plateau of Mbe in Pool-North in Republic of Congo Brazzaville.American Journal of Environmental Protection. Vol. 7, No. 3, pp. 40-54. doi: 10.11648/j.ajep.20180703.11,.

[3]. Lemarechal, A. (1966). Contribution à l'élude des plateaux bateke; géologie, géomorphologie hydrogéologie, Rapp.ORSrOM- Brazzaville Cote M.C.137; 43 pages.

[4]. Sautter G. (1952). L'eau sur les Plateaux Batekes. Rapport ronéo, ORSTOM géographie Brazzaville.

[5]. Sautter G. (1953). Les villages des Plateaux Batekes et le problème de l'eau. Rapport ronéo ORSTOM Géographie17p. Brazzaville. D35.

[6]. Hudeley H. (1952). Etude hydrogéologue du Plateau Koukouya et de la région de Djambala. Rapport ORSTOM, 13p. + annexes.

[7]. Mermollod, (1961). Compte rendu de mission sur le Plateauau Koukouya. (8-12 Juin1960) rapport ronéo IRGM Brazzaville. Réf. AH-T. 20.

[8]. Archambault J. (1960). Note sur le Plateauau Koukouya. BUBGEAPR. 282, Rapport ronéo 4p.

[9]. Palausi G. (1960). Note préliminaire sur le forage du Plateauau Koukouya. BRGM Brazzaville.

[10]. Sautter Gilles, (1960). Le plateau congolais de Mbe.In: Cahiers d'études africaines, vol. 1, n°2, pp. 5-48.

[11]. P. de La Souchere et R. Bosseno, (1974). Etude pédologique de trois terrains situés aux environs des villages Odziba-Imbama- Mbe (Plateau de Mbe). ORSTOM de Brazzaville.

[12]. Dadet, P. (1969). Notice explicative de la carte géologique de la République du Congo Brazzaville.

[13]. Boudzoumou, F. et al, (1993). Notice explicative de la carte géologique de la République du Congo Brazzaville au 1/1000.000e, p. 21-22.

[14]. Mainguet (M.), (1972). Le modelé des grès, Etude de photo-interprétation. Tome l et II, IGN –Paris.

[15]. Frédéric Lalbat, (2006). Fonctionnement hydrodynamique de l'aquifère du Miocène du bassin de Carpentras. Th. Doctorat Hydrogéologie, LHA, Univ. Avignon.

[16]. Molinier M. et al. (1974). Note hydrologique sur les rivieres mary et gamboma (Plateau de Mbe). Laboratoire d'Hydrologie ORSTOM, centre de Brazzaville.

[17]. Moukolo N. (1987). Ressources en eau souterraine et approvisionnement, Données hydrogéologiques de la région de Brazzaville, Notes de synthèse.Rapport ORSTOM-DGRST, 30 p.

[18]. Moukolo N. (1984). Ressources en eau souterraine et approvisionnement, Essai d'analyse socio-economique en région équatoriale humide'', Thèse de 3e cycle, Montpellier, 90 p. + annexes.

[19]. Moukolo N. (1992). ''État des connaissances actuelles sur l'hydrogéologie du Congo Brazzaville'', Journal d'Hydrogéologie, no 1-2, 2992, pp. 47-58, 6fig.