MOUNOU SAMBIENI Kassa I., et. al. International Journal of Engineering Research and Applications
www.ijera.com
ISSN: 2248-9622, Vol. 12, Issue 11, November 2022, pp. 160-170

RESEARCH ARTICLE OPEN ACCESS

Analysis of the productivity of SONEB's groundwater drillings in the commune of Porto-Novo

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ABSTRACT:
Groundwater from the quartenaire and terminal continental aquifers is collected in boreholes by the Nationale Water Company of Benin named SONEB, as a source of supply for the population of the Porto-Novo agglomeration in Benin. Despite numerous efforts to maintain the normal operation of the system, the quantities of water produced are insufficient to cover the growing demand. The aim of this study is to improve the productivity of all these boreholes. The approach used consists of a comparative analysis using hydrodynamic, physico-chemical and bacteriological data of the captured waters. The percentage of total exploitation flow of 72.87% suggests that the system's catchment works are under-utilized. Also, the daily water production of the plant represents only 9.9% of the national average. In addition, the estimate of the transmissivity of the aquifers collected shows that the quaternary aquifer has a low water transmission capacity, which may be the cause of the drop in productivity. The head losses between the catchment works and the plant are estimated at 1.066 bar to which must be added the water leaks observed on the transport network, reducing the volume of water produced. The water collected is highly aggressive. The average carbon dioxide (CO_2) content of the water is 68.28 mg/L. To achieve the purpose of this study, a more accentuated follow-up of the parameters obtained, of the equipments taking into account for the production is recommended.

Key Words: SONEB, aquifer, physico-chemical, hydrodynamic, under-exploited, head loss

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Date of Submission: 06-11-2022 Date of Acceptance: 20-11-2022

I. INTRODUCTION

Water is a rare and precious resource. Life on earth is only possible thanks to the existence of this vital resource which is a basic necessity for living beings. The largest liquid reserve of fresh water on the planet is underground. It accounts for 30% of the entire amount of fresh water available on earth (Luzolo, 2012). These statistics demonstrate that availability and access to the resource is an issue that humanity will face in the future.

In Africa, groundwater resources are less accessible than in other regions of the world. Making drinking water available to consumers requires its collection, treatment and distribution. All these operations require very expensive technical and financial means, which makes it difficult for developing countries in general and Benin in particular to acquire. The only drinking water production and distribution unit in Benin is the Société Nationale des Eaux du Bénin (SONEB). It provides drinking water in urban and peri-urban areas. The main sources of water used in Benin by SONEB are surface water and groundwater.

In the city of Porto-Novo, the water used by SONEB to supply the population consists solely of groundwater located in aquifers. They are mobilized by means of developed catchment works (boreholes).

The risk of a borehole being totally or partially productive depends not only on purely geological and hydrological factors, but also to an equal extent on knowledge of the region concerned. Thus, the performance of a well is its ability to provide adequate quantities of water to meet water needs (Jackli, 1970). However, despite efforts to improve the performance of SONEB's boreholes in the city of Porto-Novo, there are still problems with low volumes of water received at the plant and a lack of water in consumers' taps. These difficulties are due to the decrease in production at the plant and depend on hydrodynamic, physico-chemical and bacteriological parameters. The analysis of the productivity of these boreholes will make it possible to identify the flaws and insufficiencies of these and to highlight the avenues for improvement for a better service..

II. Materials andMethods

2.1. Materials

In this study, several materials were used, some for measurements and others for analysis. These include conductivitymeter, turbidimeter, piezometric probe, petri dish, test tubes, iron box, etc.

Photo 1 : Conductivity meter to measure electrical conductivity and temparature

Photo 2 : turbidimeter for measuring turbidity

Photo 3 : petri dishes containing agar solution + water and test tubes containing Mac Conkey Broth solution + water, for bacteriological analysis

Photo 4 : Iron case containing the dosing bottles and the measuring plate

Photo 3 : Piezometric probe for static and dynamic level measurement of boreholes

2.2.Methods

2.2.1 Taking of static and dynamic levels

In this study, the tour of the various boreholes facilitated the taking of statistical and dynamic levels. The procedure consisted in introducing the piezometric probe into the borehole through a probe line. As soon as it reaches the water surface, an electrical circuit is activated and emits a "beep". The water level can then be read on a graduated tape, usually with an accuracy of one centimeter. But note that normally the water level is recorded in meters, below a reference point, for example the upper edge of the casing. Manual piezometer probing is generally considered a reliable and relatively safe method of obtaining water level data. However, data provided by the remote borehole water level software was also used.

2.2.2. Determination of the specific flow rate of the boreholes

The specific flow rate or specific capacity of the water tables of boreholes F4, F7, F8, F11, F12 were determined using available data (technical data sheets for these different boreholes). The classifications of the C.I.E.H (Interafrican Committee for Hydraulic Studies) were used to assess the distribution of the drilling flows according to the following relationships :

Qsp < 0.1 m2/h for a low specific flow; 0.1 m2/h < Qsp < 1 m2/h for a medium specific flow and Qsp > 1 m2/h for a high specific flow.

The specific flow rate is the ratio between the pumping rate and the drawdown induced by the pumping; the drawdown being the difference between the water levels (dynamic level and static level). It has the formula

Qsp = $\frac{Q}{Nd-Ns}$ (Equation 1)

With Nd: dynamic level; Ns: static level and Nd-Ns: drawdown.

The knowledge of the specific flows allowed to appreciate the transmissivity of the aquifers of the concerned drillings. The following relationship between T and Q/s of the "log-log" type was used for this purpose and allows to associate the high values of transmissivity to the high values of specific flow:

$\mathbf{T=\alpha(\frac{Q}{S})^{\beta}}$ (Equation 2)

With : $\frac{Q}{S} = Qsp$,

S being the drawdown; α and β are real numbers.

2.2.3. Calculation of head losses on the transport network

The calculation of head loss gave an idea of the pressure loss in each of the pipes carrying water to the treatment plant. There are three feeder pipes that carry the water from the boreholes (F2, F4, F5, F6, F7, F8, F9, F11, F12) to the plant. These are the canals CA1 for the drillings F2, F4, F5, F6; CA2 for the drillings F7, F8, F9; and CA3 for the drillings F11 and F12. Boreholes F13 and F3bis are not F13 sends water directly to the Sèmè-Kpodji station and F3bis is inside the water plant.Thanks to the DARIES chart (Fig. 1) showing the different values of linear head losses according to the diameters of the different canals as well as the flows.that pass through them, the linear head losses have been determined.

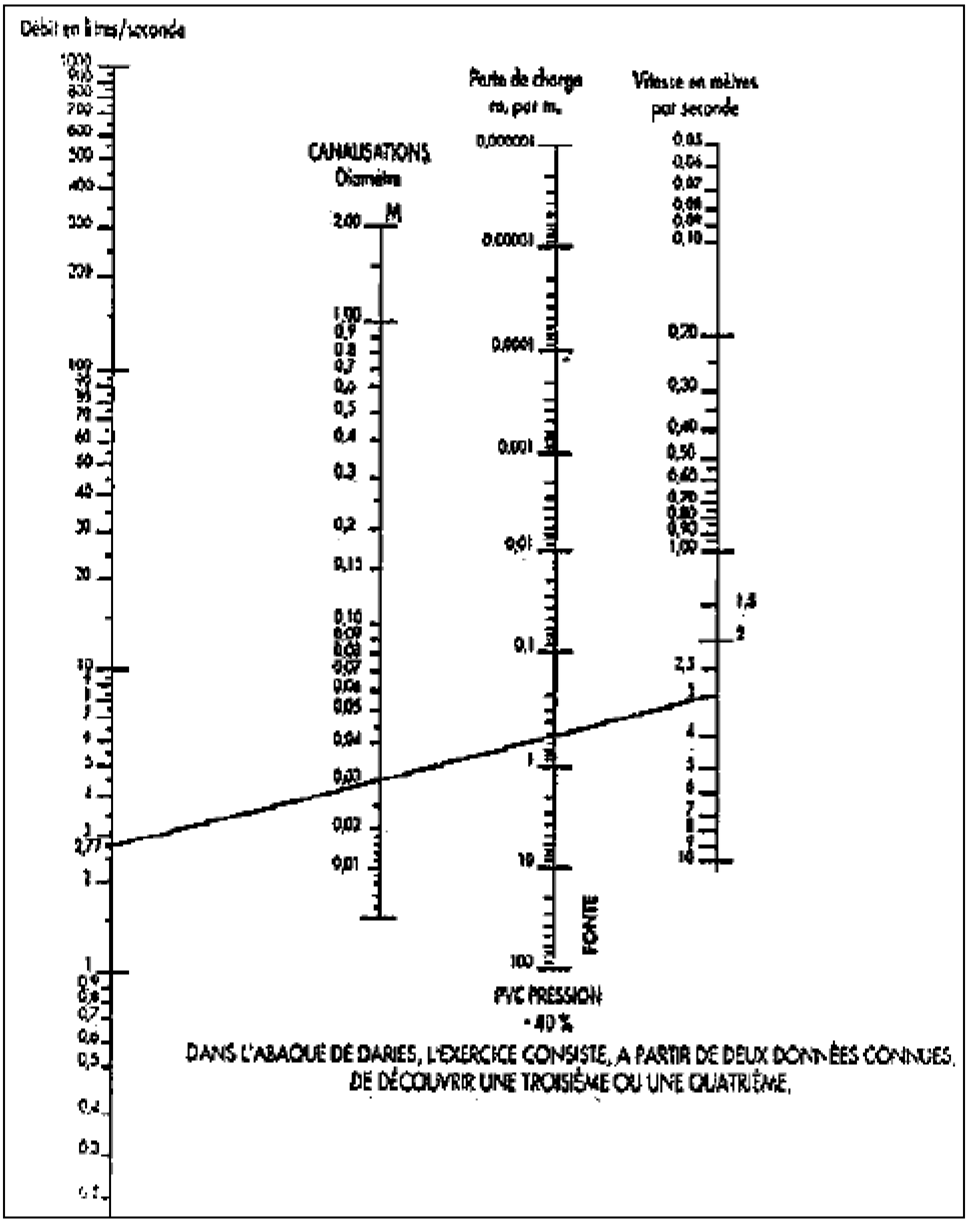

Figure 1 : DARIES Chart

The different lengths of the pipes are presented in the following table:

Table 1 : Lenghts of feeder pipes

	CA1	CA2	CA3
L	1750m	3600m	2800m
L'	23m	20m	12m
L''	4m	4m	2,5m

The total pressure drop was determined using the following formula:

$\Delta T = (\sum L + \sum L' + \sum L'')$ (Equation 3)

L: length of pipe,

L' : equivalent length of elbows,

L'' : equivalent length of valves.

2.2.4. Studies of the physico-chemical and bacteriological parameters of the borehole water

These are the following parameters: Free CO2, aggressive CO2, electrical conductivity, turbidity, temperature, pH, Ca2+ , Mg2+ , TAC, O2, etc....All the water drilling sites of SONEB in the city of Porto-Novo were visited in order to determine these different parameters. Some parameters were not obtained in situ but in the laboratory of the water plant. The parameters that were determined were: electrical conductivity, temperature, turbidity, iron, hydrotimetric titre and pathogenic and common germs.

2.2.4.1. Determination of electrical conductivity, temperature and turbidity

Electrical conductivity was determined using a conductivity meter. A given amount of borehole water is taken into a small container and the conductivity meter probe is inserted. After a few seconds, the displayed value is read. The unit of measurement for electrical conductivity is microsemens per centimeter (µs/cm). Temperature is measured in degrees Celsius (°C) and its value is read directly on the conductivity meter. Turbidity is measured with the turbidimeter. The water is taken from the borehole in a small bottle designed for this purpose and is introduced into a small hole made on the turbidimeter to receive the small bottle to the level of an adjustment line on the bottle. To this sample, six (06) drops of a reagent Fe N°1 are added and the mixture is shaken. To the mixture obtained, six (06) drops of another reagent Fe N°2 are added and the mixture is stirred. Finally, six (06) drops of another reagent named Fe N°3 are added to this last mixture and the mixture is stirred. The addition of this last reagent makes the mixture turn more or less purple. With the help of a white plate positioned behind the bottle containing the mixture, the value corresponding to the concentration of iron in mg/L is read by comparing the color of the mixture with the colors marked on the bottle.

2.2.4.3. Determination of the total hardness or hydrotimetric title (TH)

The TH of the water is determined by the concentration of calcium and magnesium ions. It expresses the content of calcium and magnesium salts in the water. To determine the concentration of calcium ions in water, 100mL of the water to be analyzed is taken in a 250mL Erlenmeyer flask and 3 to 5 drops of Tashiro reagent are added and the mixture is shaken. We then add to the mixture, drops of hydrochloric acid diluted to 1/3 of its concentration) until a pink coloration is obtained. In the same mixture we add 5 to 8 drops of soda 400g/l and we obtain a green coloration then we add a pinch of Murexide indicator. Finally, the mixture is titrated drop by drop with a reagent, EDTA (Ethylenediaminetetraacetic acid) or Triplex B until a purple coloration is obtained.
The concentration of calcium ions in mg/L is given by the formula:

$[Ca^{2+}]$mg/L = V(mL) x 1,78 x 4.008 (Equation 4),

Where V is the volume of the EDTA titrant solution used.

The concentration of magnesium ions is determined by continuing the assay operation. 5mL of HCl 1/3 is added to the previously obtained mixture and allowed to react for 5 minutes. Then 5mL of 28% concentrated ammonia solution and a pinch of Eriochrome T Black indicator (NET) are added. The mixture is titrated dropwise with EDTA or Triplex B until a blue coloration is obtained.

The concentration of magnesium ions in mg/L is given by the formula :

$[Mg^{2+}]$mg/L = V(mL) x 1,78 x 2,43(Equation 5) containing the water, then the measurement process is started by a small button on the turbidimeter. After a few seconds, the displayed value is read.

2.2.4.2. Determination of the iron content

With the help of a sampling bottle, a water sample is taken until it is full. The sample is adjusted

The TH of the water is calculated according to the formula :

TH = [Ca2+] + [Mg2+] (Equation 6)

2.2.4.4. Determination of bacteriological parameters

The water from each borehole is collected in a bottle under the best conditions for sampling. The water from the bottles is added to the culture media (nutrient agar and Mac Conkey broth) already prepared for this purpose. The nutrient agar medium is used to test for common germs in the water, while the Mac Conkey broth medium is used to test for total coliforms. 1ml of each water sample is taken and added to the culture media respectively. Then the mixtures are put back in the incubation oven. In the presence of total coliforms, the Mac Conkey broth takes on a yellowish or whitish color and one notes the presence of air bulbs in the tube containing it. In this case, we continue the analysis in search of pathogenic germs such as: Escherichia Coli, Enterococci, Clostridium. In the presence of common germs (yeasts, bacteria, molds), we note round net points in the petri dish containing the agar + water.The reading of the results of the analyses is done after 24h and after 48h. The data of the results obtained after 48h are retained.

I. STUDY AREA

3.1. Geographic location

The study area (the city of Porto-Novo) is located in the south of Benin, 30 km from Cotonou, and is situated between 6°30 north latitude and 3°30 east longitude (Gandonou, 2006). It is bordered to the north by the communes of Akpro-Missérété and Avrankou, to the south by the commune of Sèmè-Kpodji, to the east by the commune of Adjarra and to the west by the commune of Aguégués. The city of Porto-Novo covers an area of 52 km² or 0.05% of the national territory. It is divided into five districts: Houèzoumè, Attakê, Djassin, Houinmè and Ouando. The following figure is a map showing the location of the commune of Porto-Novo with the various SONEB groundwater wells.

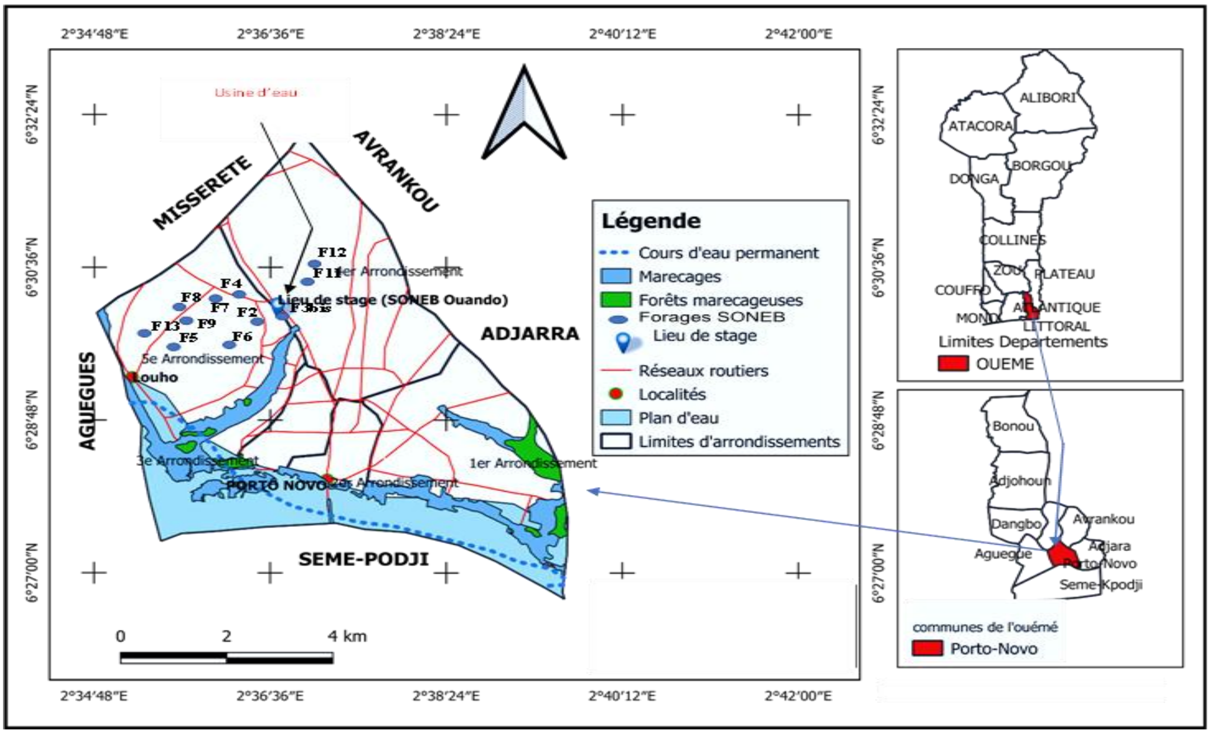

Figure 2 : Map of the location of the various SONEB groundwater boreholes in the commune of Porto-Novo

ISSN: 2248-9622, Vol. 12, Issue 11, November 2022, pp. 160-170

2.2. Geology and hydrogeology of the study area

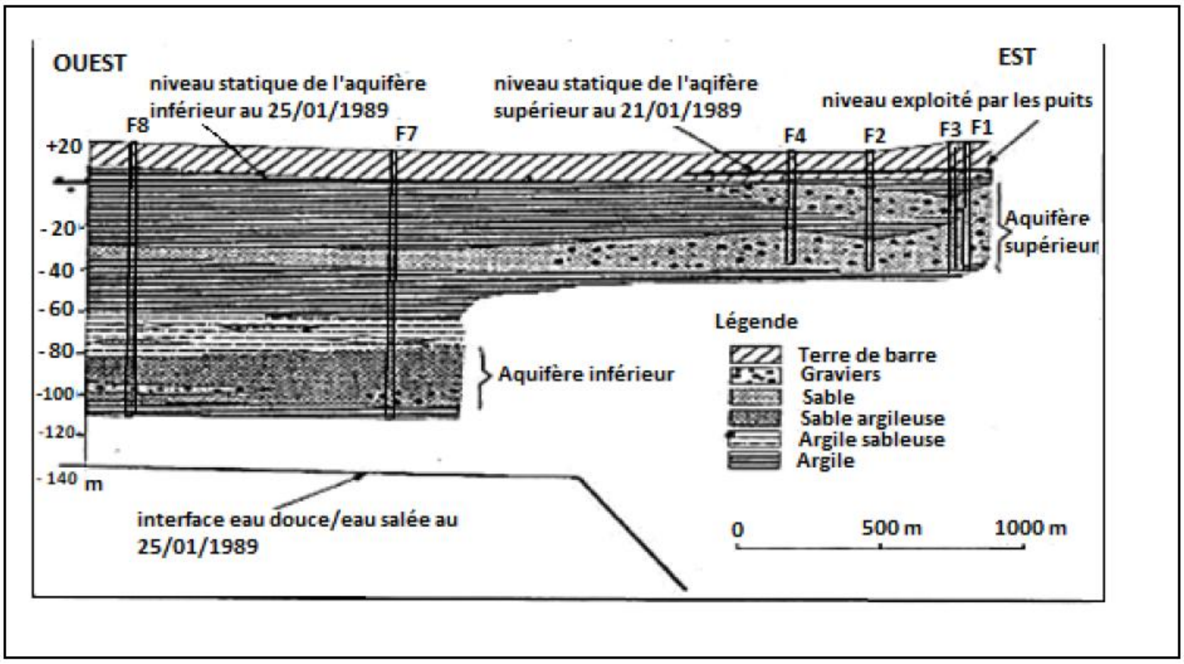

Figure 3 : Synthetic hydrogeological section of the SONEB/ Porto-Novo wellfield (Azonnakpo, 2007)

In the commune of Porto-Novo, the soils are essentially made up of deposits from the coastline (ancient sands), an alluvial deposit composed of sands, clays with gravels and a unit called the upper Miocene, made up of quartz sands, clays, gravels and sandstones. According to the summary hydrogeological section of the SONEB wellfield, the boreholes it operates in Porto-Novo draw water from two aquifer levels. A lower aquifer called the Quaternary aquifer that develops below the upper aquifer system. It is made up of clayey sand containing in places lenses of gravelly sand. It is 34m thick and is isolated from the upper aquifer by a thick layer of clay that acts as a screen against liquid infiltration from the upper horizons. This aquifer also rests on a fairly thick clay layer. The upper aquifer, the terminal continental aquifer, is at a shallow depth (from 15 m). Just below the bar land, it consists of sands whose thickness increases from the southwest to the northeast. In these types of aquifers, the boreholes operated by SONEB are located at least 250m apart. In addition, the water reserves contained in the city's aquifers cannot be evaluated due to the lack of available data. However, the recharge capacity of aquifers throughout the country can be estimated at an average of 1.9 billion cubic meters per year (Azonnankpo, 2007).

IV. Résultats

4.1. Characterization of the boreholes

This part reports the following data: depth of the boreholes, operating flow rates and some hydrodynamic data (static and dynamic levels), characteristics of the submersible pumps and of the dewatering equipment. These data will provide an overall view of all the boreholes and the equipment installed in them. The TABLE 2 presents the technical characteristics (depths, operating flows, piezometric levels) of the different boreholes.

The analysis of this table allows us to say that the current total flow of the operation of the drillings is lower than the total recommended operating flow (572.80 m3 /h < 786 m3 /h). In addition, the exploitation rate of all the boreholes is estimated at 72.87% compared to the total recommended at the time of their realization. We deduce from these data, an under exploitation of the system's catchment works. However, it should be noted that the current operating flow rate on borehole F5 is higher than the recommended operating flow rate (54 m3 /h > 41 m3/h). F5 is overexploited

Table 2 : Technical characteristics of the drillings

Forages	Depths in meter	Operating flow (m^3/h)		Piezometric levels (m)	
		Recommanded	Current	Statics levels (Ns)	Dynamics levels (Nd)
F2	56,8	91	30	Notavailable	Notavailable
F3bis	117	95	90	11,60	30,7
F4	53	80	61	11,30	21,46
F5	57,5	41	54	16	20,81
F6	62	39	38,40	Notavailable	Notavailable
F7	127	70	49,20	13,26	24,30
F8	122	120	99,20	15,68	36,11
F9	134	80	24	Notavailable	Notavailable
F11	127	60	55	22,27	57,10
F12	93,33	77	45	22,38	42,33
F13	68	33	27	16,78	24,58
		786	572,8		
		Total operated			

Tableau 3 : characteristics of submersible pumps and exhaurs

	Pumps					Exhaurs		
	Power	Rotational speed	Nominal flow rate	Hmt	Depth of immersion	Nature of the drainage	Diameter of the drain	Length of the drain
F2	5,5KW	2900tr/min	30 m^3/h	46m	48m	foraduc	100mm	37,8m
F4	15KW	2840tr/min	77 m^3/h	48m	33m	foraduc	150mm	Notavailable
F5	13KW	2840tr/min	46 m^3/h	69m	Notavailable	Acier inox	100mm	42m
F6	9,5KW	Not available	48,5m^3/h	35m	43m	foraduc	100mm	42m
F7	15KW	Not available	77 m^3/h	48m	44m	foraduc	150mm	43m
F8	30KW	Notavailable	125 m^3/h	61m	44m	foraduc	150mm	43m

Moreover, by analyzing the two hydrodynamic data (static level and dynamic level), it appears that the drawdowns are quite significant on the wells F11, F8, F3bis and F12. Overall, we can classify the boreholes whose water levels are known according to the observed drawdowns. Thus: RF11 >RF8>RF12>RF3bis>RF7>RF4>RF13>RF5
With R = observed drawdown.
Each borehole is composed of hydraulic equipment, tubular equipment and aerial equipment. Among the hydraulic and tubular equipment, we note the submersible pumps as well as the dewatering pipes. TABLE 3 presents the characteristics of the different equipment found in the boreholes.

4.2. Estimation of the specific flow rates of boreholes F4, F7, F8, F11 and F12

To determine the productivity of each borehole, the specific capacity (specific flow) of these boreholes was evaluated. The knowledge of the specific flow rates allowed us to appreciate the transmissivity of the aquifers captured by these wells. Table 4 below presents the specific capacities of these aquifers.

Table 4 : Boreholes specific flow rate

Forages	Pumping rates (m^3/h)	drawdown	Specific flow or capacities (m^2/h)
F4	100	12,7	7,87
F7	123	28,92	4,25
F8	167	34,39	4,86
F11	38,06	24,09	1,58
F12	51,62	22,89	2,25

It can be seen that all the specific flow rates are above 1m2/h. Based on the classification of the CIEH, we can say that the water tables captured by these drillings all have a high specific capacity or a high specific flow. However, the water table captured by borehole F4 has a higher specific capacity and that captured by borehole F11 has a low specific flow. The specific flow rates of these boreholes can be classified in the following order: QspF4>QspF8>QspF7>QspF12>QspF11.

From equation (2), we can classify the transmissivities of the aquifers as follows: TF4>TF8>TF7>TF12>TF11. Since borehole F4 collects water from the upper aquifer and boreholes F7 and F8 collect water from the lower aquifer, we can deduce that the upper aquifer, known as the terminal continental aquifer, has a higher transmissivity than the lower aquifer, known as the quaternary aquifer. One of the aquifers exploited by SONEB in Porto-Novo therefore has a low water transmission capacity, which may explain the drop in productivity of the boreholes installed in this area.

4.3. Average monthly production trend for all boreholes

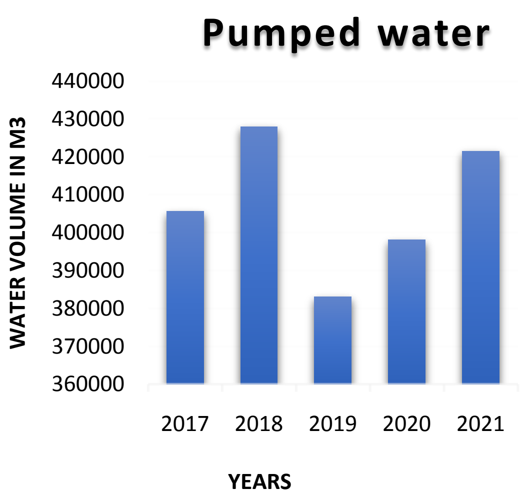

Figure 4 : Change in average monthly production from 2017 to 2021

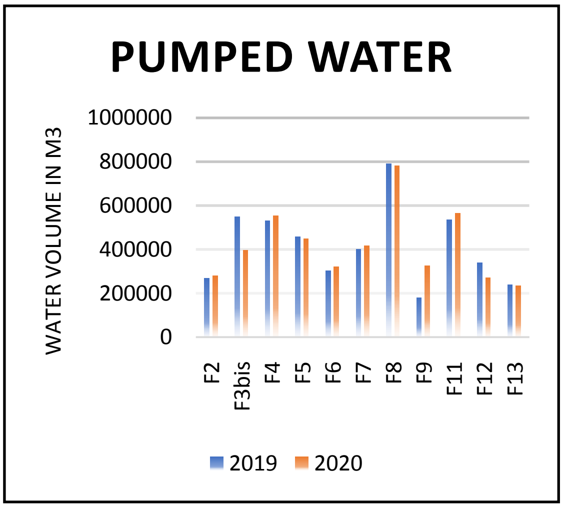

Figure 6 : Change in annual production for each borehole from 2019 to 2020

All the boreholes produced on average per month about 405589 m3 in 2017. There was a fairly significant increase in this production in 2018. But in 2019, the production has dropped considerably to below 390000 m3. The operating data from 2019 to date show an increasing variation in production and thus an improvement compared to those of 2017 and 2019. It is also noted that the average monthly production in 2021 has not yet reached that observed in 2018 before it falls in 2019. This is due to the failure and inadequacy of production facilities and equipment, as well as the water losses recorded. It is therefore important to work towards improving production factors in order to guarantee better productivity in the years to come..

4.4. Annual evolution of production on each borehole

According to the figure below (Fig.5), we note that on the drillings F2, F4, F6, F7, F9 and F11, the production in 2020 is higher than that of 2019 contrary to the drillings F3bis, F5, F8, F12 and F13 which present a production more important in 2020 than in 2019. There is therefore an increasing variation in annual production for the first six (06) wells mentioned above and a decreasing variation in this production for the remaining five (05) wells.
It should also be noted that the production of drillings F4, F8 and F11 are higher than those of the other drillings. The operating data for borehole F8 show a high production in both 2019 and 2020 and this production (790883 m3 in 2019 and 782151 m3 in 2020) far exceeds that of other boreholes.

However, it is necessary to work on changing the decline factors on all the boreholes to improve their productivity

4.5. Comparative study between the quantity of water produced and consumed

With the exception of borehole F13, the other boreholes together produce 545.8 m3 of water in one hour with the current operating flow rates (2021) which are not constant (527.5 m3/h in 2020). Thus, these drillings produce in 24 hours, 13099.2 m3 of water which represents only 9.9% of the national daily production. Note that in 2020, the daily production was on average 12660 m3. In addition, data on the daily consumption of the population showed that it varies between 10585 m3 and 12072 m3 for a period of three (03) months, which is close to the amount of water produced per day by the drillings. This production can therefore vary according to the operating flow rates or in the case of drilling stoppages and still does not allow consumers to be totally safe from problems related to water shortages at their taps because the initial quantity of water produced by the drillings will be reduced on the transport/distribution route by head losses, pipe breaks, etc. ....

4.6. Determination of head losses

The geographical coordinates of the sampling points for bacteriological analysis show that the elevations of the areas served by the network are between 0 and 37m. However, the storage tank for the water distributed to the population is located at 25m from the coast according to the geographical coordinates of the water plant. Moreover, the insufficiency of the resource forces the plant to reduce the delivery capacities of the surface pumps (low water outlet pressure from the plant) in order to make the production and distribution proportional. With these topographical conditions and the low outlet pressure of the water discharged from the plant, localities with an altitude of between 30 and 37m are confronted with problems of lack of pressure or even a shortage of the resource at their taps.

The calculation of the head losses on the different supply channels is as follows:

- ✓ For feeder line 1

Flow rate = 183,4 m3/h = 50,94 l/s ;
Diameter = 300 mm = 0.3 m; JL = 0.0012 m/m
$\Delta T = (1750 + 23 + 4) \times 0.0012$
$\Delta T = 2.13$ m

- ✓ For feeder line 2

Flow rate = 172,4 m3/h = 47,89 l/s ;
Diameter = 300 mm = 0.3 m; JL = 0.0008 m/m
$\Delta T = (3600 + 20 + 4) \times 0.0008$
$\Delta T = 2.90$ m

- ✓ For feeder line 3

Flow rate = 100 m3/h = 27.78 l/s ;
Diameter = 200 mm = 0.2 m; JL = 0.002 m/m
$\Delta T = (2800 + 12 + 2.5) \times 0.002$
$\Delta T = 5.63$ m

Analysis of these results shows that the pressure losses in feeder line 3 (F11 + F12) are greater than those in the other two lines. Knowing that one bar corresponds to 10 m of water column, then we have respectively in the supply lines CA1, CA2 and CA3, a pressure decrease of 0.213 bar, 0.29 bar and 0.563 bar.

4.7. Discussions

The physico-chemical analyses reveal that the water collected is aggressive. The aggressiveness of a water is related to the amount of CO_2 it contains. Stormwater leaches chemical elements from the atmosphere (CO_2 being one of these elements) to surface and groundwater. Thus, the CO_2 leached by the stormwater is transported into the wellbore through the openings seen on the wellheads. This CO_2 increases the acidity of the borehole water (lowering its pH) and consequently causes its aggressiveness. For drinking water, WHO guidelines and Beninese standards require that the pH be between 6.5 and 8.5. In 2020, the pH of the water treated at the plant in July and August is lower than the prescribed standard while that of September is in conformity with it.

In 2021, we note the presence of iron in wells F8 and F9. This iron is a trace element essential to human health when its content is less than or equal to 0.3 mg/L. It has no effect on health. At high concentrations, it induces a red color and rust stains on the production and distribution equipment and even on the taps of the customers.

The results obtained for the bacteriological parameters are due to the important depths of the drillings; this allows a complete filtration of the water which flows on the surface of the ground through the different geological formations before reaching the groundwater. They are also explained by the effective protection of the wells.

Knowledge of the physico-chemical and bacteriological parameters of the raw water (water from the boreholes) makes it possible to set up the various appropriate treatment processes in order to bring the water back into the best possible condition for consumption.

SONEB only uses 72.87% of the total recommended operating flow rate for the boreholes, which does not encourage better production. In fact, almost all of these boreholes are under-utilized compared to the initial recommended flow rates, despite the fact that some boreholes (F4, F7, F8, F11 and F12) have a high specific capacity and therefore a high transmissivity.

In addition, head losses on the transport network and leaks in the borehole equipment cause a drop in production. They are caused by the friction of the water against the walls of the pipes (Mabillot, 1979) and are related to the flow rates, the diameters of the pipes and the speed of the water. They therefore act indirectly on the flow rate and also on the volume of water produced. To reduce them, it is necessary to act on the diameter of the supply pipes and on the flow of water passing through them. On the other hand according to the work done by OUIYA S. (2017), water losses can also result from the manipulation of production figures, metering errors and poor meter handling. In addition, the topographical conditions of the localities affected by water shortage problems do not favor a satisfactory distribution of the resource. However, this factor could be countered by the installation of booster pumps at strategic points of the distribution network.

V. Conclusion

The drop in pressure and even the shortage of water recorded at the tap of drinking water consumers in the city of Porto Novo is due to a slight drop in the productivity of the catchment works used to mobilize the resource. This drop is itself caused by the fall in some hydrodynamic parameters related to the works and the topographical conditions of the localities concerned by the problems of access to water. Thus, although it is slight, it induces a limited production, varying, inferior or equal to the consumption and not allowing the subscribers to be totally sheltered from the complaints emitted. In addition, the significant depth of the collection works ensures an almost irreproachable quality of the mobilized water; this water is aggressive and contains a high iron content that can lead to rust and corrosion of the system's equipment. However, effective treatments are carried out to improve the quality of the water.

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