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Performance of Boreholes Capturing the Aquifers Systems in the Crystalline Peneplain of Benin

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Abstract

The water supply in the regions of the crystalline peneplain of Benin is ensured by the mobilization of groundwater. The objective of this study is to assess the productivity of fractured and/or fissured aquifers in the communes of Nikki, N'Dali and Pèrèrè located in northern Benin. The methodological approach is based on the comparative analysis of the physical and hydrodynamic parameters of the catchment structures associated with the interpretation of pumping tests of long and short durations combined. It appears from this study that the most productive depths are between 21.6 and 76 m. Some of the boreholes studied (32.37%) have a low flow rate. The transmissivity values vary from $3.06.10^{-5}$ to $6.95.10^{-4}$ m^2/s with an average of $2.38.10^{-4}$ m^2/s; the specific flow varies from 0.25 to 2.20 m^2/h with an average of 0.82 m^3/h. The classification of the distribution of flows and transmissivities established by the Lasm criterion (2000) showed that most of the boreholes have high transmissivities, which are witnesses of productive boreholes in the study area.

Keywords

Fractured and/or Fissured Aquifers, Productivity, Borehole Depth, Hydrodynamics, Transmissivity

1. Introduction

Water, also called "blue gold", is a vital resource for living beings in general and for man in particular. All the water on earth represents a volume of approximately 1.4 billion km^3, available in the form of liquid, solid, or gas [1]. However, most of the water (97%) is contained in the oceans, and is salty, which makes it unusable by humans. Fresh water represents only 3% of the water on earth, half of this water represents fresh water available for human use, *i.e.* only 0.3% of the volume of water in the planet, or 4 million km^3. This water is accessible in various natural resources such as rivers, shallow aquifers, or lakes [1]. Indeed, in Africa, the drinking water supply of the rural population comes from groundwater. The waters contained in the bedrock in particular are exploited by thousands of boreholes and wells. In reality, the territory of Benin is 80% made up of basement and there is a high rate of borehole failure in this area [2]. The communes of Nikki, Pèrèrè and N'Dali are no exception to this situation. Despite the goodwill of leaders to satisfy the demand for water, these numerous cases of failure slow down the achievement of their objectives and affect the economy. In order to increase the success rate of drilling in these environments, it is important to know the most productive zones of the aquifers exploited in the complex. Indeed, aquifers are generally characterized by their ability to store water and ensure its mobility. Hydrodynamic parameters are indices that define the ability of the aquifer to recover and deliver water. They are essential to know the aquifer and its volumes of water that can be exploited by a well or borehole [3]. In view of the resolution of this problem, the present work whose theme is: "the productivity and hydrodynamics of aquifer systems in the crystalline peneplain of Benin" aims to study the hydrodynamic parameters of these aquifers in relation to productivity.

2. Materials and Methods

2.1. Presentation of the Study Area

Covering an area of 9069 Km^2, the study area of our work is in the department of Borgou and is located east of the Kandi fault between latitudes 9˚25'N and 10˚15'N and longitudes 2˚00'E and 3˚35'E. The climate is of the Sudano-Guinean type characterized by a rainy season which extends from April to October and a dry season from November to March. However, despite the quantity of available water that flows and infiltrates, the supply of drinking water remains an important issue due to the geological nature of the subsoil.

Geologically, the study area is located on the crystalline peneplain. To the east, it has a dominant facies of migmatites and biotite granitoids. It brings together the Agramarou migmatite formations and the Pan-African intrusions. To the west, the geological domain is represented by migmatitic gneissic formations and also migmatites of the axial zone of Kandi. Faults are observed in places from North-East to West as well as formations of the Ouémé furrow and intrusive granite in the South-East.

2.2. Data

The data used in this study concerns technical drilling data (localities, geographical coordinates, end-of-drilling flow rate, total depth drilled), and pumping test results (long and short duration), made available to us by the ESSOR engineering office and the General Direction of Water. More than 207 technical drilling sheets, made in the crystalline peneplain of Benin, were used, including 15 pumping test sheets. The boreholes used during the study are presented on the map in "**Figure 1**". To produce the graphs and maps presented in the document, we used the hydrogeological map of Benin at the scale of 1/500000th and geological sheets Parakou-Djougou-Nikki, that of Dunkassa then that of Bembèrèkè on a scale of 1/200000th.

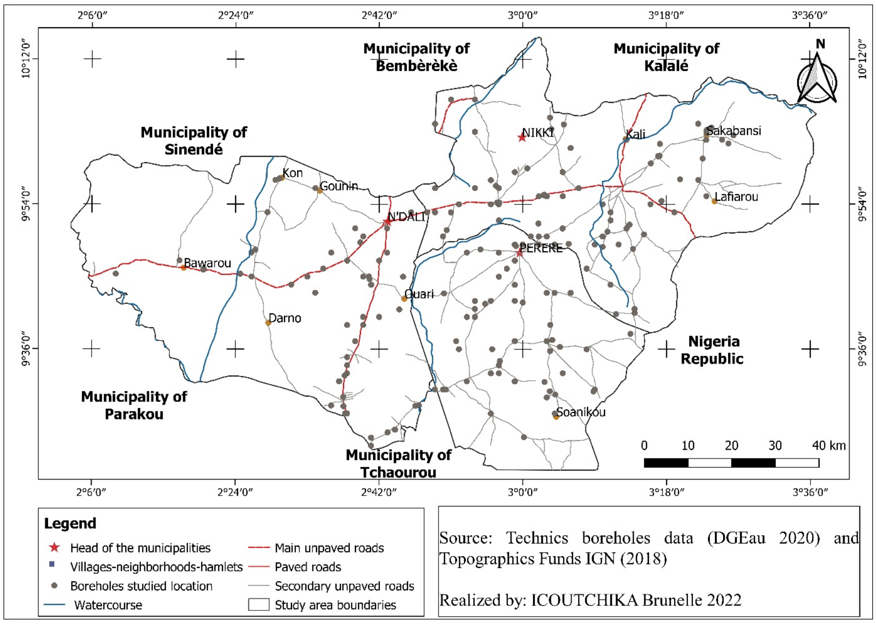

Figure 1. Projection map of the coordinates of the boreholes studied.

2.3. Methods

- Productivity evaluation

Productivity is the ability of an aquifer to provide a minimum usable flow through the channel of a catchment structure [4]. In order to evaluate the productivity of the basement aquifers in our study area, a comparative analysis was carried out between the flow rates of the boreholes and the hydrodynamic parameters (transmissivities and specific flow). The distribution of these flows and transmissivities has been established by various authors such as [5]-[7].

The classification is as follows (**Table 1**).

Table 1. Classification of flows and transmissivity [5].

Flow (m^3/h)		Transmissivity (m^2/s)	
Values	Classification	Values	Classification
0 - 1	Very low flow	$<10^{-5}$	Low class
1 - 2.5	Low flow	$10^{-5} < T < 10^{-4}$	Middle class
2.5 - 5	Average flow	$T > 10^{-4}$	High class
>5	High flow	-	-

- Hydrodynamic approach to aquifers

Determination of transmissivity T

This study was carried out using pumping test data obtained from the various drilling data sheets. These data were used to determine the hydrodynamic parameters, namely transmissivity (T) and specific flow (Qs). By the rise method, the transmissivity value is much more reliable because the pressure losses are much more negligible. Thus, based on long-term tests, to assess transmissivity, we therefore used the Theis rise method as recommended by (Lasm, 2000) [5] in [8] according to the formula:

$$\boldsymbol{T} = \frac{2.3 * \boldsymbol{Q}}{4\boldsymbol{\pi} * \Delta \boldsymbol{s}'} \tag{1}$$

With:

T: transmissivity in m^2/s; Q: the constant pumping rate in m^3/h and $\Delta s'$: the variation of the residual drawdown s' [9].

In fact, Theis' formula for transmissivity is based on the logarithmic relationship. This requires conversion between natural and decimal logarithmic units. This is why the factor 2.3 is used in the formula.

2.3: this factor converts the natural logarithm (e) into a decimal logarithm (10), as in this formula the logarithm is calculated in base 10. This factor is used to adjust the logarithmic scale and make the equation consistent. Consequently, the 2.3 * Q term in this formula is a factor that adjusts the flow rate to match the model's logarithmic scale.

The graph in "**Figure 2**" obtained from the long-term pumping test carried out on the Donkpraoui borehole in the municipality of Nikki highlights $\Delta s'$.

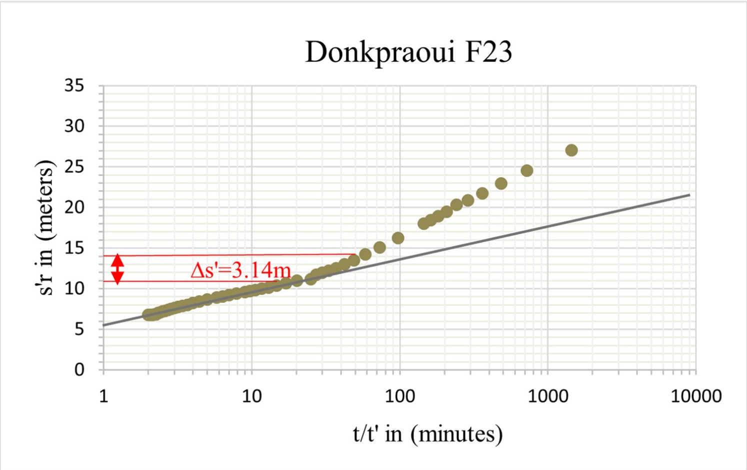

Figure 2. Determination of the slope of Jacob on the site of Donkpraoui F23.

➢**Determination of the specific flow Qs**

Data from pumping tests in stages at constant flow (short duration) allowed the calculation of the specific flow (Qs). It gives indications on the characteristics of the boreholes and on the connectivity between the fracture networks ([5] in [10]).

It was calculated at the end of the first level at all the boreholes using this formula:

$$Qs = \frac{Q}{s}$$

With: Qs: specific flow in (m2/h); Q: pumping rate in (m^3/h) and s: drawdown in (m).

3. Results and Discussions

3.1. Borehole Productivity Analysis

From the results obtained from the distribution histogram of the borehole flow classes in the study area; 25.12% of boreholes have very low flow rates, 32.37% with low flow rates, 18.35% with medium flow rates and 26.57% with high flow rates. Thus, in our study area productivity is low. However, 77.29% of boreholes have flow rates greater than or equal to 1 m^3/h. According to Soro (1987) quoted by [7] in [10] these flows are acceptable for Village Hydraulic projects for the Drinking Water Supply of populations in rural areas. The flow distribution histogram of the aquifer system in the crystalline peneplain of Benin is given in "**Figure 3**" below.

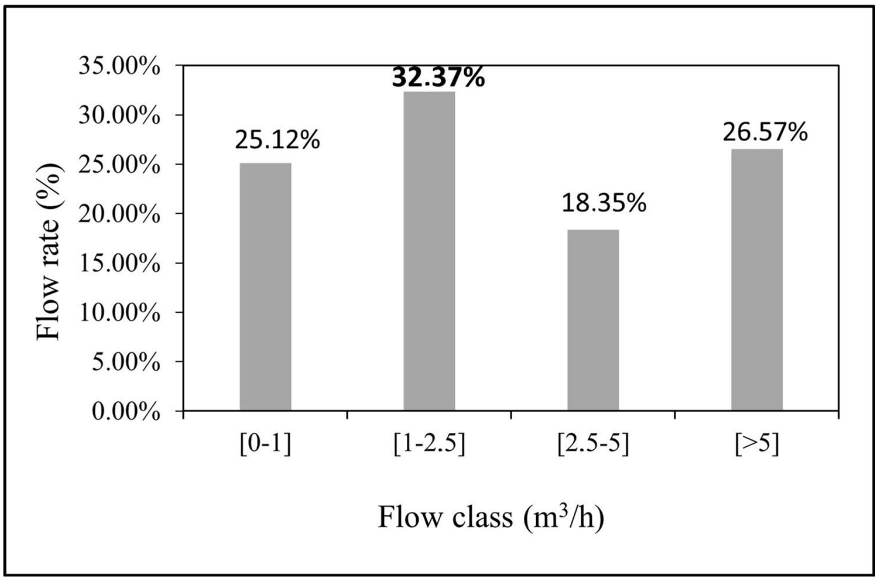

Figure 3. Histogram of flow classes.

- **Productivity and physical parameters of boreholes (total depth)**

The relationship between drilled depth and instantaneous flow is represented by the graph in "**Figure 4**". Analysis of the graph indicates that the majority of significant flows (> 5 m^3/h) are between 21.6 and 76m deep . Also the majority of flows are in the range of 21 to 80 m. However, flows greater than 15 m^3/h are between 36 and 75.5 m. So we can say that the productive slice is 21.6 to 76 m. In the same basement context, [10] suggest depths between 30 and 75 m as optimal depths. However, there are some flows greater than 5 m^3/h between 86 and 104 m.

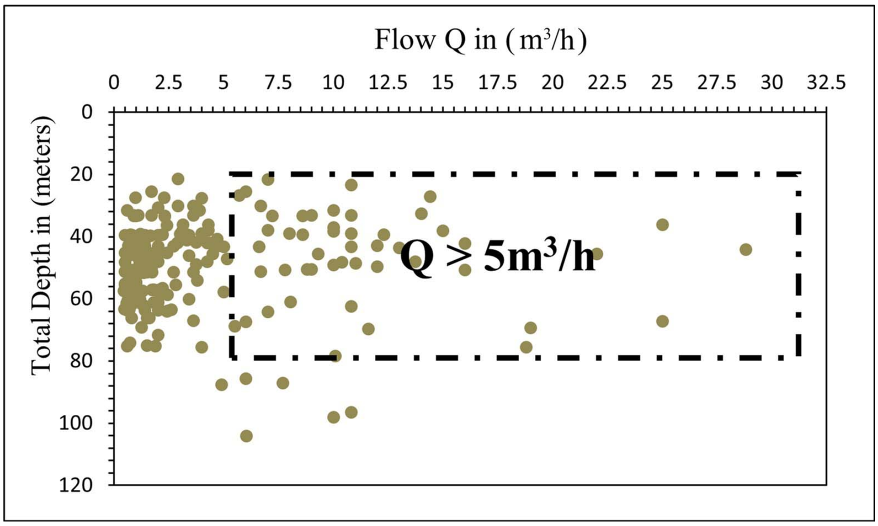

Figure 4. Relationship between discharges and total depth.

3.2. Determination of Hydrodynamic Parameters and Spatialization

The interpretation of long-duration pumping tests using the Theis rise method (1935) made it possible to determine the values of transmissivity T and of the specific flow rate Qs (**Table 2**).

Table 2. Calculated transmissivity values from long-term tests.

Town	Locality	Transmissivity (m^2/s)	Flow Q (m^3/h)	Δs' (m)
N'Dali	Boko	1.20×10^{-4}	20.03	2.16
N'Dali	Darnon	1.05×10^{-4}	20.03	4.37
N'Dali	Sonnoumon	2.47×10^{-4}	20.03	4.16
Nikki	Donkpraouin F'1	1.27×10^{-4}	20.03	4.75
Nikki	Donkpraouin F23	3.24×10^{-4}	20.03	3.14
Nikki	Sakabansi F'22	8.59×10^{-5}	20.03	3.11
Nikki	Sakabansi F'1	3.06×10^{-5}	20.03	8.62
Pèrèrè	Boro-Centre	6.95×10^{-4}	20.03	0.94
Pèrèrè	Gninsy-Centre	1.43×10^{-4}	20.03	1.85
Pèrèrè	Gninsy-Peulh	2.08×10^{-4}	20.03	1.22
Pèrèrè	Sontou	5.37×10^{-4}	20.03	0.65

The previous table relating to the calculated values of transmissivity of the various structures studied shows that the values of transmissivity are of the order of 10^{-4} m^2/s except for the boreholes of the localities of Sakabansi (F1 & F22) which are of the order of 10^{-5} with a general average of $2.38.10^{-4}$ for all the works. Thus, the structures within the scope of the study have transmissivities ranging from medium to high.

The values of the specific flow calculated for the crystalline peneplain aquifer system, obtained from the 1st stage of the short-term pumping test data, are presented as in the following "**Table 3**":

Table 3. Calculated specific flow values.

Town	Locality	Drawdown (m)	Flow Q (m^3/h)	**Specific flow Qs (m^2/h)**
NIKKI	Sakabansi F1	8.09	2	0.247218789
NIKKI	Domplawi F1	7.42	9.32	1.25606469
NIKKI	Sakabansi F22	4.69	1.6	0.341151386
NIKKI	Domplawi F23	3.92	5.39	1.375
PERERE	Boro-Centre (SE3-F2)	1.17	2.57	2.196581197
PERERE	Gninsy-Centre	7.92	2.53	0.319444444
PERERE	Guinangourou	7.23	2.5	0.345781466
PERERE	Boro (SE1-F1)	1.88	2	1.063829787
PERERE	Gninsy-Peulh	2.66	2.5	0.939849624
PERERE	Sontou (SE3)	1.76	1.47	0.835227273
PERERE	Souanworoussou	16.07	6.26	0.389545737
N'Dali	Boko	3.78	1.9	0.502645503
N'Dali	Darnon	11.88	5.15	0.433501684
N'Dali	Sonnoumon	3.31	5.4	1.63141994
N'Dali	Ouénou-Peulh	6.65	3.07	0.461654135

The values obtained vary from 0.25 m^2/h to 2.20 m^2/h with an average of 0.82 m^2/h. The maximum value is obtained in the locality of Boro-Centre with a drawdown of 1.17. The minimum value is found in the locality of Sakabansi with a drawdown of 8.09. Consequently, the specific flows in the study area are mostly very low (66.66%) with the exception of structures in the localities of Sonnoumon, Domplawi and Boro which are low (33.33%).

Spatialization of the distribution of hydrodynamic parameter values T and Qs

The spatial distribution of the values of transmissivities in m^2/s and specific flow rates in m^2/h shows that low transmissivities and specific flow rates are more concentrated in the South-West and North-East of the crystalline peneplain of Benin "**Figure 5**". At the level of the highest values, they are observed in the direction (South-East; North-West) of the study area.

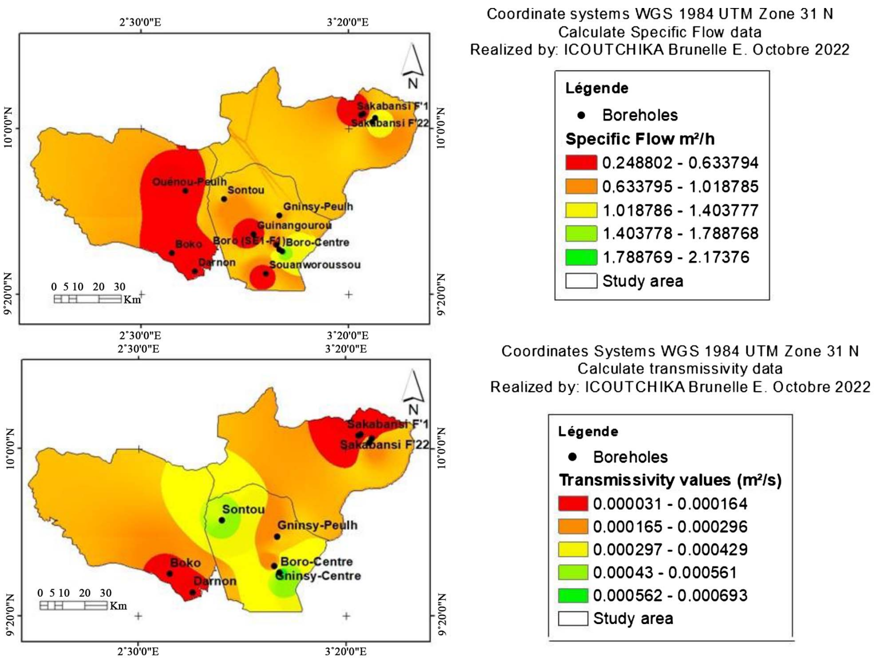

Figure 5. Spatial distribution map of transmissivity and flow values specific to the study area.

3.3. Productivity and Hydrodynamic Parameters

Statistical analysis of the hydrodynamic parameters of the various structures studied shows that the transmissivity values vary from $3.06.10^{-5}$ to $6.95.10^{-4}$ m^2/s with a standard deviation of $2.06.10^{-4}$ m^2/s, an average of $2.38.10^{-4}$ and a coefficient of variation of 0.87. The graph in **Figure 6** illustrates the transmissivity class histogram. Of this graph, 18.18% are included in the class of medium transmissivities and 81.82% in the class of strong transmissivities. Thus we note that the structures studied have strong transmissivities. We can deduce that the basement aquifers captured in our study area have an average transmissive function.

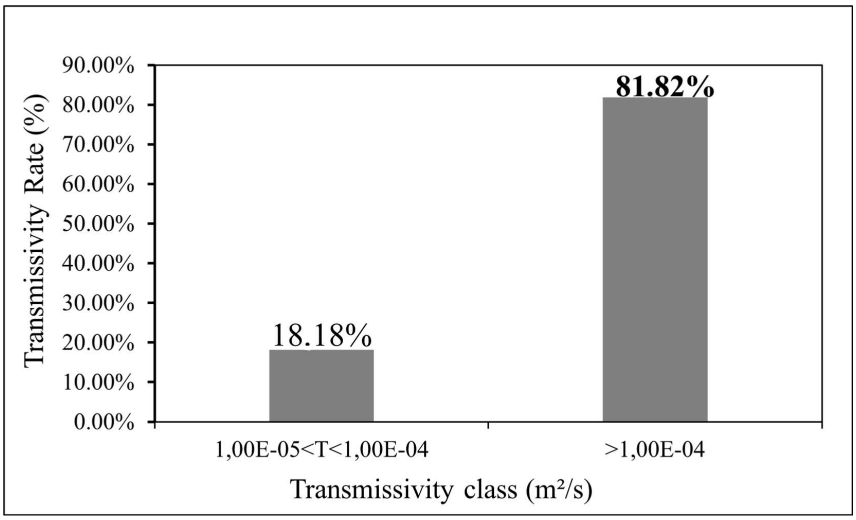

Figure 6. Histogram of the class of transmissivities. (Data used 2020)

Statistical analysis of the specific flow of the various structures studied shows that the values vary from 0.25 to 2.20 m^2/h with a standard deviation of 0.58 m^2/h, an average of 0.82 m^2/h and a coefficient of variation of 0.71. The distribution of the specific drilling flows according to the depth of the structures shows that the specific flows are found in the range of intervals from 50 to 90 m. However, most specific flow rates above 1 m^2/h are between 50 and 70 m. A drop in specific flows is observed after 70 m. This slice joins the one cleared at the level of the productive drilling depth (**Figure 7**).

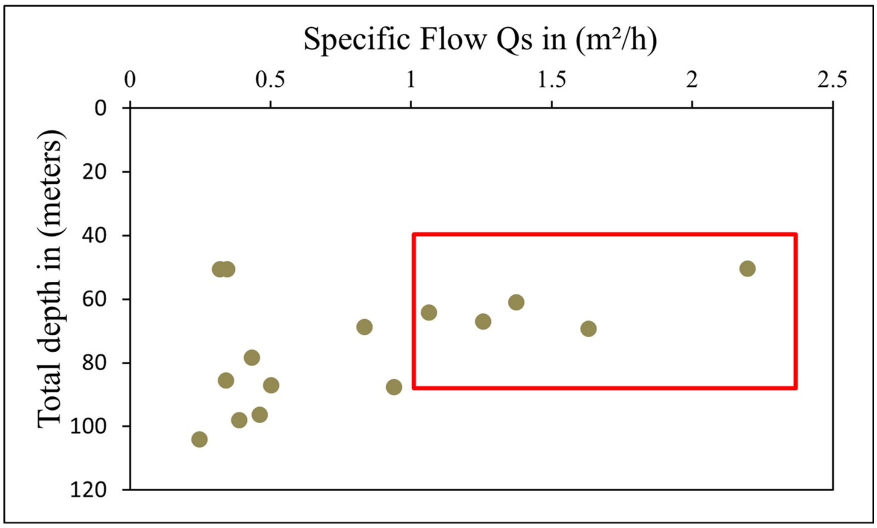

Figure 7. Relationship between specific flow rates and total borehole depth.

4. Discussion

In the Nikki-Pèrèrè-N'Dali complex, the total depth of the boreholes varies from 21.3 m to 104.01 m with an average of 49.47 m. The productive depth range is between 21.6 and 76 m. These values are close to those found by [10] in Côte d'Ivoire in the Katiola region where the values for the most productive depths are between 30 and 75 m. However, flow rates greater than 5 m^3/h are observed between 86 and 104 m; this could certainly mean that not having obtained the expected flow, the drilling was continued. The end-of-bore flow rate (instantaneous flow rate) of the boreholes varies from 0.45 m^3/h to 28.8 m^3/h with an average of 4.30 m^3/h. The histogram of the flow distribution of the boreholes of the Nikki-Pèrèrè-N'Dali complex indicates that it is the class of low flows that dominates in the study area, *i.e.*, 32.37%. We also note that 77.29% of these boreholes have flow rates greater than or equal to 1 m^3/h; acceptable flow rates for Village Water Supply projects to supply drinking water to rural populations (Soro 1987) in [10].

The transmissivity values obtained by the Theis rise method are between $3.06.10^{-5}$ and $6.95.10^{-4}$ m^2/s with an average of $2.38.10^{-4}$ m^2/s. According to the classification of flows and transmissivities according to [5] the values of transmissivities are divided into three classes. The class of low transmissivities ($T < 10^{-5}$ m^2/s); the medium transmissivity class ($10^{-5} < T < 10^{-4}$ m^2/s) and the high transmissivity class (T>10−4 m2/s) of the latter, 81.82% of the structures studied in the area of study have strong transmissivities, a little more than the percentage obtained by [11] in the commune of Savalou (76.47%). The specific flow values of the boreholes studied vary from 0.25 m2/h to 2.20 m2/h with an average of 0.82 m2/h. These values indicate that the specific flow rate of the area is mostly low; this confirms the dominant class of low-end-of-drilling flow rates within the study framework. This is certainly due to the fact that during Village Hydraulic campaigns, the search for very productive fractures is not a priority.

5. Conclusion

This study shows that the crystalline peneplain found in the communes of Nikki-Pèrèrè-N'Dali in Benin is a geologically difficult hydro zone for water supply. Despite the high transmissivity values obtained in the area, productivity in the communes of Nikki, Pèrèrè and N'Dali is generally low. This can be seen in the flow rate values, which range from 0.45 to 28.8 m^3/h, with an average of 4.30 m^3/h. Although we are aware that we have only just provided an answer to the many problems that arise in the basement within our study area, we suggest that, in order to bring greater precision to our knowledge of these aquifers, a fracturation map of the area should be produced in order to identify the fracture networks making up the aquifer system and their inter-connectivity. This will enable us to confirm the conductive or non-conductive function of the aquifer systems.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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