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Comparative Analyses of Hydrodynamic Parameters, a Way of Understanding the Productivity of Complex Crystalline Basement Aquifers: the Case of the Tenkodogo Commune, Burkina Faso

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Abstract This hydrogeological study, carried out in the commune of Tenkodogo (Burkina Faso), aims to gain a better understanding of the productivity of aquifers using the hydrodynamic parameters of existing boreholes. The geological and climatic context of the region, characterized by a crystalline basement and a tropical climate, presents major challenges for water resource management, particularly due to low rainfall, high evapotranspiration and aquifers with low rechargeability. The analysis covers 165 boreholes, for which various data were collected, such as depth, thickness of alteration, fracturing, flow rates and local geology. The results show that 73.33% of the boreholes are productive, with a significant proportion of high-flow boreholes (> 5 m³/h), reflecting the relative abundance of groundwater resources in this region. The study highlights the importance of alteration thickness and fracturing in determining borehole flow rates. In particular, the best productivity is observed in zones with alteration between 15 and 40 m and fracturing between 20 and 50 m. The analysis also shows that boreholes drilled in geological formations such as granites, tonalites and leptynites are the most frequent and have a wide range of flow rates. The results of this study provide crucial information for the sustainable management of groundwater resources in Tenkodogo, by identifying the most promising areas, such as the leptynites, for new boreholes and optimising the use of available aquifers. This work will thus contribute to our understanding of crystalline basement aquifers and to improving drinking water supplies in this region of Burkina Faso.

Keywords: *Groundwater, basement aquifer, productivity factors, flow rates, Tenkodogo, Burkina Faso*

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1. Introduction

Burkina Faso is a landlocked country in the heart of West Africa, with a population of 20,321,378 spread over an area of 274,200 km2 [1]. 80% of Burkina Faso's territory is made up of crystalline bedrock, its topography is relatively flat and the country's climate is tropical. Because of the early drying up of surface water, the population's water needs are essentially based on groundwater [2,3,4]. However, the mobilization of this resource from wells and boreholes is most often confronted with enormous constraints. Low rainfall and high evapotranspiration are not conducive to groundwater recharge [5,6,7]. The discontinuous nature of the crystalline basement aquifers also has consequences for the distribution of groundwater [8]. This is compounded by the overexploitation of groundwater caused by high demand from various users [9], which is likely to contribute to the disruption of the aquifer balance. In addition to these constraints, geophysical investigations are currently difficult to carry out successfully. In view of this situation, a hydrogeological study is required to meet the population's water needs. The hydrodynamic parameters of existing boreholes offer a way of identifying the most productive aquifers [10,11,12]. This approach has been used by a number of specialists in several countries around the world, particularly in the field of complex basement aquifers, to identify productive aquifers [8,13,14,15,16,17]. The hydrodynamic data generally used are the depths of structures, weathering thicknesses, water inflows, static levels, flow rates and lithological information. In Ivory Coast, this approach has shown that flows in excess of 5 m^3/h are within the class range of 15 to 40 m of weathering thickness [14]. These values are of the same order of magnitude as those found by [15] in Burkina Faso, stipulating that alteration layers between 15 and 40 m give good flow rates, but outside this range the clay fraction becomes dominant, resulting in low or even zero flow rates. As a result, from the extensive investigations carried out by the Bilan d'Eau project and the Ministry of Water in the 1990s, good drilling flow rates were observed in the shales [13]. As a result, a study of the hydrodynamic parameters of existing boreholes in the Tenkodogo commune is necessary to gain a better understanding of the productivity of the aquifers in question. The aim of this study is therefore to gain a better understanding of the hydrodynamic parameters associated with borehole productivity, with a view to identifying aquifer productivity and increasing the coverage of water points in the Tenkodogo commune.

2. Study Area

The commune of Tenkodogo is located in the northern part of the Boulgou province, capital of the Centre-Est region of Burkina Faso (Figure 1). It is about 185 km from Ouagadougou, covers a surface area of 1147 km² and possesses a population of 159,105 [1]. The area has a tropical climate, with rainfall ranging from 600 mm to 900 mm. The area's vegetation consists of shrubby savannah in the north and wooded savannah and trees in the south. The relief of the area is a vast peneplain generally flat with slight variations in the east and center, and locally overlain by lateritic. Altitudes range between 250 and 350 m. Depressed areas, averaging around 250 m, are located in the south and southwest, following the direction of watercourse flow, while elevated areas, reaching 350 m, are found in the north. The local geology belongs to the Birimian basement, with plutonic formations, volcano-sedimentary belts and metamorphic facies [18]. The commune is underlain leptynites, surrounded by banded granodiorite/tonalite both intruded the Tenkodogo granite. The leptynites and the granodiorite/tonalite exhibit a structural fabric (foliation or regional shape) oriented NE-SW, aligning with the dominant regional deformation direction [19, 20]. The Tenkodogo granite is the southern edge of a 125 km-length NE-SW oriented massif affected by dextral strike-slip [21]. Regional megafractures running NE-SW intersect these geological formations (Figure 2).

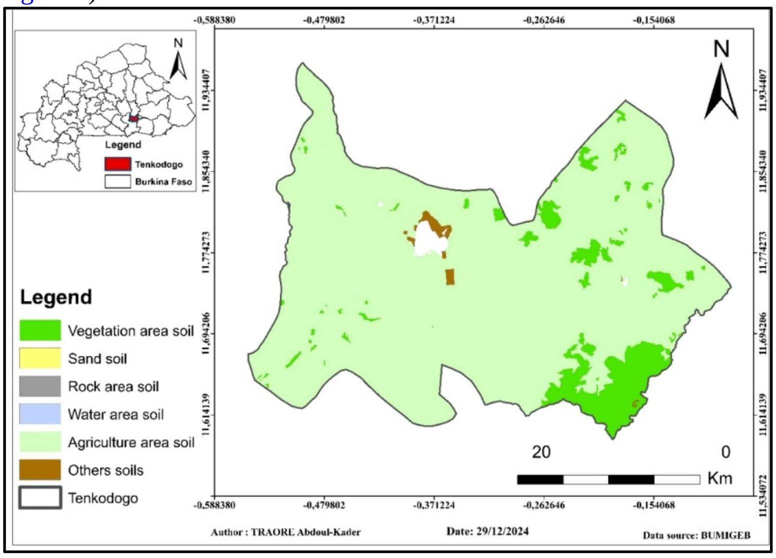

Figure 1. Location of the study area

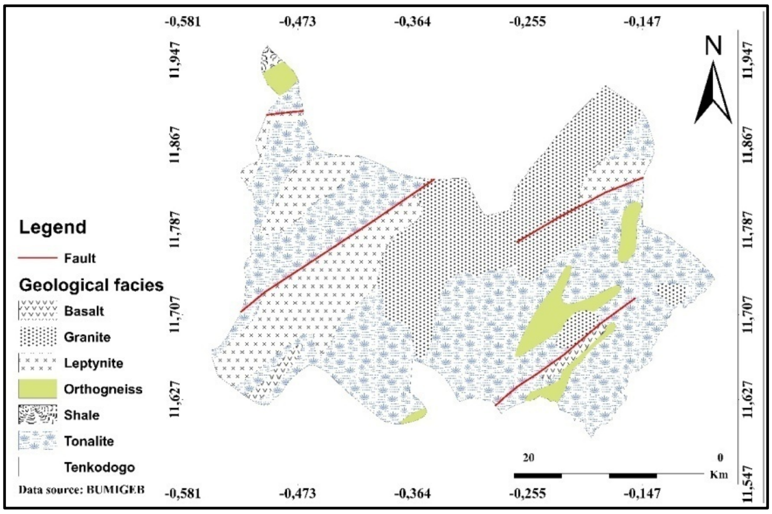

Figure 2. Geological map of the study area

3. Material and Methods

3.1. Data

Data on the characteristics of the boreholes were obtained from Burkina Faso geological service BUMIGEB. In total, 165 borehole data were concerned by this study. The following details were collected during the drilling operations: geographical location, altitude, type of the borehole, lithology of the point, depth of boreholes, thickness of alteration, thickness of fissured fringe, static levels, instantaneous flow rates. The weathered zone is defined as the thickness of unconsolidated to easily friable material, coinciding with the soil, saprolite, and heavily weathered rock. The fissured fringed is define as the zone ranging from the corestone to the front of the bedrock. In addition to these data, geographical data from the IGB was required to produce the thematic maps.

3.2. Data Analysis and Processing

We carried out a series of multivariate statistical analyses, in which the behavior of each parameter on productivity was recorded individually. These analyses consisted of analyzing the data by parameter and grouping them into intervals of amplitude 5 or 1. This was done on the basis of the minimum and maximum values for each parameter. The flow rate is averaged for each interval to produce histograms and scatter plots. A spatial model of weathering thickness and fissured zone thickness was developed using linear interpolation to vizualize their regional distribution and variation between boreholes. The data processing platforms used are ArcMap 10.8 and Excel.

To better appreciate the distribution of borehole flow rates, we used the classification of CIEH which is as follows: 0 to 0.7 m^3/h: very low flow rates; 0.7 to 2.5 m^3/h: low flow rates; 2.5 to 5 m^3/h: medium flow rates; over 5 m^3/h: high flow rates.

In general, in village hydraulics, a flow rate of at least 0.7 m^3/h is required to equip a borehole. In addition, a flow rate of less than 0.7 m^3/h can be accepted depending on the scarcity of the resource [22]. However, for the purposes of this study, a borehole with a flow rate of less than 0.7 m^3/h will be declared negative.

4. Results and Discussion

4.1. General Analysis of Drilling Parameters

4.1.1. Flow Rates

The results of the classification of the flow rates of the boreholes studied using the CIEH method gave us the rate of boreholes per flow rate class. It emerges that 26.67% of the boreholes drilled in this locality are negative because their flow rates are very low, i.e. less than 0.7 m^3/h. In addition, 24.24% of boreholes have low flow rates. Medium-flow boreholes account for 18.79% of all boreholes and high-flow boreholes for 30.30% (Figure 3). Overall, 73.33% of boreholes are positive in the Tenkodogo commune. In addition, almost 30% of the flow rates recorded are greater than 5 m^3/h, which represents acceptable flow rates for a mini drinking water supply network for the population. These results reflect the abundance of groundwater resources in the Tenkodogo commune. These results are of the same order of magnitude as those found by other authors in the West African base [13,20].

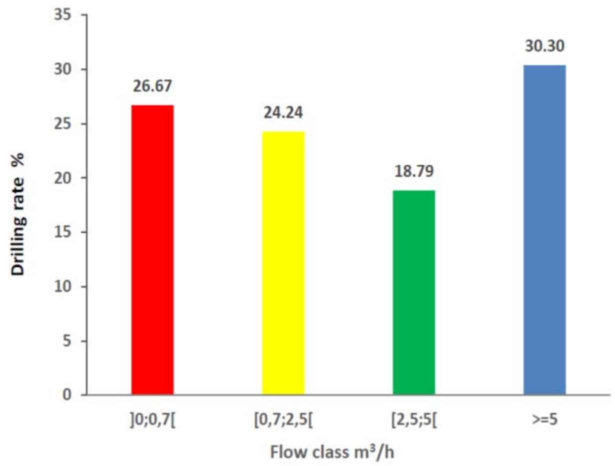

Figure 3. Drilling rate by flow rate class

4.1.2. Correlation Between Flow Rates and Weathering Thickness

The map of weathering thicknesses in the Tenkodogo commune shows that 60% of the area is covered by weathering of between 10 and 20 metres. Alteration thicknesses of between 20 and 30 m and between 30 and 40 m are largely represented in the western part of the locality. A reading of the map shows that no negative boreholes are located in the 30-40 m alteration thickness range. The range of alteration thicknesses below 10 m is only found in the eastern part of the area (Figure 4). This observation would indicate a low infiltration rate of rainwater in this eastern part of the Tenkodogo commune, thus compromising groundwater recharge at this level. This hypothesis is confirmed by the presence of boreholes with very low to low flow rates.

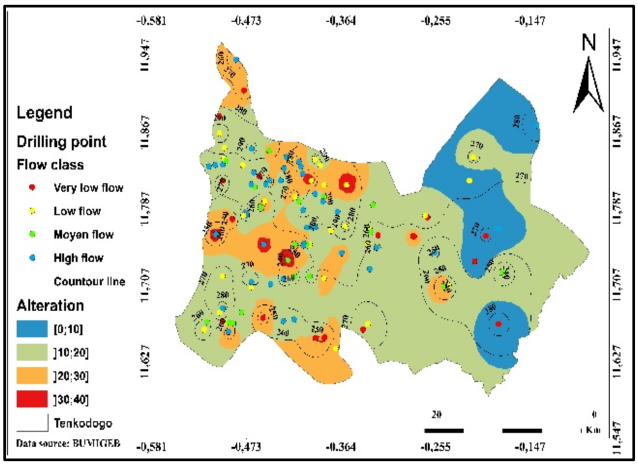

Figure 4. Interpolated map of weathered zone thickness in the Tenkodogo commune (contour lines = elevation contour lines)

Analysis of the graph (Figure 5) shows a low correlation coefficient between flow rates and weathering thickness, suggesting that there is no relationship between the two parameters in our specific context. However, it can be seen that alteration thicknesses between 5-15 m and 25-35 m have very high flow rates. From a thickness of 35 m, the flow rate from the boreholes decreases sharply. These values are more or less of the same order of magnitude as those found by [14] and [15] stipulating that alteration layers between 15 and 40 m give good flow rates, but outside this range the clay fraction becomes dominant, resulting in low or even zero flow rates.

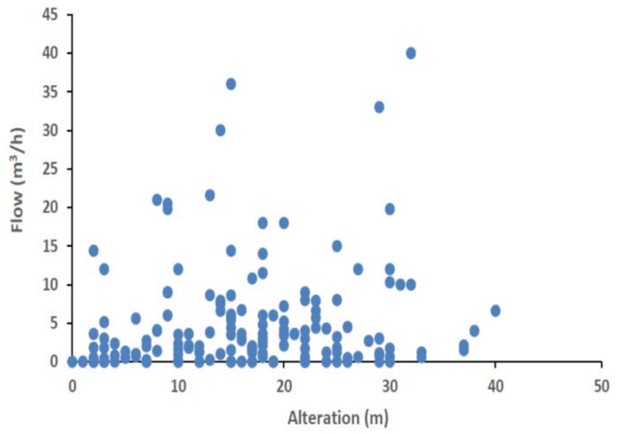

Figure 5. Evolution of flow rates with weathering thickness.

4.1.3. Flow Rate and Thickness of the Cracked Fringe

Observation of this map shows that around 50% of high-flow boreholes are located in zones where the thickness of fracturing is between 20-30m (Figure 6). It can also be seen that the most dominant class of fractured fringe is that between 30 and 45m. A study of the average flow rate by fracture thickness class shows that the highest flow rates are concentrated between 20 and 50 m thickness. Beyond 50 m, most of the boreholes obtained are negative or have almost no flow (Figure 7). For fracture thicknesses of less than 20 m, there are a few high flow rates. However, the majority of boreholes in this thickness range have medium and low flow rates.

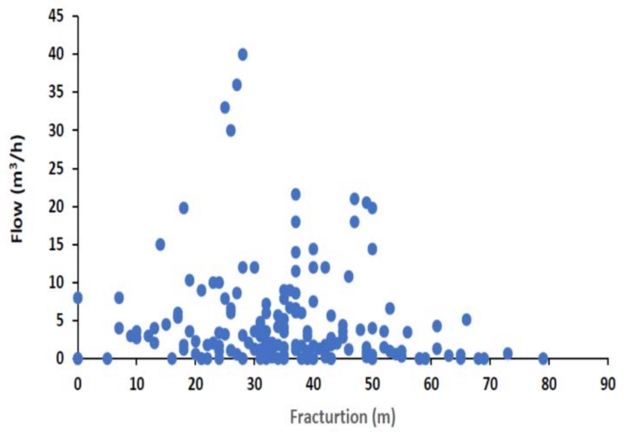

Figure 6. Graph showing the evolution of flow rates with the thickness of the fissured fringe

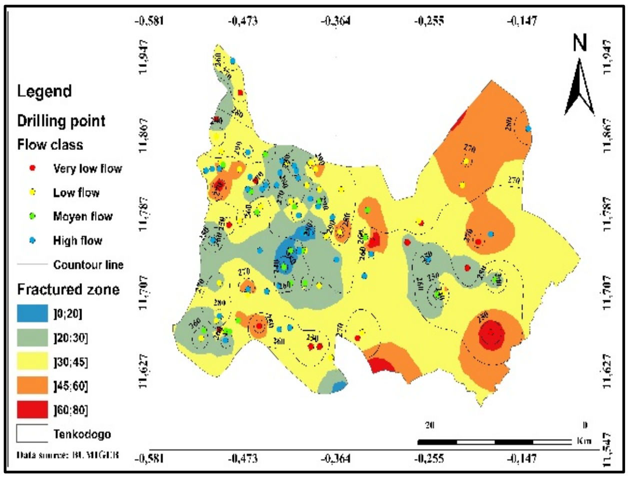

Figure 7. Interpolated map of fissured fringe thickness in the Tenkodogo commune (contour lines = elevation contour lines)

4.1.4. Drilling Rate and Depth

The various borehole depths vary between 12 and 85 m, with an average of 52 m and a very low correlation coefficient with flow rate. Figure 7 shows that from a depth of 20 m, average flow rates increase with depth up to 60 m.

High flow rates are mainly obtained between 40 and 60 m depth. This result confirms the findings of [24], who state that the most productive boreholes are at depths of between 40 and 60 m in crystalline environments (Figure 8).

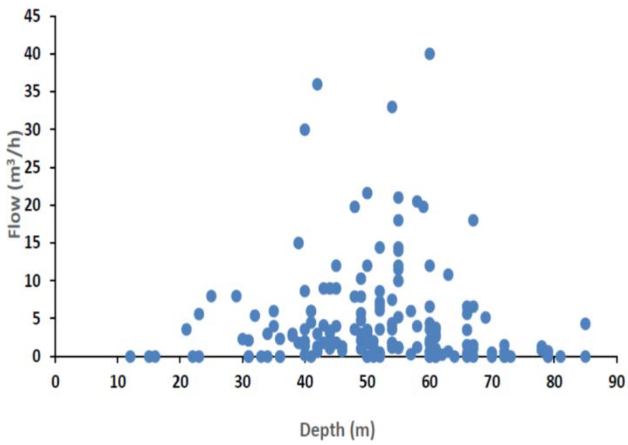

Figure 8. Echanges in flow rate vs drilling depth

4.1.5. Flow Rate and Topography

The altitude at which the boreholes are located varies between 230 and 322 m, with an average of 286 m and a very low correlation coefficient (0.18) with flow rate. The topographical map (Figure 9) of the municipality of Tenkodogo shows that the boreholes with the highest flow rates are located on the slopes at altitudes of between 270 and 310 m. However, low flow rates are also observed in this same altitude range. Remarkably, low flow rates were obtained in the valleys, which contradicts the results of [25], who state that boreholes generally located in valleys have the highest flow rates.

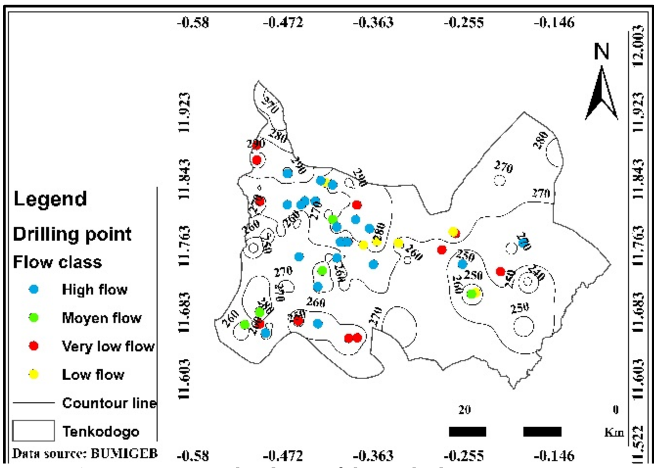

Figure 9. Topographical map of the Tenkodogo commune

It would be difficult to say that all the boreholes drilled in the valleys will have good flow rates. From these observations, we can say that other factors such as alteration, fracturing and geology play a very important role in determining which boreholes will have good flow rates.

4.2. Flow Distribution According to Lithology

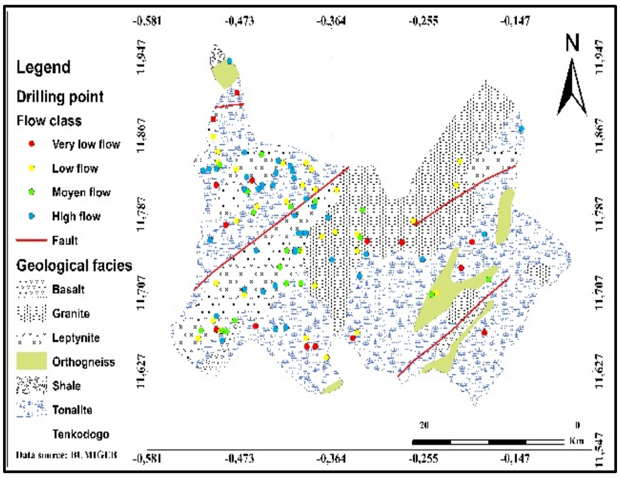

Figure 10. Geological map and distribution of boreholes

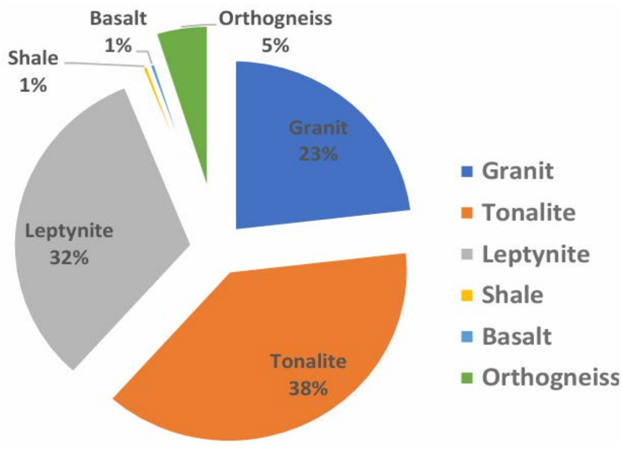

Figure 11. Distribution of boreholes by geological formation

The geological formations in the Tenkodogo commune belong to the crystallophyllous basement and consist mainly of tonalite, leptynite granite, orthogneiss, schist and basalt (Figure 10). However, 93% of the 165 boreholes surveyed were in granites (23%), tonalites (32%) and leptynites (38%). In the other formations, there are not enough boreholes to analyse the productivity of the aquifers (Figure 11). It can be seen that all these lithologies have variable flow rates, ranging from very low to very high. Table 1 shows the statistics for the hydrodynamic parameters of boreholes by lithology in the municipality of Tenkodogo.

The hydrodynamic characteristics of the boreholes show that the average depths at which the boreholes were stopped were 83 m, 68.75 m and 68.42 m respectively for leptynites, tonalites and granites. We note that the decision to continue or stop drilling is linked to several factors, which include the flow rate of water sought, the state of fracturing of the rock, the geological facies and the technical control of the drilling [26]. In terms of flow rate, the leptynites are the most productive aquifers in the Tenkodogo commune. In fact, the leptynite aquifer has the highest average flow rate (6.14 m^3/h). There is a difference between the average alteration thickness for the leptynite (18.45 m) and the other formations (15.75 m for the tonalites and 13.39 m for the granites). This explains the highly porous nature of the leptynites, marked by significant fracturing within this aquifer. This favours significant infiltration of rainwater to add to the underground water reservoirs in the leptynites (Table 1).

Table 1. Statistics of borehole hydrodynamic parameters by lithology

Formations	Positive Borehole	Flow Average	Thickness of weathering average (m)	Depth of borehole average (m)
Leptynite	83,01	6,14	18,45	48,49
Tonalite	68,75	4,61	15,75	53,46
Granite	68,42	3,91	13,39	52,58

5. Conclusion

The hydrogeological study carried out in the commune of Tenkodogo provides a better understanding of the productivity of underground aquifers and identifies the key factors influencing borehole yield. The results reveal a wide range of flow rates, with the majority of boreholes producing satisfactory flows, particularly in areas where the thickness of alteration and the depth of the boreholes are optimal. Indeed, alteration zones of between 15 and 40 metres, as well as boreholes between 40 and 60 metres deep, are associated with the best yields. On the other hand, certain areas with little alteration or particular geological formations, such as basalts and shales, have lower yields. However, despite the presence of low-flow boreholes, the potential of groundwater resources in the municipality remains promising overall. Around 73.33% of boreholes have flow rates that are deemed adequate, which means that drinking water can be supplied to a large extent. These results, which corroborate previous studies carried out in the region and beyond, provide a solid basis for optimum management of water resources. This study is therefore a crucial tool for the development and sustainable management of village water supply in Tenkodogo. It will be used to guide water infrastructure extension projects, targeting high-potential areas such as the leptynites, and taking into account the geological and hydrodynamic factors influencing borehole productivity. In the future, we plan to use isotope chemistry to gain a better understanding of the hydrodynamics of groundwater.

Abbreviations

BUMIGEB : Bureau des Mines et de Géologie du Burkina

CIEH: the Comité Interafricain d'Études Hydrauliques

IGB: Institut Géographique du Burkina (IGB

INSD: Institut National de la Statistique et de la Démographie

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