

Lithological and Hydrodynamic Controls on Borehole Productivity in Basement Aquifers of the Poro Region, Northern Côte d'Ivoire

Koffi Yao Honoré^{*}, Kpan Oulaï Jean-Gautier, Kouadio Assoué Sylvestre, De Lasme Omer Zéphir

Department of Geosciences, UFR Biological Sciences, Péléforo Gon Coulibaly University, Korhogo, Côte d'Ivoire
Email: *koffiyao@upgc.edu.ci

How to cite this paper: Honoré, K.Y., Jean-Gautier, K.O., Sylvestre, K.A. and Zéphir, D.L.O. (2026) Lithological and Hydrodynamic Controls on Borehole Productivity in Basement Aquifers of the Poro Region, Northern Côte d'Ivoire. *International Journal of Geosciences*, 17, 835-850.
<https://doi.org/10.4236/ijg.2026.1710039>

Received: June 30, 2026

Accepted: October 27, 2026

Published: October 30, 2026

Copyright © 2026 by author(s) and Scientific Research Publishing Inc.
This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).
<http://creativecommons.org/licenses/by/4.0/>



Open Access

Abstract

This study investigates the lithological and hydrodynamic controls on borehole productivity in basement aquifers of the Poro Region, northern Côte d'Ivoire. The aim is to identify the factors controlling yield contrasts and borehole drying risks in fractured crystalline terrains. The methodology combines borehole technical sheets, metre-by-metre descriptions of drill cuttings, lithological logs, pumping-test interpretation using the Cooper-Jacob recovery method, and statistical analyses of hydrogeological parameters. The results show a typical weathered-fractured basement architecture, including lateritic duricrust, weathered clays, granitic saprolite and fractured granite. First water strikes mainly occur within fractured granite, with several of water inflows recorded between 27 and 60 m depth. Boreholes have an average depth of 79 m, an average exploitation yield of 8.09 m³/h, an average specific capacity of 0.25 m³/h/m and an average transmissivity of 2.38 × 10⁻⁴ m²/s. Correlations and normalized principal component analysis indicate that productivity is primarily governed by transmissivity, hydraulic conductivity and specific capacity, whereas simply drilling deeper does not guarantee higher yields. These findings support the need for structural and geophysical targeting of connected fractures, together with long-term piezometric and hydrochemical monitoring.

Keywords

Basement Aquifer, Fractured Granite, Transmissivity, Specific Capacity, Boreholes, Poro, Côte d'Ivoire

1. Introduction

In the basement regions of West Africa, the supply of drinking water depends

largely on boreholes in discontinuous reservoirs, consisting of a weathered mantle that provides storage and a conductive fissured horizon. Synthesis work on hard-rock aquifers shows that these systems are strongly controlled by weathering and hydraulic connectivity rather than by drilling depth alone [1]-[4]. In Côte d'Ivoire, crystalline and crystallophyllian rocks occupy a large part of the territory. Basement aquifers are a strategic resource for urban and rural water supply, but productivity remains variable owing to lithological heterogeneity and the spatial variability of weathering and fractures [4]-[7]. Studies in West Africa further show that borehole yield is influenced by weathered-layer geometry, transmissivity and recharge conditions [8]-[12]. In the Poro region, water needs are increasing as a result of population growth, urbanization of Korhogo and the intensification of agricultural and pastoral activities. However, several structures are experiencing performance declines or seasonal drying. The present study therefore aims to specify the lithological and hydrodynamic controls of borehole productivity in basement media. The objectives are 1) to characterize the lithological architecture of the boreholes and 2) to identify the hydrogeological and hydrodynamic parameters and analyse the relationships between depth, weathering, water inflows, transmissivity and specific capacity.

2. Geographical, Geological and Hydrogeological Framework

The Poro region, of which Korhogo is the capital (**Figure 1**), is located in northern Côte d'Ivoire, approximately between 8° 40' and 9° 45' North latitude and 5° 20' and 6° 20' West longitude. The region has a dry tropical climate and a monomodal rainfall regime, with a rainy season concentrated from May to October and a long dry season. The relief is dominated by plains and gently undulating plateaus drained by the Bandama and its tributaries, in particular the Lofigué and the Solomougou.

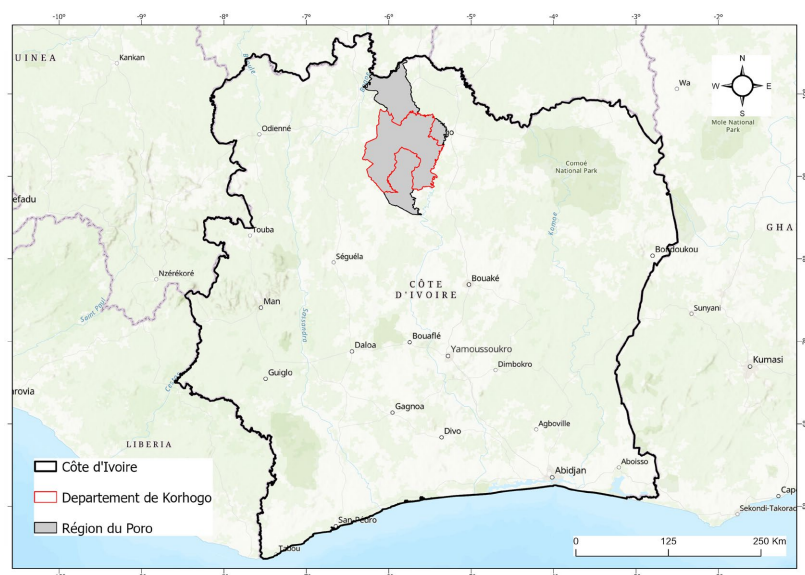


Figure 1. Geographical location of the study area in the Korhogo Department (adapted from [13] Camara, 2024).

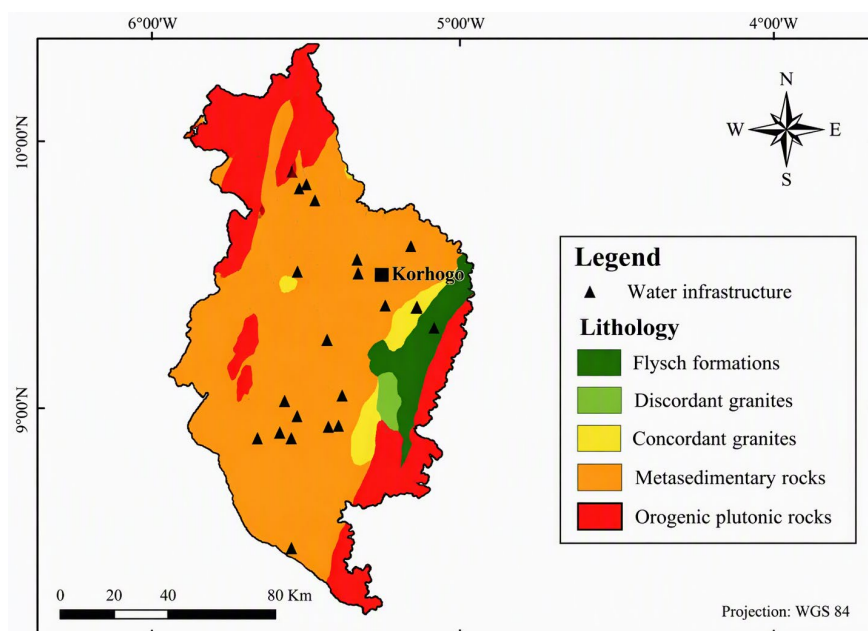


Figure 2. Geological map of the Poro Region showing the lithological formations and the locations of hydraulic structures (after [13] Camara, 2024).

Geologically, the Poro region belongs to the Birimian domain of the West African craton. The geological formations include granitoids, granodiorites, migmatites, shales, and volcano-sedimentary formations (Figure 2). These units are affected by fractures whose hydraulic effectiveness depends on weathering, aperture and connectivity; the presence of a mapped lineament alone does not establish a productive aquifer [2] [9] [14] [15].

Hydrogeologically, two complementary reservoirs are distinguished: the generally more capacitive weathered materials and the more conductive fractured horizon (Figure 3). This model is consistent with conceptual studies of crystalline aquifers and field investigations in Côte d'Ivoire and Nigeria [1]-[4] [16] [17].

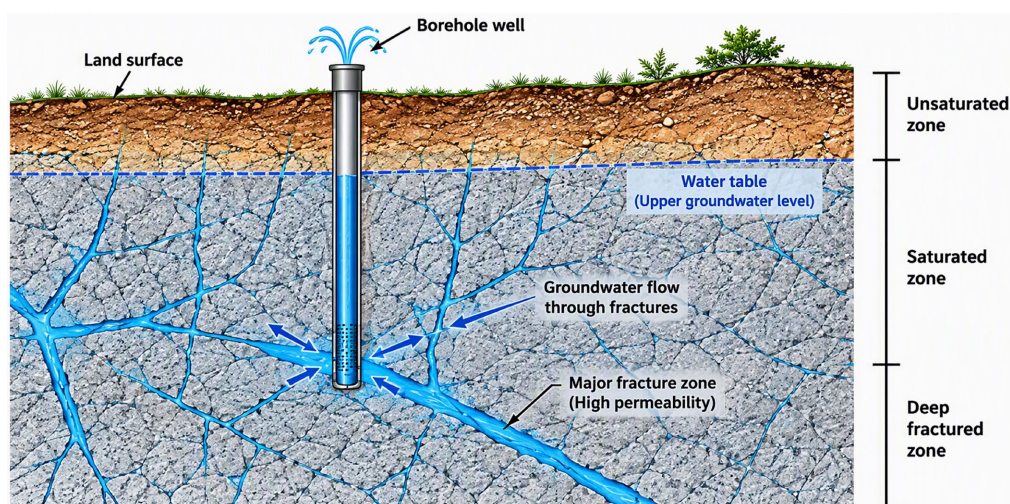


Figure 3. Schematic illustration of the weathered-fractured system of basement aquifers.

3. Materials and Methods

The database includes drilling data sheets, drilling reports, pumping test results and lithological descriptions made from cuttings collected meter by meter (**Figure 4**). The variables studied are the total depth, the static level, the depths of water strikes, the thickness of the weathering mantle, the pumping-test discharge, the specific capacity, the transmissivity and the hydraulic conductivity.

3.1. Sampling and Description of Drill Cuttings

Drill cuttings were collected at regular 1-m intervals and macroscopically described according to color, grain size, texture, the lithological nature of the rocks intersected by the boreholes, and groundwater inflows. These observations were used to construct lithological logs and determine the thickness of the weathered layer, the depth to the top of the fresh basement, the position of productive fractured horizons, and the total depth of each borehole. The integrated interpretation of weathering and fracturing patterns was used to define the vertical organization of the aquifer system and to identify the horizons likely to provide groundwater storage and flow. Similar combinations of borehole logs and geophysical information have been used to characterize weathered-rock aquifers [15] [17] [18].



Figure 4. Boxing of crushed samples collected at one-meter intervals in the Dikodougou area, Northern Côte d'Ivoire.

3.2. Technical and Geometrical Borehole Parameters

Borehole productivity was assessed using air-lift yields and operational pumping rates. The air-lift yield, measured after borehole development, was used as a preliminary indicator of productivity and was not considered equivalent to the sustainable operational yield. Borehole productivity in the Poro Region was classified according to the adapted [19] classification presented in **Table 1**.

Table 1. Operational classification of air-lift yields adapted from [19].

Air-lift yield class (m ³ /h)	Productivity level
0 to <1	Very low
1 to <2.5	Low
2.5 to <5	Moderate
≥5	High

Hydrodynamic parameters were determined from pumping tests conducted at a discharge rate maintained as constant as practicable. Before pumping began, the static water level was measured from a fixed reference point. During both the drawdown and recovery phases, time, discharge rate, and water levels were recorded. The resulting datasets were subsequently checked to identify outliers, discharge-rate variations, and inconsistencies in time records or measurement units. Such quality control is important when interpreting pumping and recovery tests in heterogeneous formations [7] [20] [21].

3.3. Determination of Transmissivity Using the Cooper-Jacob Method

Transmissivity was estimated using the Cooper-Jacob semi-logarithmic method, which represents a late-time approximation of the Theis solution. In basement aquifers, where the assumptions of homogeneity, isotropy and lateral continuity are rarely fully satisfied, the method was applied only to the approximately linear late-time segment of the drawdown-time curve. The effects of heterogeneity on this approximation have been examined in pumping-test studies [20] [21]. Transmissivity was calculated as follows:

$$T = 0.183Q/\Delta s$$

where T is transmissivity (m²/s), Q is the pumping rate (m³/s), and Δs is the change in drawdown over one logarithmic cycle of time.

Recovery data were used as an independent control, while recognizing that non-ideal test conditions can affect their interpretation [21]. Equivalent hydraulic conductivity was calculated using the following relationship:

$$K = T/e$$

where e is the saturated thickness of the aquifer. In a fractured medium, this value represents the overall hydraulic behaviour of the tested interval rather than the intrinsic hydraulic conductivity of each individual fracture. Specific capacity was calculated as follows:

$$Q_{sp} = Q/s_m$$

where Q is expressed in m³/h and s_m is the maximum drawdown in meters. To ensure comparability among boreholes, discharge rates and drawdowns were considered at the same stage of the test or at the end of the final stabilized step.

3.4. Principal Component Analysis (PCA)

A standardized Principal Component Analysis (PCA) was subsequently per-

formed to identify associations among the variables and the main factors controlling borehole productivity. Depending on data availability, the input matrix included total borehole depth, air-lift yield, operational pumping rate, maximum drawdown, specific capacity, transmissivity, and hydraulic conductivity. Measurement units were harmonized, after which the variables were centred and standardized. Strongly skewed variables were logarithmically transformed where necessary. The components were extracted from the correlation matrix. The number of retained components was determined by combining eigenvalues greater than 1, the scree plot, the cumulative proportion of explained variance, and hydrogeological interpretability. Data completeness and selection bias should be considered when interpreting the borehole database [4] [22].

The PCA was interpreted using factor loadings, variable contributions, squared cosines ($\cos^2$), correlation circles, and borehole projections on the factorial planes. Components characterized by high contributions from transmissivity, hydraulic conductivity, specific capacity and discharge rates were interpreted as hydraulic-productivity gradients. Components dominated by borehole depth, weathered-layer thickness or drawdown were associated with reservoir geometry, degree of weathering or operational constraints. The analysis of relationships among the parameters was based on descriptive statistics, bivariate correlations and standardized PCA; related approaches have been applied to fractured aquifers in Côte d'Ivoire [6] [7] [23].

Finally, the results obtained from the lithological logs, pumping tests, and PCA were integrated into a combined interpretation. This approach made it possible to distinguish boreholes whose productivity was primarily controlled by hydraulically effective fracturing from those whose performance was associated with a thick weathered layer or specific local conditions. It therefore provides an objective basis for classifying boreholes and guiding future siting campaigns in crystalline basement aquifers.

4. Results

4.1. Lithological Architecture of the Boreholes

The lithological logs reveal a typical succession comprising, from the top to the base, a lateritic duricrust, lateritic or variegated clays, a granitic saprolite and a fissured granite. The superficial horizons mainly provide a storage function, while the fractures in the granite control the preferential circulation and exploitable groundwater inflows (Figure 5). Comparable vertical weathering profiles and fractured horizons have been described in crystalline aquifers [1]-[4] [17].

This interpretation should be considered alongside evidence that the geometry of the weathered profile can influence borehole productivity [4] [9].

Analysis of the first water strikes indicates that several of them occur in the fissured granite, mainly between 27 and 60 m depth (Figure 5). This result confirms that productivity depends more on the interception of open and connected fractures than on the presence of a significant thickness of weathered materials

alone.

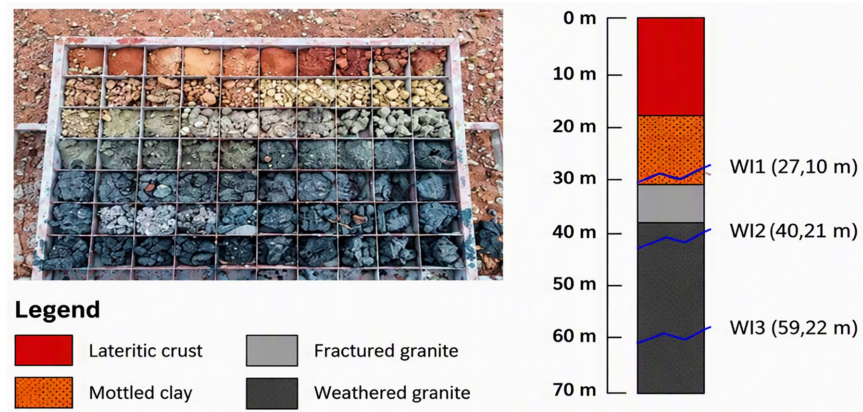


Figure 5. Lithological logs and position of water inlets in the boreholes studied.

4.2. Hydrogeological and Hydrodynamic Parameters

Table 2 presents all the hydrogeological and hydrodynamic parameters. The total depths vary from 59.77 to 104.90 m, with a mean of 79 m. Static levels range from 2.75 to 18.88 m, with an average of 10.51 m. The first water inflow is observed on average at 23.22 m. The average pumping-test discharge rate is 8.09 m³/h, which indicates substantial potential for rural water supply, although the dispersion of values remains high. Specific capacities range from 0.04 to 0.61 m³/h/m, illustrating the heterogeneity of fractured-basement aquifers. The mean transmissivity is 2.38×10^{-4} m²/s, with minimum and maximum values of 3.84×10^{-5} m²/s and 1.05×10^{-3} m²/s, respectively (**Table 3**). The variability of transmissivity is comparable in principle to the heterogeneous hydraulic behaviour reported in other Ivorian fractured aquifers, although direct numerical comparison requires consistent test conditions and units [7] [23].

Table 2. Parameters analyzed and hydrogeological purpose.

Parameter	Method/Calculation	Purpose
Lithological logs	Macroscopic description of drill cuttings by lithological horizon	Identify aquifer materials and levels
Water strikes (AE)	Depths intercepted during drilling	Locate productive horizons
Transmissivity T	Cooper-Jacob analysis of recovery data	Assess the aquifer's transmissive capacity
Specific capacity Q_{sp}	$Q_{sp} = \frac{Q}{S_{max}}$	Compare the relative productivity of boreholes
Hydraulic conductivity K	$K = \frac{T}{e}$	Assess the effective permeability of the aquifer
Standardized PCA and correlations	Descriptive statistics and Pearson correlations	Identify productivity drivers

Table 3. Statistical synthesis of hydrogeological parameters.

Parameter	Minimum	Maximum	Mean
Total depth (TD) (m)	59.77	104.90	79.00
Static level (WSL) (m)	2.75	18.88	10.51
First water inflow (WI1) (m)	10.40	55.60	23.22
Pumping-test discharge rate (Q) (m ³ /h)	2.00	20.00	8.09
Specific capacity (Q_{sp}) (m ³ /h/m)	0.04	0.61	0.25
Weathering thickness (WT) (m)	3.91	48.40	12.71
Transmissivity (T) (m ² /s)	3.84×10^{-5}	1.05×10^{-3}	2.38×10^{-4}

The total depths vary from 59.77 to 104.90 m, with a mean of 79 m. The average static level is 10.51 m, while the first water inflow is observed on average at 23.22 m (Figure 6). The average pumping-test discharge rate is 8.09 m³/h, which indicates substantial potential for rural water supply. The mean transmissivity is 2.38×10^{-4} m²/s, but the values span more than one order of magnitude, illustrating the typical heterogeneity of fissured aquifers.

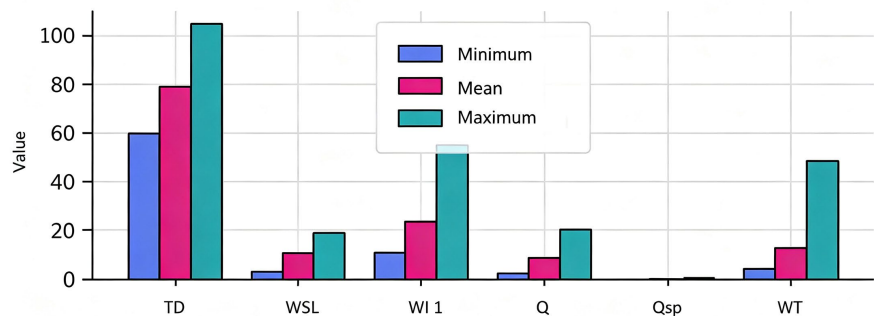


Figure 6. Statistics of drilling parameters (TD: Total depth; WSL: Static level (m); WI: First water inflow; Q: Pumping-test discharge rate in m³/h; Q_{sp} Specific capacity in m³/h/m; WT: Weathering thickness (m)).

The statistical analysis of the regional pumping-test discharge presented in Table 4 and Figure 6 shows the positions of the minimum, mean and maximum values on the CIEH class scale. The regional average (7.6 m³/h) places the region in the “high” category. The observed minimum (0 m³/h) falls into the “very low” class, while the observed maximum (20 m³/h) reaches the “very high” class (Figure 7).

Table 4. Regional hydrodynamic characteristics.

Parameter	Mean	Minimum	Maximum	CV (%)
Specific capacity (Q_{sp}) (m ³ /h/m)	0.24	0.04	0.61	75
Transmissivity (T) (m ² /s)	2.38×10^{-4}	3.84×10^{-5}	1.05×10^{-3}	95
Pumping-test discharge rate (Q) (m ³ /h)	7.60	0.00	20.00	74
Hydraulic conductivity (K) (m/s)	2.82×10^{-5}	1.20×10^{-6}	3.10×10^{-4}	98

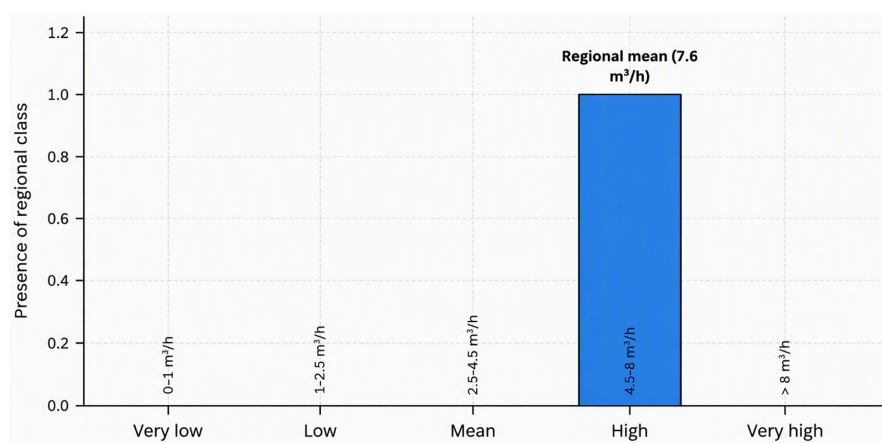


Figure 7. Histogram of the pumping-test discharge classes of the Poro region according to the regional average and the CIEH classification.

In accordance with the CIEH classification, regional pumping-test discharges are shown in **Figure 8**. The study carried out in the Poro region indicates that 85.29% of the boreholes exceed 1 m³/h, although a significant proportion still exhibits low discharge rates. This reflects an average productivity that is generally acceptable, but spatially heterogeneous.

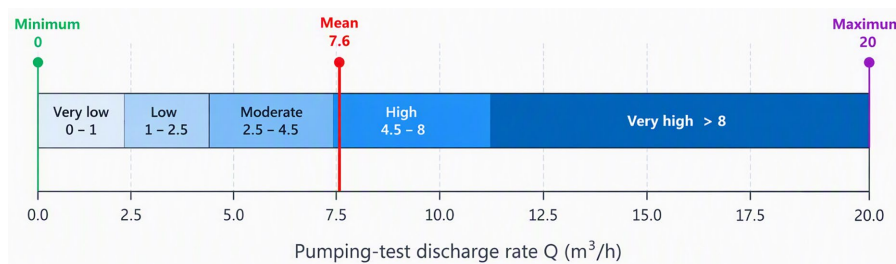


Figure 8. Position of the region's pumping-test discharge on the CIEH scale (1978).

4.3. Productivity of Intercepted Aquifer Levels

The average productivity increases as successive aquifer levels are intercepted: the average discharge increases from 2.34 m³/h at WI1, to 4.28 m³/h at WI2, then to 5.87 m³/h at WI3 (**Table 5**, **Figure 9**). This progression suggests that the deeper horizons intercepted by drilling often correspond to better-developed or better-connected fractures, without, however, implying that systematic deepening is always effective. Comparable studies caution against treating greater drilling depth as a general guarantee of higher yields [4] [8] [9] [24].

Table 5. Depths and average flows of successive water inflows.

Aquifer level	Mean depth (m)	Mean discharge (m³/h)	CV (%)
WI1	23.22	2.34	0.49
WI2	33.38	4.28	0.46
WI3	44.58	5.87	0.46

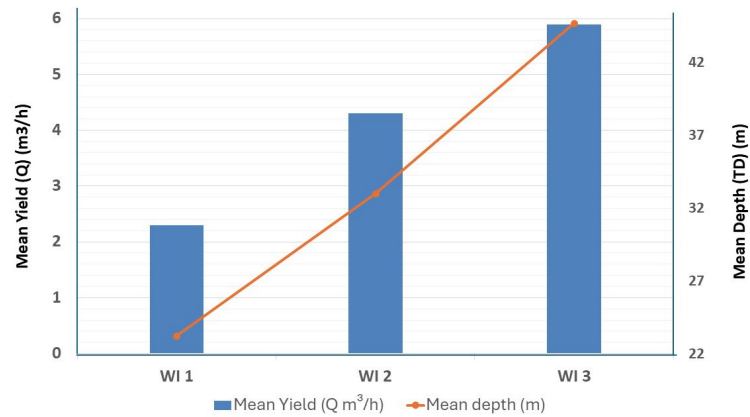


Figure 9. Evolution of mean yield with intercepted aquifer levels and depth.

4.4. Relationships between Productivity Parameters

The major correlations between the hydrodynamic parameters are presented in **Table 6**. The strongest correlations are observed between transmissivity and hydraulic conductivity ($r = 0.95$), between specific capacity and transmissivity ($r = 0.80$), and between pumping-test discharge and air-lift flow ($r = 0.79$). These relationships confirm that the most productive structures are associated with more transmissive and hydraulically better connected environments. Conversely, the negative correlations between discharge and depth of water inflow ($r = -0.74$) and between specific capacity and total depth ($r = -0.70$) show that depth alone is not a reliable indicator of productivity.

Table 6. Major correlations between hydrodynamic parameters.

Pair of variables	r	Interpretations
T-K	0.95	Very strong positive
Q_{sp} -T	0.8	Strong positive
Q-Qairlift	0.79	Strong positive
Pt-WSL	0.66	Moderate positive
Pt-WI	0.66	Moderate positive
Q-K	0.67	Moderate positive
Q-WI	-0.74	Strong negative
Q_{sp} -TD	-0.7	Strong negative

The linear relationship between transmissivity and specific capacity is expressed as $T = 1.04e-03 \times Q_{sp} - 1.61e-05$, with $R^2 = 0.678$ (**Figure 10**). This relationship confirms the usefulness of specific capacity as an indicator of the transmissive capacity of fractured horizons, even if the dispersion of the points reflects the effect of lithological and structural heterogeneity. Empirical relationships between specific capacity and transmissivity have also been examined in the Lacs and San-Pedro regions, but their coefficients are site-dependent [7] [23].

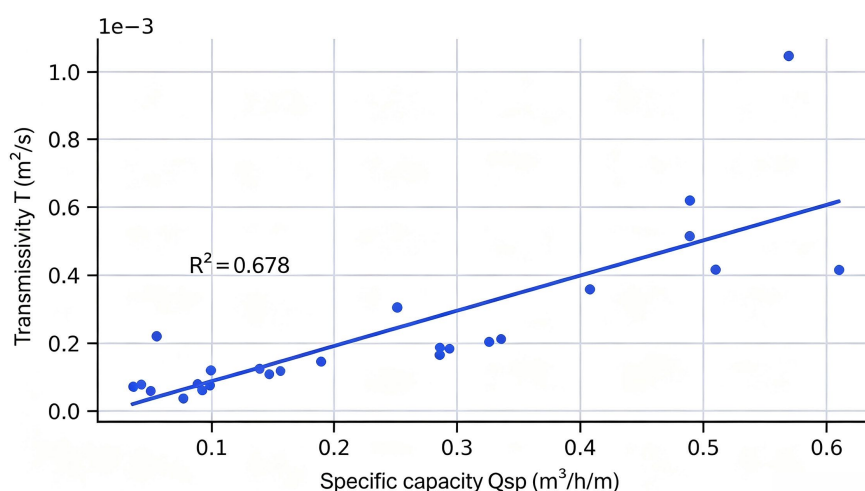


Figure 10. Relationship between transmissivity and specific capacity of boreholes.

4.5. Standardized Principal Component Analysis (PCA)

Table 7 summarizes the variation in productivity and lithological architecture. The first three axes of the PCA explain 79.87% of the total variance. Axis F1, which explains 47.92% of the total variance, is mainly associated with the hydrodynamic productivity variables (**Figure 11**): transmissivity, hydraulic conductivity, specific capacity and flow rate. Axis F2 is more closely linked to the lithological architecture (**Figure 12**) and to the depths, in particular to the weathering-depth relationship (**Table 7**). This analysis confirms the separation between direct hydraulic control of productivity and geological control that modulates the probability of intercepting productive fractures. The PCA should be read as an exploratory description of covariation rather than proof of causal controls [4] [6] [22].

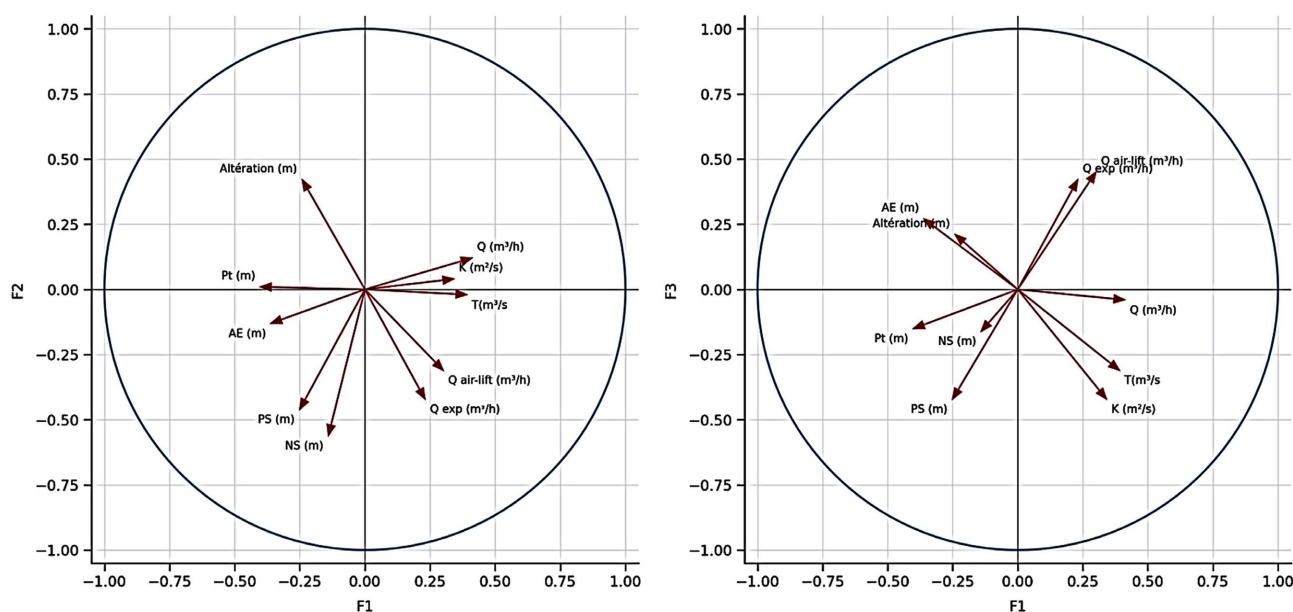
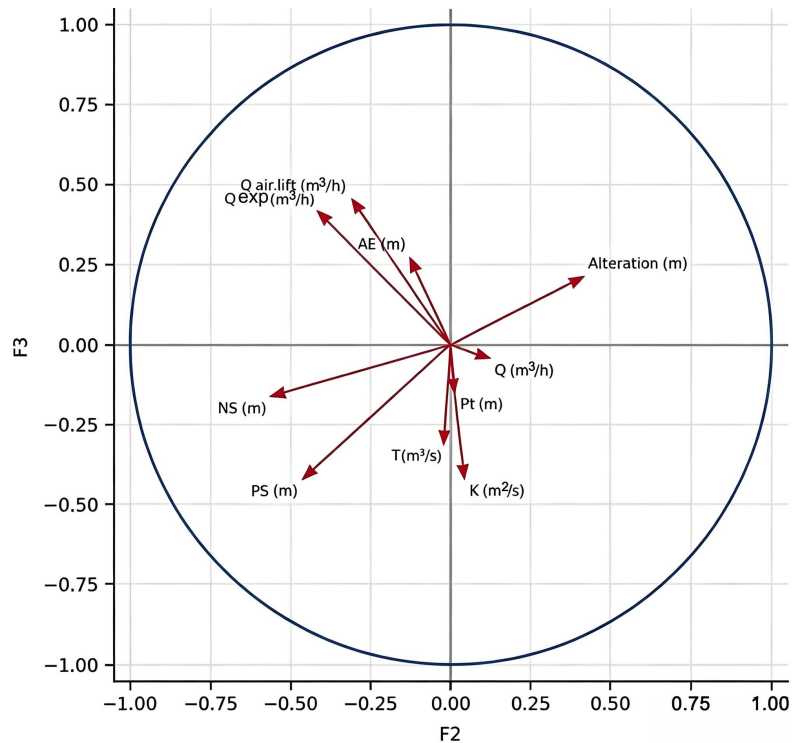


Figure 11. Circle of PCA correlations on the F1-F3 plane.

Table 7. Eigenvalues and variance explained by the first three axes of the PCA.

Axis	Eigenvalue	Explained variance (%)	Cumulative variance (%)
F1	4.792	47.92	47.92
F2	1.799	17.99	65.91
F3	1.396	13.96	79.87

**Figure 12.** Circle of PCA correlations on the F1-F2 plane.

5. Discussion

The results highlight a hydrogeological architecture consistent with the basement-aquifer model: weathered materials mainly provide a capacitive function, while the fissured/fractured horizon provides a conductive function [1]-[4]. The predominance of fissured granite among first water inflows in Poro supports the importance of hydraulically effective fractures but does not imply that saprolite is irrelevant to groundwater storage and recharge [4] [11] [16]. Field investigations in Nigeria and Burkina Faso similarly show that the weathered cover, the fractured zone and local heterogeneity must be interpreted together [9] [15] [17].

The mean transmissivity of $2.38 \times 10^{-4} \text{ m}^2/\text{s}$ and the dispersion of borehole productivity in Poro should be viewed in the context of regional heterogeneity rather than compared without qualification to values from different testing protocols. Studies from the Lacs, San-Pedro, Bagoué and Gagnoa areas report marked variations in transmissivity, specific capacity and borehole yield [5]-[7]. A larger borehole database from western Côte d'Ivoire likewise documents strong variation in water strikes and emphasizes the need to screen drilling records before

regional interpretation [4]. Modelling work in tropical Africa shows that the factors governing sustainable abstraction can vary with the target discharge and with recharge and aquifer geometry [8] [10].

The positive relationships among transmissivity, hydraulic conductivity and specific capacity support their use as complementary indicators of borehole performance, subject to an important qualification: hydraulic conductivity is derived from transmissivity and saturated thickness, so their correlation is not wholly independent. Relationships between transmissivity and specific capacity have been quantified in Ivorian fractured aquifers [7] [23]. Nevertheless, the regression obtained in Poro is local, and its use elsewhere would require recalibration against pumping tests. The interpretation of semi-logarithmic drawdown and recovery data should also account for departures from ideal aquifer conditions [20] [21].

The negative correlations involving depth indicate that deeper drilling is not invariably productive after the main connected fractures have been intercepted. Published work links borehole yield to weathering profiles and the hydraulic characteristics of intercepted structures rather than to total depth alone [2] [4] [9] [24]. Hydrogeophysical studies show that the resistivity signature of a fracture is affected by overburden, fracture geometry and material contrasts, and must be validated against borehole evidence [16] [18] [25]. A field observatory in southwestern Nigeria and an integrated study in west-central Côte d'Ivoire illustrate the value of combining logs, geophysics and hydraulic observations [14] [17] [28].

The PCA differentiates a hydrodynamic productivity gradient from the effects of lithological architecture and depth, in line with a PCA-based assessment of fissured aquifers in Gagnoa [6]. However, correlated derived variables and incomplete drilling records may affect the stability of multivariate interpretations; these axes indicate association rather than causation [4] [22]. Published work using village water-supply well data also highlights the value of checking lithological descriptions and integrating geological mapping [15].

In practice, borehole siting should combine structural mapping, weathering-profile assessment, remote sensing, electrical geophysics and field validation rather than rely solely on lineament density or greater drilling depth [9] [14]-[16] [18] [25] [26]. Following construction, repeated monitoring of groundwater levels, pumping performance and hydrochemical quality is needed to evaluate long-term resource conditions, not just initial discharge [3] [10]-[12]. Studies in Ghana, Nigeria and the Sahel illustrate how hydrochemical observations, seasonal measurements and groundwater-access records can complement hydraulic indicators in management decisions [27]-[30].

6. Conclusion

This study shows that borehole productivity in the Poro Region is controlled by the weathered-fractured system of the basement aquifers. Fissured granite is the most favourable unit to groundwater flow and abstraction, with several of the first water inflows between 27 and 60 m. The most discriminating parameters are

transmissivity, hydraulic conductivity and specific capacity. On the other hand, the total depth of the borehole alone does not guarantee an improvement in performance. The success of the structures therefore depends on the interception of open, connected fractures hydraulically connected to the weathered mantle. These results support the need to prioritize structural field analysis and geophysical surveying before drilling and regular piezometric monitoring to optimize groundwater abstraction in the basement environment.

Acknowledgements

The authors gratefully acknowledge BARAN International Consulting Firm for its logistical support. The authors also wish to express their sincere gratitude to its Director, Dr Kouadio Assoué Sylvestre, for making the existing borehole data available for this study.

Author Contributions

Conceptualization, Dr. Yao Honoré KOFFI and Dr. Assoué Sylvestre KOUADIO; methodology, Dr. Assoué Sylvestre KOUADIO; software, Dr. Oulaï Jean-Gautier KPAN; validation, Dr. Omer Zéphir DE LASME, Dr. Oulaï Jean-Gautier KPAN, and Dr. Yao Honoré KOFFI; formal analysis, Dr. Oulaï Jean-Gautier KPAN; investigation, Oumar CAMARA; writing—original draft preparation, Dr. Yao Honoré KOFFI; writing—review and editing, Dr Oulaï Jean-Gautier KPAN; supervision, Dr. Omer Zéphir DE LASME.; funding acquisition, Dr Assoué Sylvestre KOUADIO. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

References

- [1] Dewandel, B., Lachassagne, P., Wyns, R., Maréchal, J.C. and Krishnamurthy, N.S. (2006) A Generalized 3-D Geological and Hydrogeological Conceptual Model of Granite Aquifers Controlled by Single or Multiphase Weathering. *Journal of Hydrology*, **330**, 260-284. <https://doi.org/10.1016/j.jhydrol.2006.03.026>
- [2] Lachassagne, P., Wyns, R. and Dewandel, B. (2011) The Fracture Permeability of Hard Rock Aquifers Is Due Neither to Tectonics, nor to Unloading, but to Weathering Processes. *Terra Nova*, **23**, 145-161. <https://doi.org/10.1111/j.1365-3121.2011.00998.x>
- [3] Lachassagne, P., Dewandel, B. and Wyns, R. (2021) Review: Hydrogeology of Weathered Crystalline/Hard-Rock Aquifers—Guidelines for the Operational Survey and Management of Their Groundwater Resources. *Hydrogeology Journal*, **29**, 2561-2594. <https://doi.org/10.1007/s10040-021-02339-7>
- [4] Bianchi, M., Palamakumbura, R.N., MacDonald, A.M. and Macdonald, D.M.J. (2023) Assessing Regional Variation in Yield from Weathered Basement Aquifers in West

- Africa and Modelling Their Future Groundwater Development and Sustainability. *Hydrogeology Journal*, **31**, 257-274. <https://doi.org/10.1007/s10040-023-02594-w>
- [5] Adeotan, Y.S.O., Vouillamoz, J.M., Lawson, F.M.A., Koita, M., Zorom, M., Traore, Y.S., *et al.* (2025) Beyond Lineaments: Exploring the Influence of Weathered Layers on Borehole Productivity in Basement Rocks of Burkina Faso, West Africa. *Hydrogeology Journal*, **33**, 411-424. <https://doi.org/10.1007/s10040-025-02876-5>
- [6] Kinglo, A.A., Hector, B., Galiez, C., Koita, M., Lachassagne, P., Lawson, F., *et al.* (2026) Are There Biases in Borehole Databases of Weathered Basement Aquifers Affecting Their Reliability to Estimate Aquifer Productivity? *Hydrogeology Journal*, **34**, 497-519. <https://doi.org/10.1007/s10040-025-02991-3>
- [7] Kouassi, K.J., Lachassagne, P., Mangoua, O.M.J., Sombo, A.P. and Dibi, B. (2024) Identifying the Origin of Springs in Weathered-Fractured Crystalline Aquifers Using a Hydrogeophysical Approach. *Scientific Reports*, **14**, Article No. 12977. <https://doi.org/10.1038/s41598-024-63748-8>
- [8] Worthington, S.R.H. (2024) Impact of Weathering on Permeability-Depth Trends in Bedrock Aquifers. *Hydrogeology Journal*, **32**, 1247-1252. <https://doi.org/10.1007/s10040-024-02803-0>
- [9] Meier, P.M., Carrera, J. and Sánchez-Vila, X. (1998) An Evaluation of Jacob's Method for the Interpretation of Pumping Tests in Heterogeneous Formations. *Water Resources Research*, **34**, 1011-1025. <https://doi.org/10.1029/98wr00008>
- [10] Trabucchi, M., Carrera, J. and Fernández-García, D. (2018) Generalizing Agarwal's Method for the Interpretation of Recovery Tests under Non-Ideal Conditions. *Water Resources Research*, **54**, 6393-6407. <https://doi.org/10.1029/2018wr022684>
- [11] Gao, Q., Hasan, M., Shang, Y. and Qi, S. (2024) Geophysical Estimation of 2D Hydraulic Conductivity for Groundwater Assessment in Hard Rock. *Acta Geophysica*, **72**, 4343-4354. <https://doi.org/10.1007/s11600-024-01310-w>
- [12] Dé Lasme, O.Z., Koffi, A.S., Onetie, O.Z., Diallo, L. and Ahondjo, X.T. (2023) Characterization of the Productivity of Basement Aquifers at Bagoué Region (North of Côte d'Ivoire). *International Journal of Hydrology*, **7**, 81-86. <https://doi.org/10.15406/ijh.2023.07.00343>
- [13] Soro, G., Soro, N., Ahoussi, K.E., Lasm, T., Kouamé, F.K., Soro, T.D., *et al.* (2010) Evaluation des propriétés hydrauliques des aquifères fracturés des formations cristalline et métamorphique dans la région des Lacs (centre de la Côte d'Ivoire). *Estudios Geológicos*, **66**, 227-242. <https://doi.org/10.3989/egol.40123.093>
- [14] Kouadio, A.K.S., Dickens, A.K.N. and Onetie, O.Z. (2025) Study of the Productivity and Hydrodynamic Properties of Fissured Aquifers in the Gagnoa Region. *GSC Advanced Research and Reviews*, **25**, 42-50. <https://doi.org/10.30574/gscarr.2025.25.2.0326>
- [15] Tigboh, R.B., Kouakou, E.G.K., Njikam, M.M.N. and Lingadé, Y. (2026) Integrated Approach for the Characterization and Modeling of a Fractured Basement Aquifer: Application to the Pézouan Industrial Site, West-Central Côte d'Ivoire. *Open Journal of Geology*, **16**, 272-292. <https://doi.org/10.4236/ojg.2026.166015>
- [16] Bianchi, M., MacDonald, A.M., Macdonald, D.M.J. and Asare, E.B. (2020) Investigating the Productivity and Sustainability of Weathered Basement Aquifers in Tropical Africa Using Numerical Simulation and Global Sensitivity Analysis. *Water Resources Research*, **56**, e2020WR027746. <https://doi.org/10.1029/2020wr027746>
- [17] De-Lasme, O.Z., Lasm, T., Oga, M.S., Youan-Ta, M., Baka, D., Ettien, F.B., *et al.* (2012) Analyse des propriétés hydrodynamiques des aquifères fissurés de la région de San-Pedro (Sud-Ouest de la Côte d'Ivoire). *Estudios Geológicos*, **68**, 217-232.

- <https://doi.org/10.3989/egol.40672.159>
- [18] Aoulou, K.A., Pistre, S., Oga, Y.M.S., Dewandel, B. and Lachassagne, P. (2021) Improving the Methods for Processing Hard Rock Aquifers Boreholes' Databases. Application to the Hydrodynamic Characterization of Metamorphic Aquifers from Western Côte d'Ivoire. *Water*, **13**, Article 3219. <https://doi.org/10.3390/w13223219>
 - [19] Demirel, S., Roubinet, D., Irving, J. and Voytek, E. (2018) Characterizing Near-Surface Fractured-Rock Aquifers: Insights Provided by the Numerical Analysis of Electrical Resistivity Experiments. *Water*, **10**, Article 1117. <https://doi.org/10.3390/w10091117>
 - [20] Kafando, M.B., Koïta, M., Le Coz, M., Yonaba, O.R., Fowe, T., Zouré, C.O., *et al.* (2021) Use of Multidisciplinary Approaches for Groundwater Recharge Mechanism Characterization in Basement Aquifers: Case of Sanon Experimental Catchment in Burkina Faso. *Water*, **13**, Article 3216. <https://doi.org/10.3390/w13223216>
 - [21] Kpegli, K.A.R., Adandedji, F., Ahouandogbo, C., Djihouessi, M.B., Hounkpe, J., N'Tcha M'Po, Y., *et al.* (2024) Groundwater Recharge Assessment in Central Benin: The Case of the Collines Region (West Africa). *Water*, **16**, Article 1330. <https://doi.org/10.3390/w16101330>
 - [22] Gao, Q., Shang, Y., Hasan, M., Jin, W. and Yang, P. (2018) Evaluation of a Weathered Rock Aquifer Using ERT Method in South Guangdong, China. *Water*, **10**, Article 293. <https://doi.org/10.3390/w10030293>
 - [23] Edet, A., Victor, I., Kudamnya, E., Bassey, B.J. and Effiong, C. (2026) Characterization of Crystalline Basement and Carbonate Aquifers, Southeastern Nigeria, Using Hydrogeoelectrical and Hydrogeochemical Methods. *Frontiers in Water*, **8**, Article 1784764. <https://doi.org/10.3389/frwa.2026.1784764>
 - [24] Manu, E., De Lucia, M. and Kühn, M. (2023) Hydrochemical Characterization of Surface Water and Groundwater in the Crystalline Basement Aquifer System in the Pra Basin (Ghana). *Water*, **15**, Article 1325. <https://doi.org/10.3390/w15071325>
 - [25] Doro, K.O., Adegboyega, C.O., Aizebeokhai, A.P. and Oladunjoye, M.A. (2023) The Ibadan Hydrogeophysics Research Site (IHRS)—An Observatory for Studying Hydrological Heterogeneities in a Crystalline Basement Aquifer in Southwestern Nigeria. *Water*, **15**, Article 433. <https://doi.org/10.3390/w15030433>
 - [26] Sidibé, A.M., Lin, X. and Koné, S. (2019) Assessing Groundwater Mineralization Process, Quality, and Isotopic Recharge Origin in the Sahel Region in Africa. *Water*, **11**, Article 789. <https://doi.org/10.3390/w11040789>
 - [27] Ouedraogo, I., Vanclooster, M., Huneau, F., Vystavna, Y., Kebede, S. and Koussoubé, Y. (2025) Surface Water-Groundwater Interactions in a Sahelian Catchment: Exploring Hydrochemistry and Isotopes and Implications for Water Quality Management. *Water*, **17**, Article 2756. <https://doi.org/10.3390/w17182756>
 - [28] Díaz-Alcaide, S., Sandwidi, W.J., Martínez-Santos, P., Martín-Loeches, M., Cáceres, J.L. and Seijas, N. (2021) Mapping Ground Water Access in Two Rural Communes of Burkina Faso. *Water*, **13**, Article 1356. <https://doi.org/10.3390/w13101356>
 - [29] Akpan, A.E., Ekwok, S.E., Ben, U.C., Ebong, E.D., Thomas, J.E., Ekanem, A.M., *et al.* (2023) Direct Detection of Groundwater Accumulation Zones in Saprock Aquifers in Tectono-Thermal Environments. *Water*, **15**, Article 3946. <https://doi.org/10.3390/w15223946>
 - [30] Ouangaré, C.A.C., Naba, S. and Lachassagne, P. (2024) Enhancement of the Geological Mapping in Weathered Plutonic and Metamorphic Rocks Areas Using Village Water Supply Wells Data (Lithology and Hydrochemistry). *Heliyon*, **10**, e40376. <https://doi.org/10.1016/j.heliyon.2024.e40376>