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IMPACT OF BAUXITE MINING ON AQUIFER HYDRODYNAMICS IN THE COGON CATCHMENT (SANGARÉDI, GUINEA): A SEASONAL PIEZOMETRIC APPROACH

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ABSTRACT

Open-pit bauxite mining on the duricrust-capped plateaus of the Boké region reshapes the land surface, yet its effects on groundwater remain poorly documented. This study assesses how the activity affects aquifer hydrodynamics in the Cogon catchment, within the concession of the Compagnie des Bauxites de Guinée (CBG). Thirty-one piezometers were monitored during two campaigns, one in the dry season (March–April) and one in the rainy season (July–August). Hydraulic heads, derived from a digital elevation model, were interpolated by ordinary kriging to map depth to water and the seasonal amplitude ΔH , and saturated thickness was integrated to estimate the geometric volume of the saturated zone. The water table is generally shallow (less than 20 m below ground over most of the catchment) and flows from northwest to southeast. Seasonal amplitude ranges from 5 to 24 m (mean ≈ 14 m); it peaks in the northeast (P1–P3) and stays moderate in the west-central sector (P19, P22, P23). The geometric saturated volume increases by $1.40 \times 10^9 \text{ m}^3$ (+29.5%) over an area of 371.4 km^2 . A closed piezometric depression centered on wells P18–P19, which coincides with active mining sectors, forms in the dry season and fades during the rains. This local signature is consistent with the effect of mine dewatering or industrial abstraction, although two campaigns are not enough to establish a causal link. Confirming it will require multi-year monthly piezometric monitoring and an inventory of abstractions.

Keywords: Bauxite; Hydrodynamics; Piezometry; Seasonal Fluctuation; Cogon Catchment; Guinea

1 INTRODUCTION

Guinea holds some of the world's largest bauxite reserves, and most of the country's output comes from the Boké region. The Compagnie des Bauxites de Guinée (CBG) has mined the Sangarédi deposits since the 1970s, and over the past decade many new operators have joined it. This expansion has made bauxite a mainstay of the national economy. It has also revived concerns among nearby communities about the availability and quality of their water, whether it comes from streams or village wells [1].

Mining is open-pit and takes place on duricrust-capped plateaus (bowé) that strongly influence the local water cycle. Stripping vegetation and soil, blasting and removing the duricrust, compacting haul roads, dewatering pits and building retention ponds all change how rainfall is split between runoff, infiltration and evapotranspiration, and therefore how aquifers are recharged [2]. In tropical weathering profiles, the aquifer sits precisely within the lateritic cover, the saprolite and the underlying fissured layer, whose hydraulic properties depend closely on the structure of the profile [3]. Disturbing the upper part of this profile may therefore mean disturbing the reservoir itself.

In these shallow systems, which depend heavily on rainfall recharge, seasonal fluctuation of the water table is a direct indicator of how the aquifer responds to water inputs and to any human stresses [4]. Mapping it alongside depth to water and flow directions makes it possible to pick out areas that behave differently from what topography and climate would lead one to expect. These are exactly the anomalies worth looking for around extraction areas.

Although the Cogon catchment lies at the heart of the CBG concession, little hydrodynamic data has been published for it, and, as far as we know, the available impact assessments do not document how its water table behaves over the seasons. Without this information, the footprint of mining on groundwater cannot be judged, and water managers have no baseline to work from.

Our overall aim was therefore to assess the impact of bauxite mining on aquifer hydrodynamics in the Cogon catchment. To do so, we mapped depth to water in the dry and rainy seasons, mapped the spatial pattern of piezometric fluctuation between the two seasons, estimated the change in the geometric volume of the saturated zone, and finally compared these results with the distribution of mined areas to identify sectors where mining-related disturbance is possible.

2 MATERIALS AND METHODS

2.1 Study area

The Cogon catchment lies in the Boké administrative region of northwestern Guinea, within the Sangarédi mining district (Figure 1). The study area covers about 579 km² and overlaps part of the CBG concession. The climate is humid tropical, with a single rainy season from May to October and a dry season from November to April. ERA5 reanalysis data from the Copernicus Climate Change Service (C3S) put annual rainfall at Sangarédi at 2,825 mm in 2025.

The landscape combines flat-topped duricrust plateaus, which host the bauxite deposits, with slopes and valleys that carry the drainage network. Geologically, the area belongs to the Paleozoic Bové sedimentary basin, made up mainly of sandstones and shales cut by dolerite intrusions. Prolonged lateritic weathering of these rocks has produced a thick profile capped by a bauxitic and ferruginous duricrust, beneath which lie clayey saprolite and then fissured rock. This profile hosts an unconfined aquifer whose behavior depends directly on infiltration through the cover.

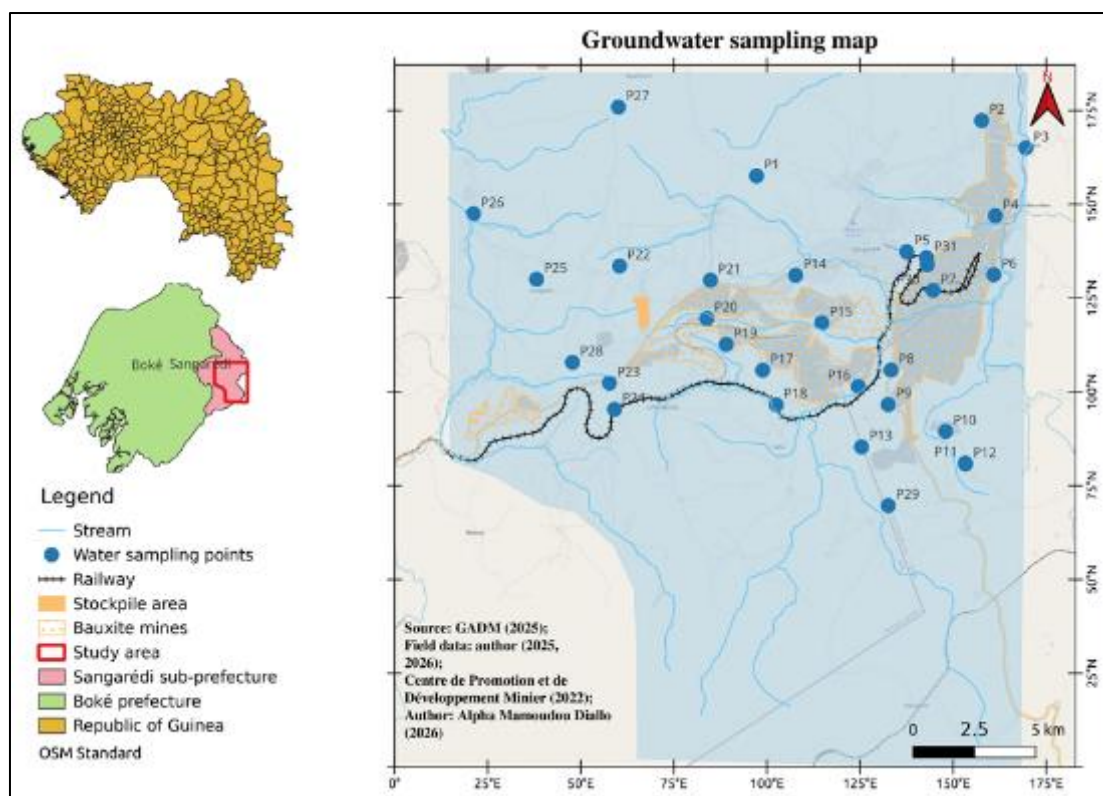


Figure 1: Location of the Cogon catchment and the piezometer network within the CBG concession (WGS 84 / UTM zone 28N)

2.2 Data acquisition

We carried out two field campaigns, one in the dry season (March–April 2026) and one in the rainy season (July–August 2025), to capture the state of the aquifer under the two main hydrological regimes. Measurements were made in 31 piezometric wells drilled by CBG and distributed across the catchment (Figure 1). For each well, coordinates were recorded by GPS and total depth was measured. Water level was measured during each campaign with a graduated electric water-level meter, which gives depth to water below ground level. All positions were recorded in WGS 84 / UTM zone 28N (EPSG: 32628).

Ground elevation at each well was extracted from a digital elevation model (DEM), which was also used to describe slopes and the drainage network. Table 1 summarizes the data used and their purpose.

Table 1: Summary of the hydrogeological data used

Data	Description	Use
UTM coordinates	X and Y of wells (WGS 84 / UTM 28N)	Mapping
Ground elevation	Z _{ground} (m), extracted from the DEM	Hydraulic head calculation
Water level	Depth to water below ground (m)	Piezometric maps
Total well depth	Well depth (m)	Saturated thickness
DEM	Catchment elevation	Topographic analysis, depth to water
Seasonal data	Dry season and rainy season	Fluctuation analysis

2.3 Data preparation and hydraulic head calculation

The measurements were compiled into a georeferenced database in which each well has an identifier, coordinates, ground elevation, depth to water and total depth. Before any processing, we checked the database for consistency: we verified the projection system, looked for outliers and systematically compared depth to water with total well depth to catch data-entry errors and dry wells. Hydraulic head was then calculated for each campaign as [5]:

$$Z_{\text{piezo}} = Z_{\text{ground}} - Z_{\text{water}} \quad (1)$$

where Z_{piezo} is the hydraulic head (m), Z_{ground} is ground elevation (m) and Z_{water} is the depth to water measured in the well (m). This gives one set of heads for the dry season and another for the rainy season.

2.4 Piezometric mapping

Piezometric surfaces were built in Golden Software Surfer 32, which produces interpolated grids, head contours and flow vectors within a single environment. Interpolation used ordinary kriging, a method suited to spatially structured variables that provides both an estimate and a measure of its uncertainty [6]. The spatial structure of groundwater levels was described by a linear semivariogram with a slope of 0.167848. Kriging was run without polynomial drift (order 0) and used all available observations. The interpolation grid is regular, with 100×62 nodes (6,200 in total) spaced 227.66 m along X and 228.00 m along Y; every node received a value.

One grid was produced for each season. Because groundwater flows from high to low heads, flow directions were derived from the hydraulic gradient and drawn as vectors perpendicular to the head contours. These plots were used to locate recharge zones, drainage axes and any depressions.

2.5 Depth-to-water mapping

Depth to water was obtained at every point by subtracting the interpolated piezometric surface from the DEM [5]:

$$D_{\text{wt}} = \text{DEM} - Z_{\text{piezo}} \quad (2)$$

where D_{wt} is depth to water (m). The few negative values, which are physically unrealistic for an unconfined aquifer and stem from extrapolation or DEM uncertainty, were set to zero and interpreted as areas where the water table reaches the surface.

2.6 Seasonal piezometric variation

The amplitude of fluctuation between the two campaigns was calculated as the difference between the two piezometric surfaces:

$$\Delta H = Z_{\text{piezo, wet}} - Z_{\text{piezo, dry}} \quad (3)$$

A positive value means the water table rose during the rainy season, which is the expected response to recharge. A small or negative value, by contrast, may point to reduced recharge, increased drainage or the effect of abstraction. We deliberately speak of piezometric variation rather than recharge: converting a rise in water level into a depth of infiltrated water requires the specific yield (or storage coefficient) of the aquifer, which was not measured here [4,7].

2.6 Estimating the volume of the saturated zone

Saturated thickness e was calculated at each well as the difference between hydraulic head and the elevation of the well bottom:

$$e = Z_{\text{piezo}} - (Z_{\text{ground}} - D_{\text{tot}}) \quad (4)$$

where D_{tot} is total well depth. The well bottom does not correspond to the base of the aquifer but to the maximum depth reached by existing boreholes, so e is a lower bound on the true saturated thickness. Thicknesses were interpolated by inverse distance weighting (IDW) in QGIS 3.34 and then integrated with the *Raster Surface Volume* tool to obtain the geometric volume V of the saturated zone for each season. The seasonal change is:

$$\Delta V = V_{\text{wet}} - V_{\text{dry}} \quad (5)$$

The calculation was restricted to the envelope of the piezometer network, i.e. 371.4 km² (64.1% of the study area), to avoid extrapolating beyond the area constrained by measurements. This is a volume of saturated rock, not a volume of recoverable water; the latter would be obtained by multiplying ΔV by the specific yield S_y [7]. Since S_y is unknown, the analysis relies on the relative change between seasons, which does not depend on this parameter.

2.7 Assessing the impact of mining

The impact of mining was assessed by overlaying the hydrodynamic maps on the footprints of mined areas taken from the 2025 land-cover map. We examined three things: flow directions, depth to water and seasonal amplitude. Sectors

close to the pits received particular attention. Closed piezometric depressions, small seasonal rises and anomalies that neither topography nor lithology could explain were treated as possible signs of disturbance. These signs remain presumptive, since rainfall, landforms, the nature of the formations, well depth and local water use can all produce similar signatures.

3 RESULTS

3.1 Piezometry and depth to water in the dry season

In the dry season, the water table lies less than 20 m below ground over most of the catchment (Figure 2). Depths of 20 to 60 m are confined to the west-central sector and the edges of the steepest relief, where the ground rises faster than the piezometric surface. Hydraulic heads range from 120 to 200 m, and the head contours, drawn at 10 m intervals, outline a regional gradient running from northwest to southeast.

This pattern is interrupted in the center of the catchment by a closed piezometric depression around the 190 m contour, near wells P18 and P19. Flow vectors converge on it from the surrounding sectors. In the far northwest, the map shows depths greater than 80 m. These are not hydrogeologically real; they are an extrapolation artifact, because kriging there operates outside the area constrained by measurements.

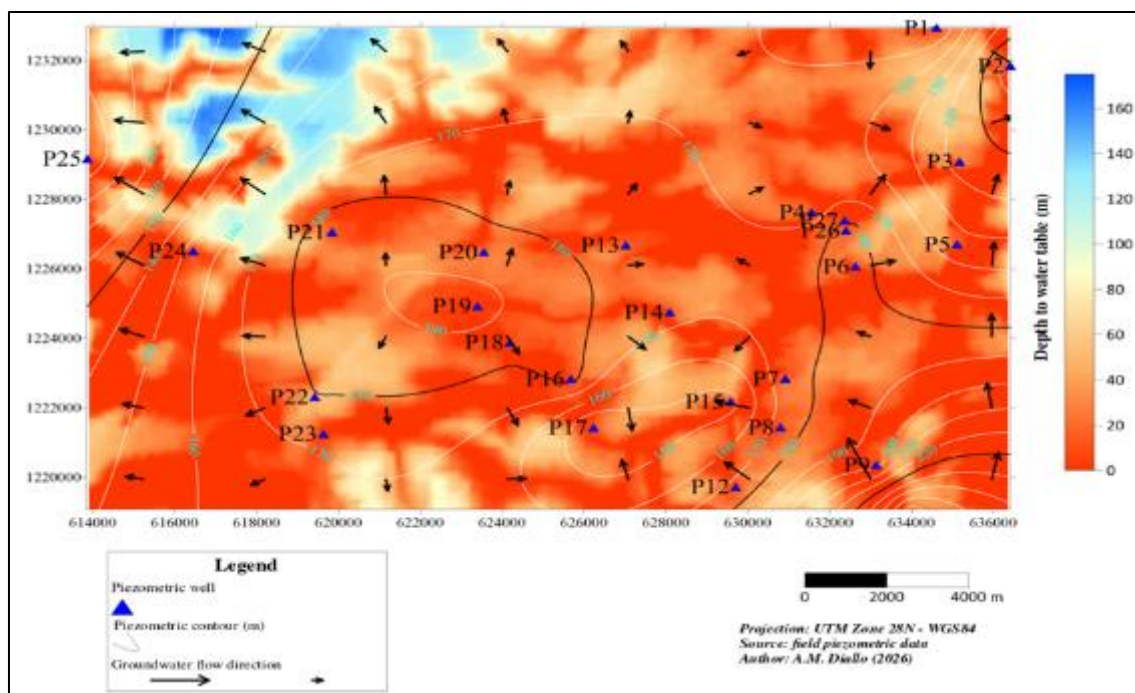


Figure 2: Piezometric map and depth to water in the dry season (March–April 2025)

3.2 Piezometry and depth to water in the rainy season

In the rainy season, the water table rises across the whole catchment (Figure 3). The shallowest depth classes, shown in red, become dominant and the distribution of depths narrows toward shallow values. Overall flow is still toward the southeast, but the contour pattern changes. In the east, around wells P8, P9 and P10, the 150 to 200 m contours bunch together over less than 5 km, indicating a much steeper gradient than in the dry season. In the center, the depression around wells P18 and P19 fades until it is almost indistinguishable at the chosen contour interval.

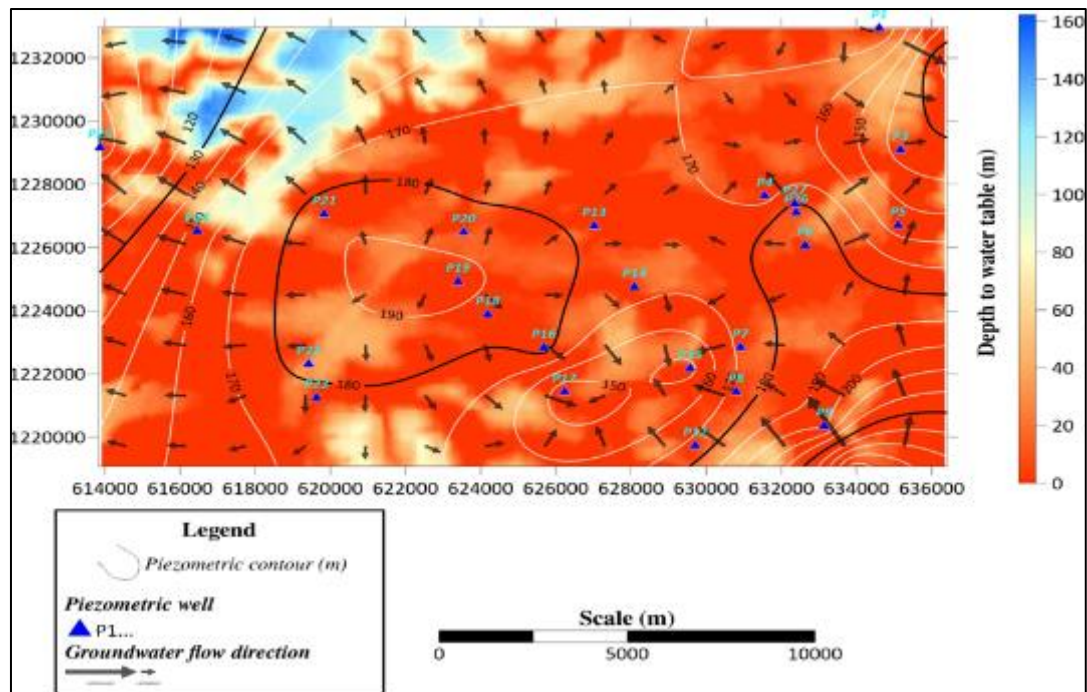


Figure 3: Piezometric map and depth to water in the rainy season (July–August 2025)

3.3 Amplitude of seasonal fluctuation

ΔH is positive across the whole catchment and ranges from 5 to 24 m, with a spatial mean of about 14 m (Figure 4). The rise is therefore general, but very uneven. The highest values, 17 to 24 m, are concentrated in the northeast around wells P1, P2 and P3, with a local maximum of 21 to 24 m surrounding P3. The lowest, 7 to 11 m, occur in the west-central sector around wells P19, P22 and P23, with a local minimum of 8 to 9 m centered on P19. Instead of a regular gradient that follows topography, the amplitude field forms closed, concentric contours around these two poles.

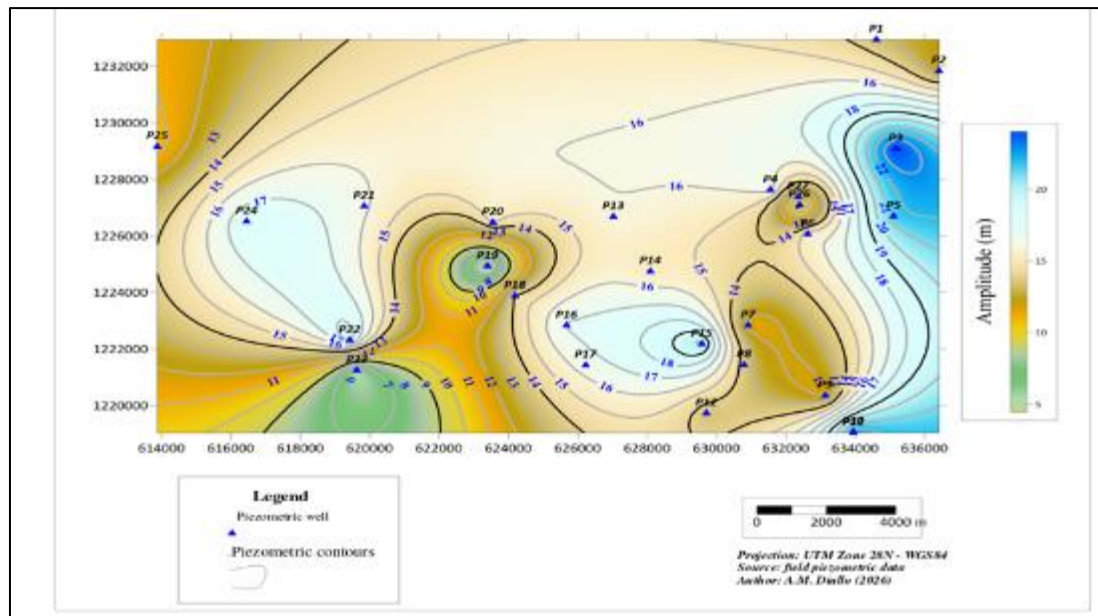


Figure 4: Map of piezometric amplitude ΔH between the dry and rainy seasons (m)

3.4 Geometric volume of the saturated zone

The volume balance shows a seasonal increase in groundwater storage between the dry-season campaign (March–April) and the rainy-season campaign (July–August). The inter-seasonal difference ΔV is $1.40 \times 10^9 \text{ m}^3$, an increase of 29.5%. This growth in geometric volume reflects a general rise of the water table. The agreement between the volume increase (29.5%) and the mean piezometric amplitude ($\Delta H \approx 14 \text{ m}$) provides an internal cross-check and supports the consistency of the results obtained by kriging in Surfer and by IDW interpolation in QGIS.

Table 2: Geometric volumes of the saturated zone in the Cogon catchment in the dry and rainy seasons

Parameter	Dry season	Rainy season
Geometric volume (m ³)	4,732,074,951.06	6,127,353,591.90
Inter-seasonal change ΔV (m ³)	+1,395,278,640.84	

4 DISCUSSION

4.1 Hydrodynamic behavior and seasonal recharge

The first lesson of this study is how responsive the aquifer is. Between the end of the dry season and the height of the rainy season, the water table rises by 14 m on average and the saturated volume grows by nearly a third. A response of this size, over just a few months, points to a shallow system fed by direct, diffuse infiltration through the lateritic cover, with storage that is largely renewed each year. This fits what is known of weathering-profile aquifers, where seasonal fluctuation is large when the specific yield of the zone of water-table fluctuation is low [3,4]. Similar amplitudes and sensitivity to rainfall have been reported from other basement and saprolite aquifers [8–10]. Guillaumot et al. showed that water-table fluctuations can be used to characterize recharge, and that the piezometric response depends on both rainfall and the thickness of the unsaturated zone [13]. In the weathered basement aquifers of West Africa, Bianchi et al. found that aquifer properties and yields vary widely with the geological and hydrodynamic characteristics of the reservoir [14]. At continental scale, Pazola et al. describe recharge that varies strongly in space under the influence of rainfall, soil moisture, vegetation and aridity [15]. All of this fits a catchment with strong seasonal recharge whose intensity changes markedly from one sector to the next. To our knowledge, these values are the first quantification of this kind for the catchment, and they can serve as a baseline for future monitoring.

Converting this rise into the volume of water actually stored depends on knowing the specific yield. Purely as an indication, a specific yield of 1 to 5%, a common range for clayey saprolite [7], applied to ΔV would give seasonal storage of roughly 14 to 70 million m³, equivalent to 38 to 188 mm of water over the calculation area. The seasonal increase was estimated from the volume of the saturated layer in each season, integrated over the whole calculation area, with saturated thickness taken as the difference between well depth and water level. Subtracting the dry-season volume from the rainy-season volume gives $\Delta V \approx 1.4 \times 10^9$ m³, which corresponds to a mean rise of 3.8 m over the area. This volume includes both the solid matrix and the water, so it is not a volume of free water. The distinction matters in weathering-profile aquifers, whose layers have sharply contrasting storage properties and hydraulic conductivities [17,20]. Bianchi et al. note that the characteristics of the different parts of the weathering profile control the yield and sustainability of abstraction from basement aquifers [14], while Pazola et al. point out that recharge estimates remain uncertain because surface conditions are heterogeneous and the available data are limited [15].

In the east, around wells P8 to P10, the head contours tighten. Yet a thicker saturated zone in the rainy season increases transmissivity, which should, if anything, flatten the gradient. Its steepening therefore suggests local control by the geometry of the reservoir or by a preferential drainage axis toward the southeast. Working on the N'Dangara and Boundou Wandé bauxite plateaus at Sangarédi, Diallo and Konaté observed flow directions that differ from one plateau to the next and related them to the organization of the hydrogeological system [19]. Koita et al. report that variations in the weathering profile and in the characteristics of the formations control groundwater circulation in West African aquifers [18]. The steeper gradient between P8 and P10 may thus reflect reservoir structure, geomorphology or permeability contrasts rather than the seasonal increase in storage alone.

Similarly, the reactivation of subhorizontal fractures in the fissured layer as water levels rise, as suggested by the dual-porosity aquifer model [3], remains a plausible hypothesis that our data cannot test directly. Lachassagne et al. describe weathered crystalline-rock aquifers as vertically layered, with a weathered zone of high storage capacity overlying fissured horizons that transmit water more readily [17]. This layering could explain why the piezometric response differs from one sector to another. The conceptual model of Dewandel et al. also assigns distinct roles to the different horizons of the weathering profile in storing and conveying water [20].

4.2. Spatial heterogeneity of the response and the signature of mining

Recharge may be effective at catchment scale, but it is far from uniform. The large amplitudes in the northeast (P1–P3) indicate rapid infiltration, which could be favored by natural fracturing of the cover or by fissuring induced by blasting of the duricrust. Blasting is a tempting explanation in a mining setting, but it would need to be confirmed by mapping the areas that have actually been blasted. Guillaumot et al. identify the thickness of the unsaturated zone as an important control on how the water table responds to rainfall [13]. The large amplitudes at P1–P3 may therefore also stem from

local conditions that favor rapid transfer of infiltrating water to the water table, without any need to invoke mining-induced fracturing.

Conversely, the modest amplitudes in the west-central sector (P19, P22, P23) allow two readings that are not mutually exclusive: a thicker unsaturated zone, which lengthens transit time and damps the recharge signal, or a reduction in net recharge caused by industrial pumping, pit dewatering or retention ponds that intercept surface water. The first reading agrees with Guillaumot et al., for whom the thickness of the unsaturated zone affects the amplitude and timing of the water-table response [13]. The second draws on Bianchi et al., who show that changes in recharge and abstraction alter how weathered basement aquifers function and how sustainable they are [14].

The depression centered on P18–P19 is the most significant anomaly. In the dry season it takes the form of a closed cone toward which flow converges, a configuration that surface morphology alone does not explain and that suggests a local hydraulic capture cell. Its position coincides with active CBG mining sectors, which points to an influence of mining through pit dewatering or industrial abstraction [2]. This hypothesis needs qualifying, however. At Sangaré, Diallo and Konaté found that flow directions vary between the bauxite plateaus they studied [19], so the P18–P19 depression may combine the natural geometry of the reservoir with a possible human disturbance. Without data on dewatering volumes and pumping rates, the effect of mining remains a potential influence, not a demonstrated cause.

In the rainy season the depression becomes almost indistinguishable; over the observed period, recharge appears to make up for the local deficit. MacDonald et al. show that mean recharge in Africa varies strongly with hydroclimatic conditions, and that some areas sustain regular recharge despite variable groundwater storage [16]. Pazola et al. also observe strong spatial variability in recharge, particularly in humid regions, and stress the uncertainty involved in representing localized recharge [15]. None of this rules out a persistent effect, which could become more pronounced during a prolonged dry season or if abstraction intensifies.

That neither topography nor regional lithology accounts for the amplitude minimum near P19 and the maximum around P3 strengthens the case for local disturbances of the piezometric regime. On its own, however, this is not enough to attribute the anomalies to mining. Bianchi et al. show that the hydrodynamic properties of weathered basement aquifers in West Africa naturally vary a great deal [14]. Koita et al. emphasize the role of variations in the weathering profile [18], and Diallo and Konaté observe flow directions that differ between sectors of the bauxite plateaus [19]. The contrasts between P3 and P19 may therefore result from the interplay of natural and human factors.

Clearing and stripping associated with mining reduce vegetation cover and alter soil properties, and with them the balance between runoff and infiltration, as other studies on the role of soil and vegetation in recharge have shown [11,12]. Across Africa, MacDonald et al. link the strong spatial variability of recharge to hydroclimatic conditions and to the characteristics of the land surface [16]. Pazola et al. confirm this heterogeneity, with an estimate that incorporates rainfall, potential evapotranspiration, soil moisture, NDVI and the aridity index [15]. These mechanisms make an effect of mining on groundwater quantity plausible, but with the present data they do not demonstrate it.

5 CONCLUSION

This study gives the first quantitative picture of how the aquifers of the Cogon catchment work. The water table is unconfined and shallow, less than 20 m below ground over most of the catchment, and flows from northwest to southeast. It responds strongly to rainfall: between the dry and rainy seasons it rises by 14 m on average, and the geometric volume of the saturated zone increases by 29.5%. Recharge is nonetheless highly heterogeneous, rapid in the northeast and subdued in the west-central sector.

In the center of the catchment, a closed piezometric depression forms around wells P18 and P19 in the dry season. Its shape, the flow convergence it creates and its proximity to active CBG mining fronts make it the clearest sign of possible mining-related disturbance, even though rainfall recharge largely erases it during the observed cycle. The causal link remains unproven. Confirming it will require several years of monthly piezometric monitoring, a denser network around the pits, an accurate inventory of dewatering and pumping volumes, and measurement of the aquifer's specific yield. The results presented here provide a baseline for that monitoring and for assessing the cumulative effects of bauxite mining on the catchment's water resources.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

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Disclosure of conflict of interest

The authors declare no conflict of interest.

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