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Hydrogeological Impact of Gold Mining, Contaminant Flow Patterns and Groundwater Quality Assessment in the Kambele Mining Area, Eastern Part of Cameroon

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Abstract

Gold mining activity is a source of income in many areas worldwide, especially in developing countries where it is often practiced illegally using unsafe techniques. In the Kambele area, artisanal and small-scale gold mining (ASGM) is widespread, and gold recovery relies on the use of toxic substances such as mercury (Hg), posing a threat to both the environment and human health. This study assesses aquifer flow directions and the impact of ASGM on the shallow aquifer in the Batouri gold district, specifically in the Kambele mining sites, where limited scientific studies have been carried out. Piezometric measurements were conducted on 36 wells, and 7 underground water samples were collected from the Kambele locality. Two trace elements (mercury and cyanide) and ten major ions were analyzed using the Atomic Absorption Spectrometer and Ion Chromatography techniques. The piezometric map revealed varying groundwater flow directions at different localities: Kambele 1 had a flow direction from west to east, while Kambele 2 and 3 had flows from east to west. Analysis showed that 72% of the samples had Hg concentrations ranging from 0.0010 mg/l to 0.0027 mg/l, and 57% of the samples had CN concentrations ranging from 0.0011 mg/l to 0.0025 mg/l. All samples had Hg and CN concentrations below the World Health Organization (WHO) guidelines for water quality, which are 0.006 mg/l for Hg and 0.007 mg/l for CN. Additionally, all major ions analyzed were within WHO guidelines. Hydrometric degree (hardness) and Sodium Adsorption Ratio (SAR) values indicated that the water is fresh and suitable for agricultural irrigation. This research highlights the importance of understanding groundwater flow patterns and contaminant transport pathways to mitigate the environmental impacts of ASGM and ensure water quality for human consumption and the environment.

Keywords

Artisanal Gold Mining, Kambele, Hydrogeological Impact, Piezometry, Water Quality

1. Introduction

Gold mining plays a pivotal role in many economies, offering opportunities for economic growth and development. However, the extraction and processing of gold ores can have significant environmental consequences, particularly on groundwater quality and hydrogeological systems [1]. The hydrogeological impacts of gold mining present complex challenges that require a comprehensive understanding of groundwater flow patterns and contaminant transport pathways to mitigate adverse effects on water resources and ecosystems.

Gold mining operations often involve the use of chemicals such as cyanide, mercury, and other heavy metals, which can leach into the surrounding environment and potentially contaminate groundwater sources [2]. Understanding how these contaminants move through the subsurface and interact with aquifers is essential for effective environmental management and resource sustainability [3].

The East region of Cameroon is known as a metallogenic province, mainly due to the occurrence of gold in many areas such as Batouri, Boden, Ngoura-Colomines, Betare Oya, and Kambele [4]-[6]. Gold mining activities in this area have led to decreased water quality of surface water [7]-[9], which might infiltrate and further pollute underground water systems, the primary sources of water for drinking, cooking, and laundry in the Kambele area. To date, no detailed study of the quality of underground water and contaminant pathways in the Kambele area is documented in the literature.

Based on this, some questions arise: Do gold mining activities have adverse effects on the shallow aquifers found in Kambele and hence on the quality of the water? What is the probable flow direction of the aquifer in this area? Gold mining activities increase the concentration of heavy metals (e.g., mercury, arsenic) in nearby surface water and groundwater, posing a risk to human health and the environment as a whole.

This research is important as it addresses the need to evaluate the transport pathways and impacts of gold mining activities on groundwater systems, determining if the water quality is suitable for human consumption and the environment. By understanding these dynamics, we can develop strategies for sustainable mining practices that consider effective environmental stewardship.

This study aims to assess the impact of gold mining on water quality, focusing on evaluating groundwater flow patterns and examining the pathways through which contaminants are transported in hydrogeological systems. By understanding the complex interplay between gold mining activities and groundwater systems, we can take proactive steps towards mitigating environmental harm, protecting water resources, and fostering responsible resource management practices in the gold mining industry.

2. Research Site

The Kambele area is found within the Adamawa-Yadé Domain (AYD) of the Central African fold belt in Cameroon (**Figure 1**). According to Van Schmus *et al.* (2008) the AYD domain extends eastwards from central Cameroon into the Central African Republic where it is known as the Yade massifs. In Cameroun, AYD is bounded to the north by the Tchollire Banyo shear zone and to the south by Sanaga shear zone towards the Yaoundé domain. The AYD is dominated by 640 - 610 Ma, syn- to late-collisional high-K calc-alkaline granitoids [10]. These granitoids intrude high-grade gneisses that represent a Paleoproterozoic basement, which was likely dismembered during the Pan-African orogeny [11]. The rocks of the AYD are classified into three main groups [11]. 1) large supracrustal blocks of Paleoproterozoic metasedimentary rocks and orthogneiss with assimilated Archean crust similar like the Ntem Complex, 2) 640 - 610 Ma syn-to late-tectonic granitoids of transitional composition and crustal origin, and 3) 612 - 600 Ma low-to medium-grade metasedimentary and meta-volcaniclastic rocks. The geology of Batouri locality is particularly dominated by syn- to late tectonic granites locally crosscut by systems of shear zones [12]. Moreover, newly published interpretations based on field observations, petrological, geochemical and geochronological data suggest that; the Adamawa-Yadé domain represents an Archaean/Paleoproterozoic microcontinent, which was detached from the northern margin of the Congo craton in the early Neoproterozoic, but became re-accreted together with the Mayo Kebbi (magmatic) arc during the Pan-African orogeny [13].

According to Assah (2010) and Jean-claude *et al.* (2019) [10] [14] the geology of Batouri area is much variable. Deformed and non-deformed Plutonic rocks are found throughout the area (**Figure 2**). Deformed rocks include migmatic gneisses, orthogneisses and mylonites, whereas undeformed rocks are constituted of tonalite, diorite, granodiorite, syeno-monzo-granite, alkaline granite [10]. At the mapping scale, four main rock types' namely tonalite, granodiorite, syeno-monzo-granite and alkaline granite have been distinguished and mapped. The main mineralization styles consist of 1) quartz vein deposits and stockworks; 2) disseminated deposits which constitute the primary gold deposits; 3) the alluvial placers and 4) eluvial placers are secondary gold deposits. Most of the artisanal mining sites such as Kambele, Mongonnam, Tikondi, Pandi, Tapare and Mama are situated at secondary placers [10]. The field data based on the relative chronology of the different structural elements observed on the outcrops and the geometric relationship between these structural features revealed that, the Batouri area is characterised by strong fracturing at both regional and microscopic scales [15]. The main directions of these fractures are NNE-SSW, NE-SW, and ENE-WSW [14]. The most significant fracture extends over 13 km with a NE trend. Gold-rich quartz veins are mainly located along these fractures and have been mined for several decades [16].

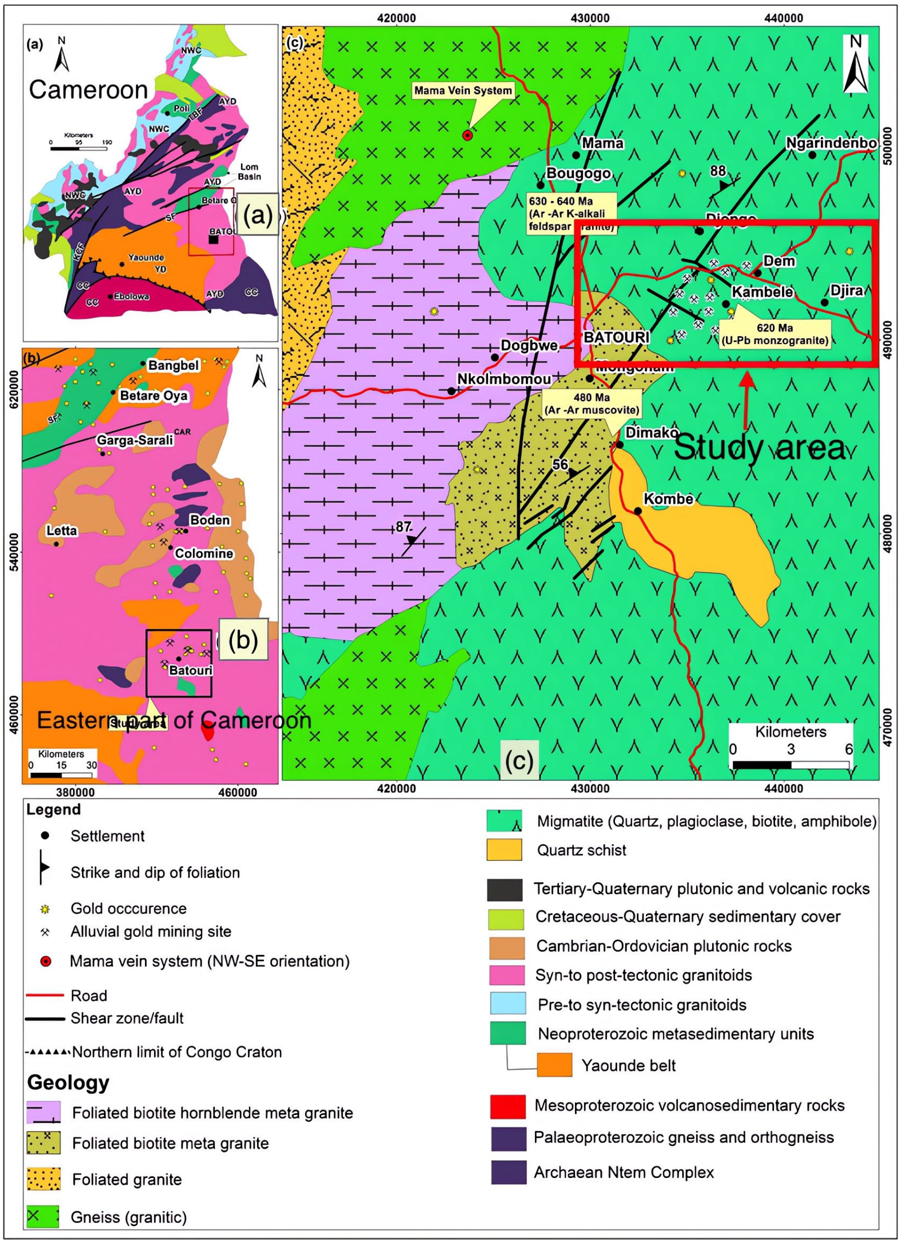


Figure 1. (a) Map of Cameroon locating the eastern region of Cameroon (red rectangle not to scale). (b) Map of the eastern region of Cameroon showing the distribution of Au occurrences. Note the concentration of gold in the eastern region of Cameroon (black rectangle not to scale). (c) Geologic map of Batouri district with the main structural and lithologic units and showing the study area Kambele [17].

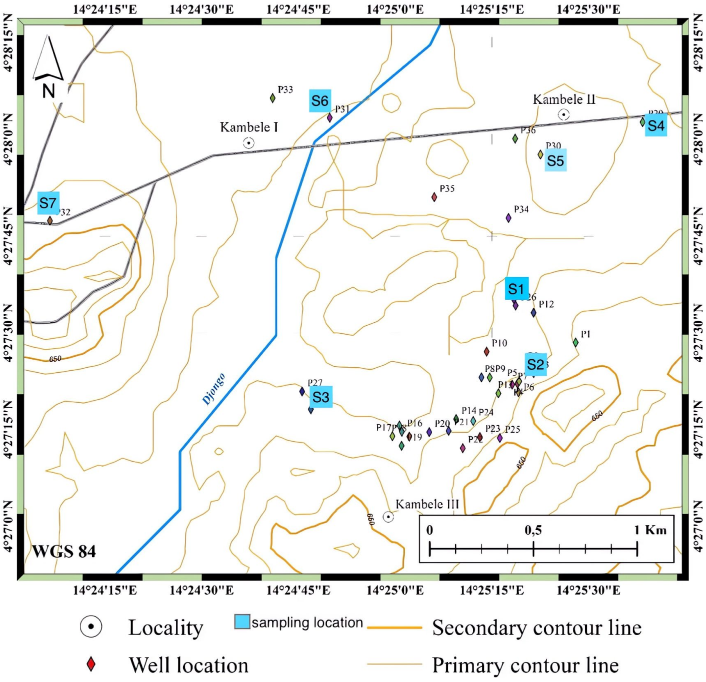


Figure 2. Well, localization map showing the sampling locations.

Generally, in the basement zone, two types of aquifers can be distinguished: the aquifer of alterites (superficial) and the fractured aquifers (deeper) [18]-[21]. According to Edet and Worden (2009) [22]; Eiriksson *et al.* (2013) [23]; Kouassi *et al.* (2016) [24], the exploitation of alterite aquifers in sub-Saharan Africa began in the 1950s - 1960s. This exploitation was mainly related to the lack of suitable means for drilling and the lack of knowledge or underestimation of the hydraulic role of fracturing in the bedrock. These aquifers, which develop in sandy-clay formations, are capable of accumulating large amounts of water, but their low permeability makes extraction difficult. Djeuda Tchapnga (1987) characterizes alterite aquifers as having high total interstice porosity, low effective porosity, and very low permeability [25]. In the granito-gneissic domain, such as in the Kadey department, alterites are unevenly rich in aquifer levels and are generally not very productive. According to Femba (2005) [21]; Eiriksson *et al.* (2013) [23], only a few shallow levels above the bedrock are of interest, especially when they are in the aquifer beating zone (piezometric level change zone). Unlike alterites, the bedrock has practically zero matrix porosity except in the superficial zone corresponding to the lower limit of the weathered layer; the permeability is good, especially in areas with a high fracturing density [18] [20] [23].

3. Methodology

3.1. Piezometric Survey

On the field, different parameters useful during piezometric map processing are taken at the level of the wells. These parameters and the measurement protocol are described as follows: The depth of static water level (SWL): After locating the well, a piezometer with a cable(tape) length of 100 m and resolution 1 mm was used. The well head (WH): Using the meter tape measure the height of the well head from the surface of the ground. GPS coordinates: a GPS receiver is place on the surface of the ground nearer the well head. The GPS coordinates are read and recorded. The coordinates can be used to establish piezometric maps

A total of 36 wells were measured for piezometric studies (**Figure 2**).

Once the data was acquired, we were able to make several calculations to have

- The actual water level (AWL) in the well;

$$\text{AWL} = \text{SWL} - \text{WH} \tag{1}$$

- The piezometric level (PL);

$$PL = \text{Alt} - \text{AWL} \tag{2}$$

- Thickness (E) of water inside the well during the month of measurement

$$E = \text{TD} - \text{SWL} \tag{3}$$

3.2. Water Sampling Method

Water was collected at 7 different locations (well) within Kambele area (**Figure 2**), based on utility and distance separating the wells. According to Harter (2003) [26], the following steps were followed: The samples were collected from the bucket attach to the well. Then, a clean plastic bottle was rinsed 3 times with water from the well before being filled up. They were then labelled using a pen and a wooden sill tape and then stored in a cooler with ice packs to prevent contaminant break down. At any point where samples were collected, geographical coordinates (longitude, latitude and elevation) were recorded using a GPS receiver. Sample preservation: Water samples were preserved according to standard protocols (EPA, 2016) to ensure their integrity during transport and storage.

The water samples were analyzed at the Water and Climate Change Research Center (CRECC-IRGM). Two analytical technics were use, that is Atomic Absorption Spectroscopy and Ion Chromatography. The determination of trace metallic element (TME) was carried out by Atomic Absorption Spectroscopy (AAS), using a 205 Atomic Absorption Spectrometer. While non-metallic trace ions were analyzed by Ion Chromatography using the Dionex ICS-1100 Ion Chromatography System (Dionex ICS-1100)

Some range of values of major ions obtain were used to determine other water quality concepts such as; Hydrometric degree (Hardness) and Sodium Adsorption Ratio (SAR).

Hydrometric degree is the most common method for evaluating water hardness, which correspond to the total content of calcium and magnesium present in the water, expressed in French degrees ($^\circ f$ or $^\circ fH$). To calculate the hardness of water in French degrees ($^\circ fH$), we need to convert the concentrations of Mg^{2+} and Ca^{2+} from mg/l to meq/l and then use the formula below (APHA, 2017) [27].

$$\text{Hardness}\left(^\circ fH\right) = \left(\text{Ca}^{2+} + \text{Mg}^{2+}\right) \times 5 \tag{4}$$

Sodium adsorption ratio is a measure of the amount of Sodium (Na) relative to calcium (Ca) and Magnesium (Mg) in water. It is an irrigation water quality parameter used in the management of sodium-affected soils. It is an indicator of the suitability of water for use in agricultural irrigation as determined by the concentrations of the main alkaline and alkaline earth cations present in the water. It can be estimated using the relation below [28]

$$\mathrm{SAR}=\frac{\mathrm{Na}^{+}}{\sqrt{\frac{\mathrm{Ca}^{2+}+\mathrm{Mg}^{2+}}{2}}} \tag{5}$$

Where Na, Ca and Mg ions concentration are express in Mili-Equivalent per liter.

SAR has been classified in different classes according to the Richard (1954) as seen in **Table 1** below.

Table 1. Sodium hazard classes based on sodium adsorption ratio value [28].

SAR (meq/l)	Remark
0 - 10	Excellent (little or no hazard)
10 - 18	Good (Appreciable hazard but can be used with appropriate management)
18 - 26	Doubtful (unsatisfactory for most of the crops)
>26	Unsuitable (unsatisfactory for all the crop)

4. Using Results and Discussion

4.1. Authors Flow Direction

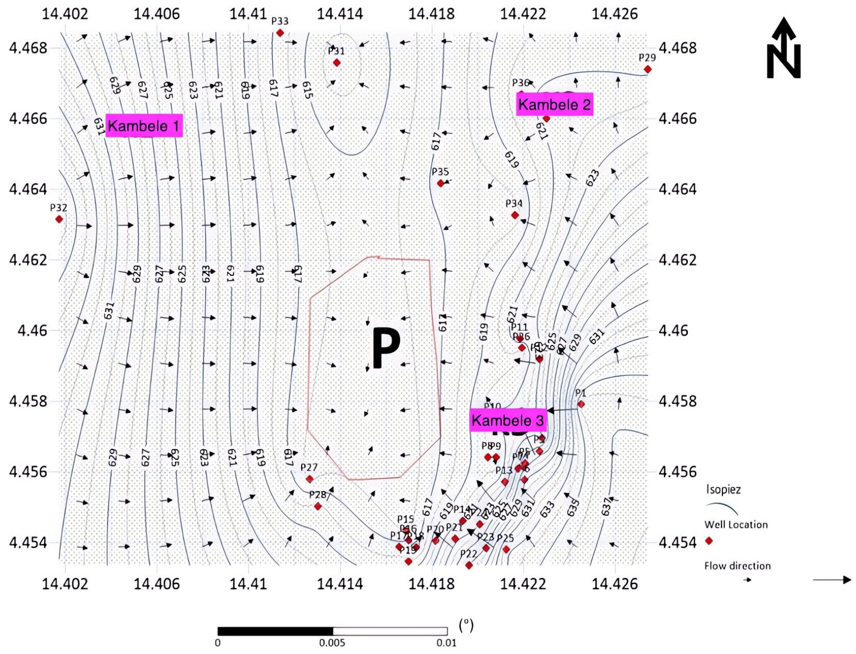


Figure 3. Piezometric map showing the flow direction.

A piezometric map is a contour map that represents the elevation of the water table of an aquifer or a piezometric maps consist of lines called contours, which connect points of equal hydraulic head or groundwater elevation at a given period of time at a given geographical location.

From the piezometric map obtain (**Figure 3**), it is observed that ground water flow in different directions within the different localities Kambele 1 (K1), Kambele 2 (K2) and Kambele 3 (K3).

At Kambele 1, located at the north west part of the study zone, ground water flows from the western part (from well 32 (p32)) to the eastern direction towards well 31 (p31) and well 27 and 28.

At Kambele 2, located at the north east part of the study zone, ground water flows in two directions towards the north east and west. At Kambele 3, located at the south eastern part of the study zone, ground water flows from east to west.

After analyzing the piezometric map, we can say that: Generally, the flow direction of underground water respects the flow direction of surface water having a meeting point towards point “P” (point “P” indicate point of lower altitude). Zones around point “P” will present more water contamination than others, because chemicals will flow from other zones and settle around zone “P”. In this area, the shallow aquifers of the different localities recharge the stream flowing closer well 31 down to well 27 at different point. Hence implying that the main source of recharge of shallow aquifers comes from effective precipitation.

4.2. Identify the Headings Hydro-Chemical Characteristics of the Underground Water in the Kambele Area

Based on the results of our analyses presented in **Table 2**, we found that 72% of the samples exhibited mercury (Hg) concentrations within the range of 0.0010 mg/L to 0.0027 mg/L, while 57% of the samples showed cyanide (CN) concentrations within the range of 0.0011 mg/L to 0.0025 mg/L. On the other hand, 28% of the samples were below the detection limit (BDL) of the measuring equipment for mercury (DL = 0.05 µg/L) [31], and 43% of the samples were below the detection limit for cyanide. However, undetected values may also result from instrument malfunctions or accidental errors by operators. The detection of mercury and cyanide in some samples, albeit at lower concentrations, indicates that mining activities are gradually impacting groundwater in the Kambele locality.

Mercury (Hg) concentrations ranged from 0.0010 mg/L to 0.0027 mg/L, while cyanide (CN) concentrations ranged from 0.0011 mg/L to 0.0025 mg/L. Notably, 100% of the samples had Hg and CN concentrations below the World Health Organization (WHO) guidelines for water quality for human consumption, which are set at 0.006 mg/L for Hg and 0.007 mg/L for CN, respectively [29] [30] (**Figure 4**). Exposure to elevated levels of mercury can damage the nervous system, kidneys, liver, and immune system [29]. Additionally, high doses of cyanide can lead to thyroid toxicity due to the inhibition of iodine uptake from thiocyanate generated through the detoxifying action of rhodanese [31].

Table 2. Values of heavy metals are obtained from analyses at the Institute of Geological and Mining Research.

Heavy metal	Mercury	Cyanide	Unit
Sample 1	0.001	BDL	mg/L
Sample 2	BDL	BDL	mg/L
Sample 3	0.0021	0.0018	mg/L
Sample 4	0.0017	0.0025	mg/L
Sample 5	0.0015	BDL	mg/L
Sample 6	BDL	0.0027	mg/L
Sample 7	0.0027	0.0011	mg/L

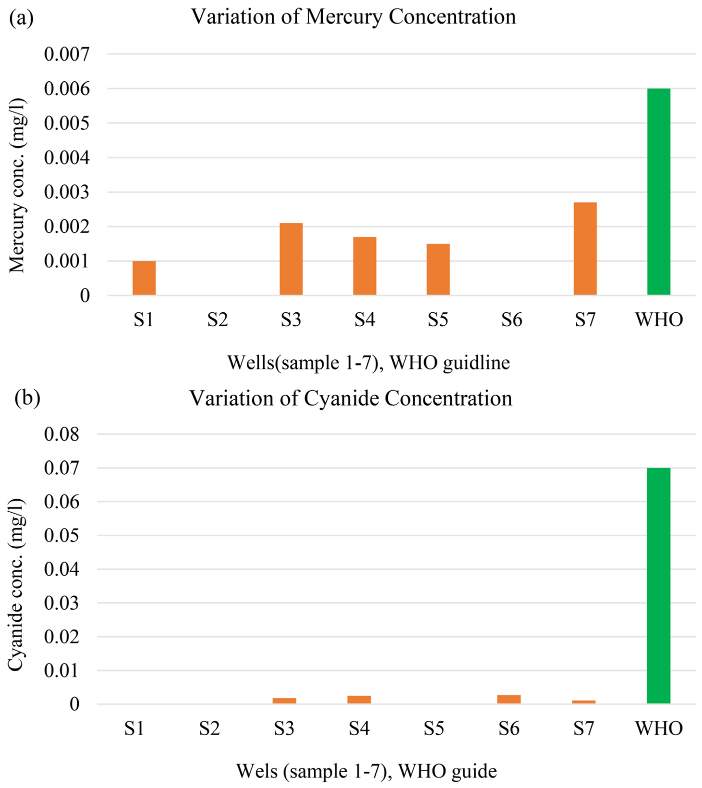


Figure 4. Variation of mercury and cyanide concentration.

Table 3. Major ions.

Ions	Fluoride	Chloride	Nitrate	Sulfate	Sodium	Magnesium	Calcium	Ammonium	Unit
S1	1.034	0.231	0.432	0.623	4.387	8.952	14.173	0.268	mg/l
S2	0.984	0.127	0.512	1.192	3.255	7.986	13.571	0.269	mg/l
S3	1.561	0.562	0.064	0.842	3.831	9.751	12.963	0.373	mg/l
S4	0.893	0.101	0.41	1.658	3.560	9.831	12.173	0.419	mg/l
S5	1.032	0.782	0.692	0.321	3.135	8.856	15.401	0.312	mg/l
S6	0.835	0.828	0.571	0.572	3.429	8.361	13.671	0.221	mg/l
S7	1.129	0.241	0.421	1.201	3.191	7.856	15.573	0.341	mg/l

Major ions were analyzed to observe the effect of Kambele shallow underground water further, not only on humans but also on the environment (**Table 3**). WHO (2022) Guidelines were use in examining the effects of the different ions to the health of humans.

Fluorine had a range of values from 0.835 mg/L to 1.401 mg/L. Its maximum acceptable WHO guideline concentration is 1.5 mg/L. All samples (S1, S2, S3, S4, S5, S6 and S7) presented concentration below Fluorine acceptable guideline (1.5 mg/L) (**Figure 5**). According to WHO (2022), drinking water with high Fluorine concentration might lead to health risks issues such as Dental fluorosis, Skeletal fluorosis.

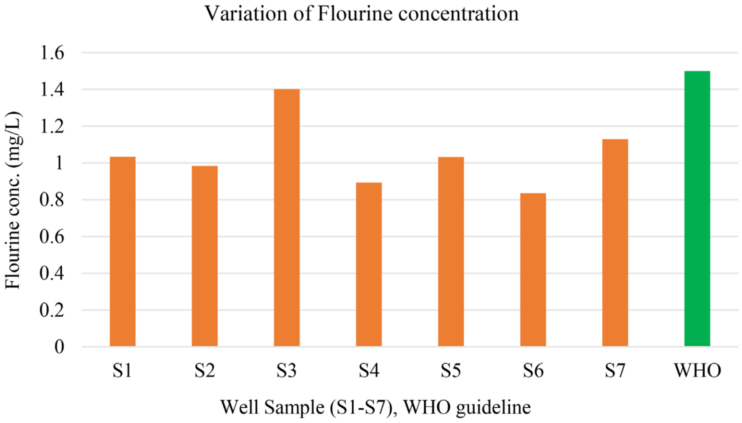


Figure 5. Variation of fluorine concentration.

Chlorine had a range of values from 0.101 mg/L to 0.828 mg/L. The levels are safe for drinking water, based on WHO guidelines (**Figure 6**). According to WHO (2022), health risks associated with excessive intake of Chlorine include Eye/nose/throat irritation and gastrointestinal problems.

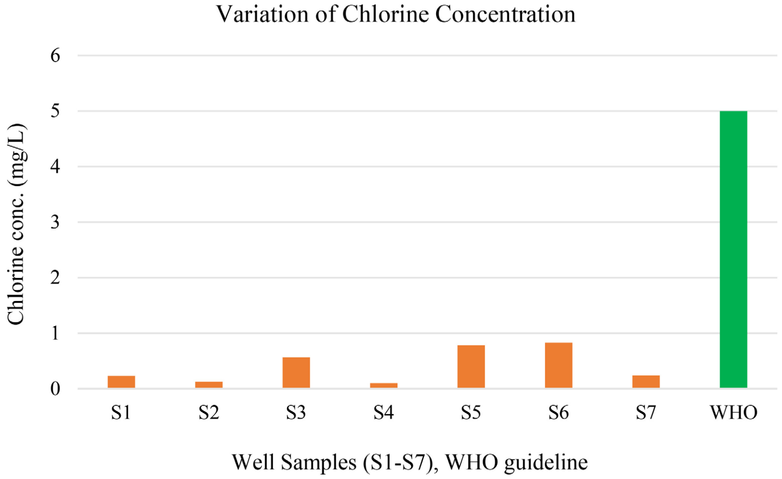
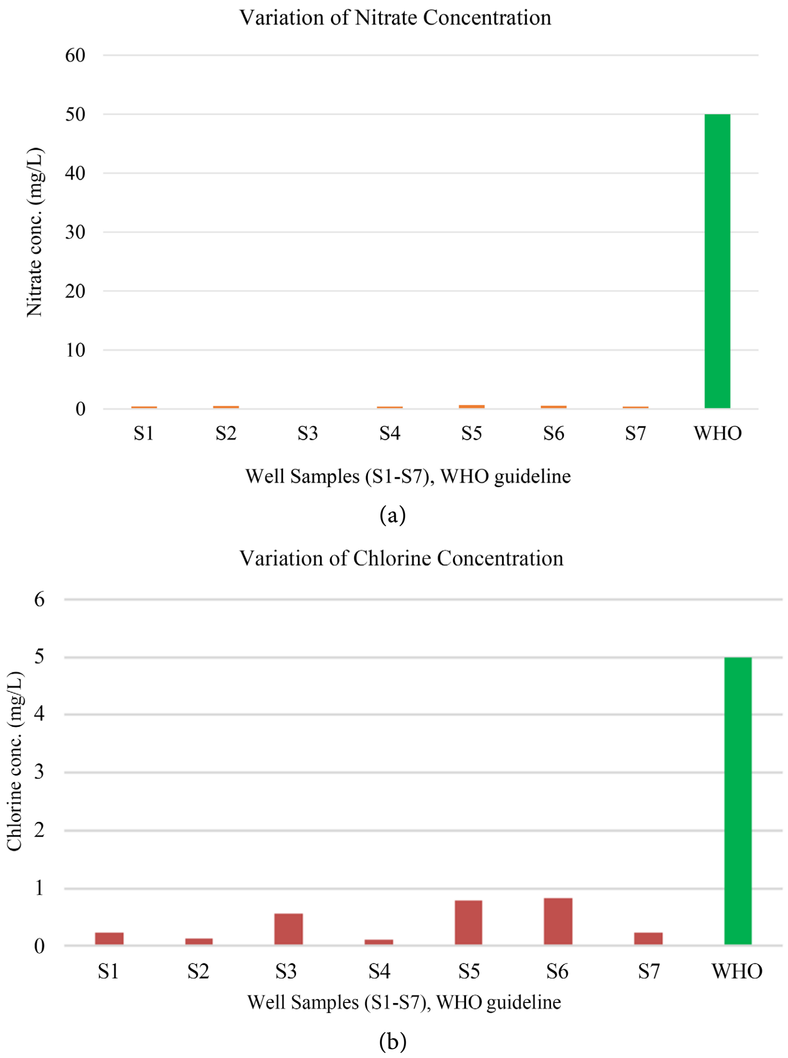


Figure 6. Variation of chlorine concentration.

Nitrate had a range of values from 0.064 mg/L to 0.692 mg/L. Its maximum acceptable WHO guideline concentration is 50 mg/L. All samples presented concentration below Nitrate and safe level (**Figure 7**). Health risks associated with excessive intake of Nitrate include blue baby syndrome and potential carcinogenic effects.



(a)

(b)

Figure 7. Variation of nitrate concentration.

Sulphate had a range of values from 0.321 mg/L to 1.658 mg/L. Its maximum acceptable WHO guideline concentration is 250 mg/L. All samples presented concentration below Sulphate acceptable guideline (250 mg/L) (**Figure 8**). Health risks associated with excessive intake of Sulphate include Gastrointestinal problems (above 250 mg/L), Diarrhea, abdominal pain (above 400 mg/L)

Sodium had a range of values from 3.135 mg/L to 4.387 mg/L. Its maximum acceptable WHO guideline concentration is 200 mg/L. All samples presented concentration below Sodium acceptable guideline (200 mg/L) (**Figure 9**). Health risks associated with excessive intake of Sodium include Hypertension (high blood pressure), Cardiovascular disease, Kidney problems.

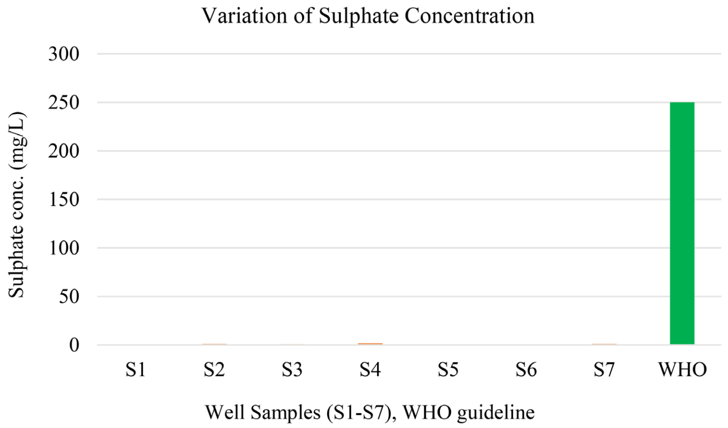


Figure 8. Variation of sulphate concentration.

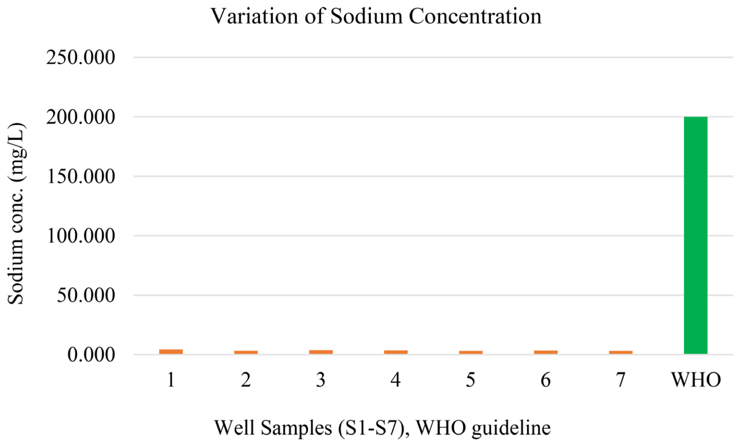


Figure 9. Variation of sodium concentration.

Ammonium had a range of values from 0.221 mg/L to 0.419 mg/L. Its maximum acceptable WHO guideline concentration is 1.5 mg/L. All samples presented concentration below Ammonium acceptable guideline (1.5 mg/L) (**Figure 10**). Health risks associated with excessive intake of Ammonium include Respiratory problems, Gastrointestinal issues, Neurological effect

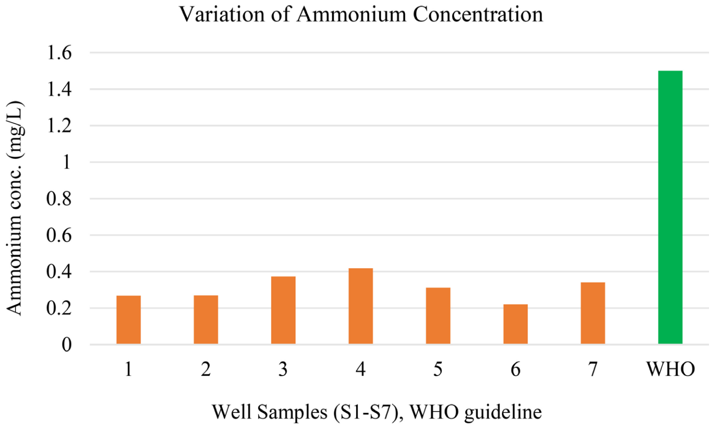


Figure 10. Variation of ammonium concentration.

The results obtained for hydrometric degree (hardness) and Sodium Adsorption Ratio (SAR) are presented as follows: The hardness values, measured in French degrees, are shown in **Table 4**. Samples 2 and 6 had hardness values within the range of 0 - 7, classifying them as very soft water, while samples 1, 3, 4, 5, and 7 had values within the range of 7 - 15, classifying them as fresh water (**Figure 11**). The mean hardness value of all samples falls within the range of 7 - 15, indicating that the hydrometric degree or water hardness from the shallow aquifer of the Kambele locality is classified as fresh water.

Table 4. Hardness values of samples.

Sample	Hardness (˚*fH*)
1	7.273
2	6.720
3	7.304
4	7.140
5	7.540
6	6.902
7	7.167
Mean value	7.149

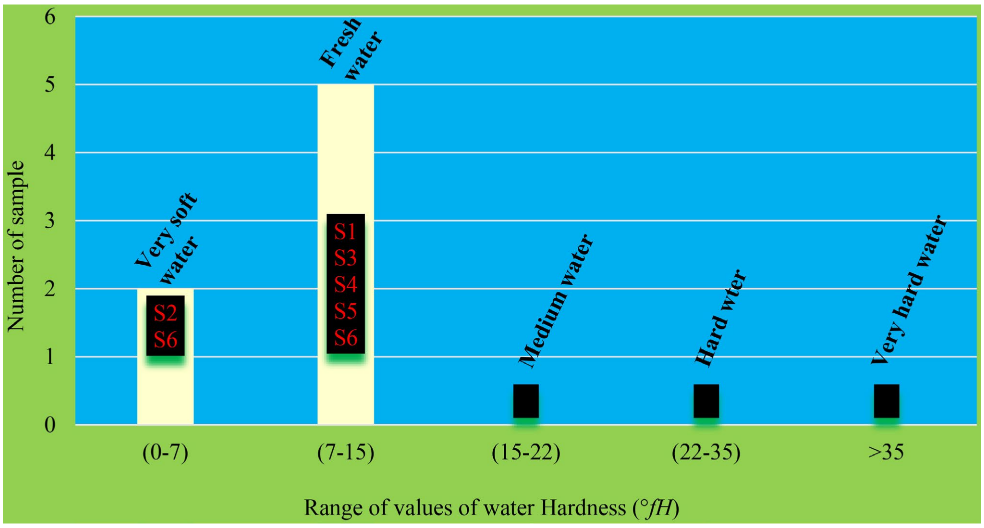


Figure 11. Water hardness classification of Kambele area.

Table 5. Sodium adsorption ratio of the different samples.

Sample	SAR (Meq/l)
1	0.214
2	0.165
3	0.187
4	0.176

Continued

5	0.150
6	0.172
7	0.157
Mean value	**0.175**

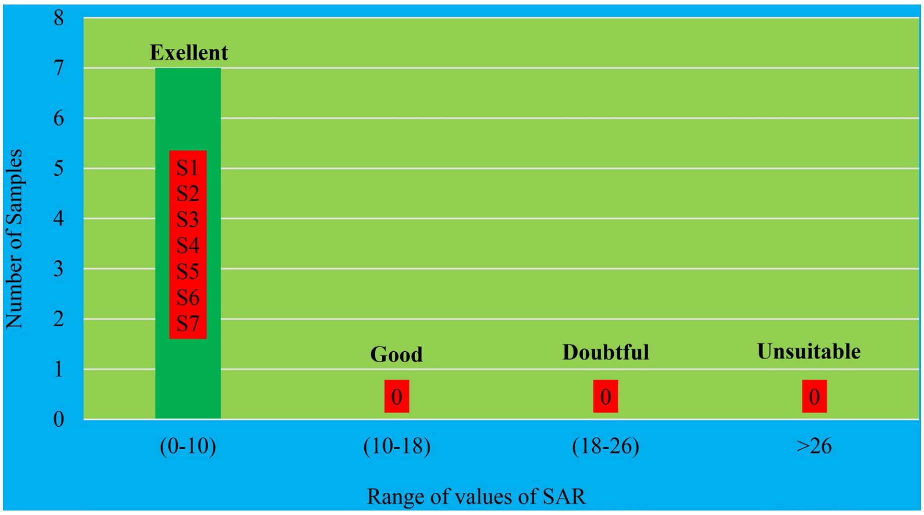


Figure 12. SAR classification of the Kambele area.

From **Table 4**, the values of SAR of the different samples were obtain as shown in **Table 5**. Hence according to Richard (1954) Classification, all the samples (1, 2, 3, 4, 5, 6 and 7) and mean value had values within the range 0 - 10 (**Figure 12**). This means Kambele shallow aquifers are excellent sources of water for agricultural irrigation.

4.3. Discussion

As a background, it should be noted that there is currently no information about mercury and cyanide concentrations in groundwater in the Kambele locality of the Batouri district. Studies to date have reported Hg concentrations in surface water [7] [8]. Thus, our study constitutes a baseline for future research concerning groundwater quality in the Kambele locality. Hg concentrations detected in our study (0.0010 mg/L - 0.0027 mg/L) were lower than the range of Hg values reported in surface waters in the Kambele locality. Ngueyep *et al.* (2020) reported Hg concentrations between 0 and 0.02 mg/L in different streams around the Batouri district, while Fonshiynwa *et al.* (2024) reported Hg concentrations between 102.64 µg/L and 5550 µg/L in several rivers and streams of the Kambele locality. Similarly, CN concentrations in our study (0.0011 - 0.0027 mg/L) were lower than the range of values reported in surface water of the Kambele locality. Fonshiynwa *et al.* (2024) reported CN concentrations between 1.45 µg/L and 28.45 µg/L.

The significant difference in values may be due to the limited interaction between surface water and shallow groundwater. This further indicates that the main source of recharge for the shallow aquifers in the Kambele locality comes from effective precipitation. These findings highlight the importance of determining the sources of aquifer recharge to identify potential sources of contamination that may affect groundwater quality. Since our measured values for mercury (0.0010 mg/L - 0.0027 mg/L) and cyanide (0.0011 mg/L - 0.0027 mg/L) were strictly below the guidelines set by the World Health Organization for potable water quality, the water is considered safe for consumption.

Several hypotheses could justify the lower concentrations observed in our samples: The inhabitants of Kambele have constructed cemented sinks (**Figure 13**) which conserve contaminated water, thereby reducing the rate of contaminant infiltration into the shallow aquifers, Geologically, Kambele's shallow aquifers are composed of laterites, which are geological formations with very low permeability, thus limiting water infiltration, Our piezometric studies indicated that the hydraulic relationship between the shallow aquifers and streams is such that water flows from aquifers to streams, thereby limiting the flow of contaminants from surface water into the aquifers, The main source of aquifer recharge is effective precipitation, and our samples were collected during the dry season when the infiltration rate was low.

These observations underscore the need for continuous monitoring of groundwater quality and the implementation of measures to protect water resources from potential contamination.

Figure 13. Gold processing in cemented sink.

5. Conclusion

In conclusion, this study aimed to evaluate the impacts of gold mining activities on groundwater systems in the Kambele locality, focusing on zones of increased contamination and determining water quality for human consumption and environmental health. By locating and sampling various wells and analyzing the collected water samples, we produced piezometric maps to determine aquifer flow directions. Our findings indicate that groundwater flow in Kambele 1 is directed from west to east, whereas Kambele 2 and Kambele 3 have flows from east to west. This downstream flow pattern suggests that shallow aquifers recharge the streams at certain points and are primarily recharged by effective precipitation. Gold mining activities were found to have adverse effects on the shallow aquifers, as contaminants such as mercury and cyanide were detected in some water samples. These contaminants are common elements used in gold mining. Despite their presence, the chemical analysis showed that the water from Kambele shallow aquifers is suitable for human consumption, as concentrations of contaminants and major ions were below the World Health Organization's guidelines. Additionally, other quality parameters like hardness and SAR were environmentally friendly. Overall, the study indicates that gold mining activities do not significantly impact the shallow aquifers in the Kambele area. However, there are limitations to the study, including a limited number of wells measured for piezometric studies, a limited number of samples, the absence of biological studies for better correlation, a lack of physical quality parameters, and limited knowledge on the quantity of toxic substances used.

The adverse effects observed, although currently within acceptable limits, could have long-term consequences for both human health and environmental sustainability if not monitored and managed properly. Future research should focus on a more comprehensive study involving a larger number of wells and samples, incorporating biological studies and physical quality parameters, and monitoring the quantity of toxic substances used.

This study provides a baseline for future research on groundwater quality in the Kambele locality. The findings emphasize the importance of continuous monitoring and the implementation of sustainable mining practices to protect water resources. Additionally, these results can be connected to broader regional or global issues related to gold mining and groundwater contamination, highlighting the relevance of this study within a larger framework. By understanding and addressing these challenges, we can contribute to better environmental stewardship and resource management.

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With profound sorrow and a heavy heart, we extend our deepest gratitude and posthumous recognition to Dr. Bello Bienvenu and Mounsi Frédéric, giants of intellect and inspiration. Their unwavering commitment to discovery and knowledge, even amidst peril, illuminated paths for countless others. Their tragic departure, as they were brutally killed and burned in the Souledé/Roua locality, has left an unbearable void, a silence that echoes painfully in the lives of their children, parents, students, colleagues, and the entire scientific world.

Their courage and passion were nothing short of extraordinary, and their work shall forever stand as a testament to their brilliance and sacrifice. We are incon-

solable in their absence, crying not just for their loss but for the dreams and potential their departure took with them. We fervently pray that such a devastating tragedy never befalls Cameroon or any other community again. Their legacy, marked with pain, pride, and profound respect, will endure eternally in our hearts. May they rest in peace.

Conflicts of Interest

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

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