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Research Article

HYDROCHEMICAL EVALUATION OF THE INFLUENCE OF GOLD MINING ON GROUNDWATER QUALITY, CASE STUDY

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ABSTRACT
Gold mining in the Baraka areas of the Republic of Guinea produced abundant gold mine tailing which entails seasonal variability of aquifer chemistry and contamination of the groundwater. Groundwater pollution is a major problem that threats all regions, located in northeast Guinea. Baraka is famous for its mining activities (industrial and artisanal), so it was important to observe the water quality in these areas, and in particular in the boreholes. Heavy metals such as Cd, Zn, As, Al, Ni, Fe, Mn and Pb were analyzed for each water sample collected during dry season, and the rainy season. The achieved values of each parameter were compared with the standard values set by the World Health Organization (WHO). The concentrations of Zn, Cu and Al obtained in some boreholes comply with WHO guideline values. However, the concentrations of Cd, As, and Pb are generally not within the WHO. The heavy metal abundance in sampled groundwater within the Baraka is in the order: Cd > As > Pb> Al > Cu > Zn for well water. The results of this study will serve as a basis for environmental policies aimed at protecting populations living in a mining environment.

Keywords: *Gold mining area, Groundwater quality, Hydrogeochemistry, Heavy Metals*

INTRODUCTION
For decades, mining has been a major potential economic source for African countries. The extensive development of many sectors, including the infrastructure, manufacturing, and ser-vices industries, has created wealth and employment through gold mining. Gold mines contain various types of pollutants such as arsenic (As), cadmium (Cd), mercury (Hg), and lead (Pb). Gold-containing ores include other potentially toxic elements (PHEs) such as chromium (Cr), cobalt (Co), nickel (Ni), copper (Cu), iron (Fe), molybdenum, and manganese (Mn) (Belle et al., 2021) is included in a small amount (Kamunda et al., 2016) like (Mo), selenium (Se), and zinc (Zn). Gold mining and processing always have a significant impact on the quality of the environment, and it depends on the scale of the mining operation. This type of mining activity generally destroyed the terrain of the land and adversely affected the hydrogeology of the area. In Africa, most of the population depends on groundwater for their domestic needs and the lack of access to groundwater is not only a violation of their basic human rights but also harms sustainable human life (Tay, 2017). The chemical composition of groundwater in the natural environment is highly variable. It depends on the geological nature of the subsoil from which it comes but also on the reactive substances that it may have encountered during the flow of groundwater (Matini et al., 2009). It was noted that the natural quality of groundwater can be altered by human activities or by the various elements. The study of water quality is a strategic program of the utmost importance in several regions of the world (WHO, 2011). This water quality can be defined in terms of physical, chemical, and biological parameters, but also by its use (Mahamane and Guel, 2015). Several scientific methods and tools have been established to assess water quality (Dissmeyer, 2000). These methods include the study of various parameters such as electrical conductivity, total dissolved solids (TDS), pH, turbidity, major elements and heavy metals. These parameters can affect the quality of drinking water if their values do not comply with the authorized standards of the World Health Organization (WHO) and other guidelines and standards of

the organization (WHO, 2011).
In recent decades, interest in groundwater chemistry has increased, as evidenced by several studies. For examples Kouassi et al., (2012); Mahamane and Guel (2015); Konan et al., (2018); Souley Moussa et al., (2019); Kouassi Serge et al., (2020). These studies based on the application of the analysis of the statistical methods and aid to the interpretation of complex data matrices to better understand the water quality and identify possible factors influencing the water chemistry.
The main gold zone of Guinea is the Birimian Basin of Siguiri. This Basin is made up of sedimentary and volcano-sedimentary geological formations, hosts of numerous gold mineralizations throughout West Africa (Leube et al., 1990). Gold mineralization found in the Birimian Basin of Siguiri is associated to late tectonic plutonism and hydrothermal events that have remobilized gold along fractures and fault zones (Tetteh and Asanti, 2016). The Siguiri basin is located in the field Baoulé-Mossi, in a straight line north of the domain Archean of Kénéma-Man. It is one of the largest sedimentary basins in the West African craton (Lebrun, 2016). Gold in the Siguiri Basin has been produced by numerous international mining companies.
Groundwater pollution is a current problem that concerns all regions with maintaining their water resources at a high level of quality and affects the Baraka area, located in the northeast of Guinea. Currently, millions of tons of waste rock resulting from gold processing, containing variable quantities of certain pollutants (Pb, Zn, Cd, Ni, As, etc.), are stored in large spaces. The challenge today in the mining sector is to find a balance between preserving the quality of the environment (groundwater) and meeting the needs of society. To our knowledge, the Baraka study area has not experienced any specific study related to the hydrochemical evaluation of groundwater quality. This study is based on water from 33 boreholes in the study area which were collected in both dry and rainy seasons. The main objectives are, firstly, to investigate the influence of gold mining activities on water quality through the characterization of the heavy metals concerning portability. Secondly to determine each parameter and compare it to the standard values set by the WHO. The results of this study will serve as a basis for environmental policies aimed at protecting populations living in mining environments.

MATERIALS AND METHODS

According to the CECIDE report (2010), the sub-prefecture of siguirini (Baraka zone) is one of the 12 sub-prefectures that make up Siguiri Prefecture. It was erected as a sub-prefecture in 1984. Located 115 km from the prefecture of Dinguiraye and 145 km from that of Siguiri, the sub-prefecture is divided into 10 districts including the central district of Siguirini, and 65 villages. These three ethnic groups in these areas practice agriculture, livestock, and petty trade as their main activities and alternate according to the seasons with artisanal gold panning. The village of Lero, the main mining site of the Société Minière de Dinguiraye (SMD), is one of the 13 villages that make up the sub-prefecture of Siguirini. The industrial

Table1. The number of well sampled per village

No.	Villages	Number of well sampled	Designated well
1	Amina	4	P1 to P4
2	Carrefour	4	P5 to P8
3	Lero	16	P9 to P24
4	Siguirini	6	P25 to P30
5	Tombani	3	P30 to P33

exploitation of gold has created a proven economic value but not perceptible in the mining communities exploited. It is on the basis of this observation in the Siguiri basin that the populations have decided to step up, for several years, to exploit gold in an artisanal way. This activity constitutes one of the main sources of income for millions of families, becoming increasingly growing and significantly impacting the environment (Figure 1).

Figure 1. Artisanal gold miners on site. *(a)* Siguirini; *(b)* Carrefour

The landscape of this region is marked by the morphology of the lateritic profile. There are also hills formed and oriented by Mesozoic dykes, sills, and dolerites. Gold deposits in the study area have experienced post-magmatic movements in the past. The lateritic cuirass is generally on the surface; rotten-textured saprolite rocks (Sap); Transition rocks (Trans) have undergone hydrothermal alterations (CECIDE report, 2010).
The selection criteria for well sampling points were based on population density and mining activities. There are a large number of boreholes for drinking water supply which are concentrated in the villages of Siguirini, Lero, Carrefour, Amina, and Tombani. These villages were selected on the basis of defined a criterion that is the number of boreholes sampled per village as can be seen in Table 1which shows the number of boreholes sampled per village.
Samples were collected and analyzed in two seasons, the dry season (October, November, and December 2019) and the rainy season (June, July, and August 2019). The MPA-ES 4210 type spectrophotometer was used in the analysis of heavy metals to determine the following parameters: Cd, Zn, Al, Fe, Mn, Cu, As, Pb, and Ni. Descriptive statistics was intended to make a comparative study between the analytical data, and the guide values of the WHO by bar histograms.

RESULTS AND DISCUSSION

Descriptive statistics was used to compare measured parameters with WHO and EU water quality standards. Results of the study were displayed in the form of bar histograms. Figure 2 show the evolution of Cd concentrations. Cd is one of the most toxic and mobile elements in the environment (Kubier et al., 2019). Cd has been linked to renal damage and it raised amounts are carcinogenic to humans (Idrees et al., 2018). It is remarkable in Figure 2 of the rainy season that the values of the wells respectively in the villages of Amina, Carrefour, Lero and Siguirini were above the authorized standards. Therefore, the observed Cd concentrations showed that water quality in the study area is unhealthy for human consumption. Similar results of high Cd values were also earlier found by authors such as Kortatsi, 2004; Oluwasanya and Martins (2006); Ayantobo et al., (2014); Armah et al., 2010; Tay et al., (2019). Kortatsi (2006) stated that the high Cd concentrations during the rainy season may suggest an anthropogenic influence. From Figure 2 of the dry season, it appears that 42% the borehole values were higher than the limit value for potable water. Both geogenic (water-rock interactions or soil-water interactions), and anthropogenic (mining and processing of gold ores) sources can raise Cd levels in groundwater (Kubier et al., 2019).

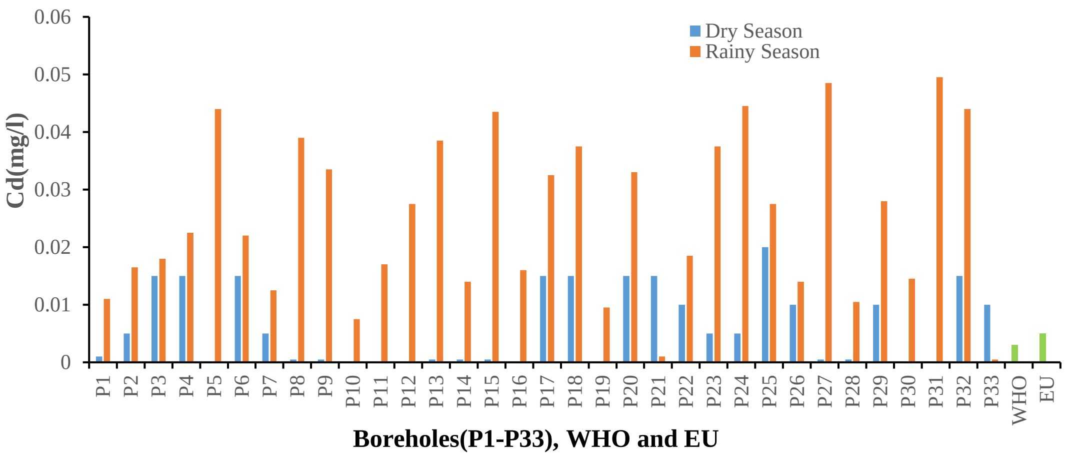

Figure 2. The evolution of Cd concentrations

Figure 3 displays the evolution of Zn concentrations. From Figure 3, it can be observed that the concentrations of Zn respectively in the rainy and dry season were within the acceptable standards of the WHO. Therefore, Zn concentrations do not showed any quality problem for groundwater usage in Baraka area.

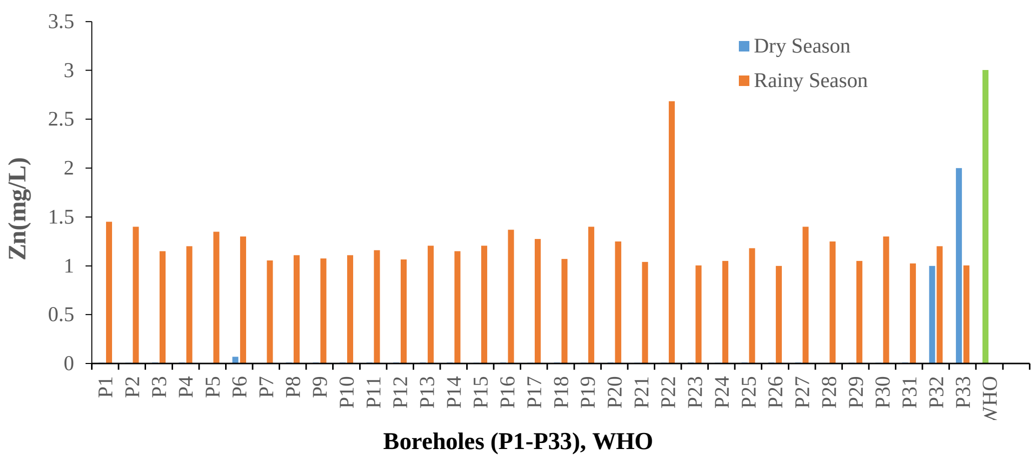

Figure 3. The evolution of Zn concentrations

Figure 4 shows the evolution of Pb concentrations. Pb is a contaminant in the environment. It is toxic and eco-toxic even at low doses. The diseases and symptoms it causes in humans or animals are grouped together under the name of "lead poisoning". Pb is a metal found generally dispersed at very low levels in soils and bedrock and concentrated in natural ore deposits. It can be observed in Figure 4 of the rainy season that 71% of the sample recorded values from wells were not in good agreement with guideline standards. Evidence of high Pb levels in groundwater has been earlier reported by authors such as Kortatsi, (2004); Armah et al., (2010); Ayantobo et al., (2014); Tay et al., (2019); Anim-Gyampo et al.,(2021). Probable reason for such high Pb levels could be attributed to the freshwater recharge during the rainy season which influences the geochemical processes and groundwater quality parameters at the study site. In contrast, Figure 4 of the dry season showed that all the Pb values in the boreholes sampled were below the guideline values. The study area is characterized by industrial and artisanal mining activities (Figure 5). These operations are characterized by the use of heavy and light machinery, semi-crusher, fuel, etc. Mining has become more mechanized and therefore able to handle more rock and ore material. In this manner, mine waste has multiplied enormously. When ore and surrounding rock are excavated during mining, the sulfides become exposed to water and air, and may form sulfuric acid (Figure 6). This acid in turn leaches toxic metals and other substances from the rocks that can harm ecosystems. Blasting in industrial mine, and the galleries made by artisanal gold miners favor the presence of cracks and facilitate the underground flow of these metals which percolate in the groundwater. It should be highlighted that Pb may come from natural geochemical processes (Dorleku et al., 2018). Therefore, the presence of the higher concentration of Pb in these sampled boreholes would be due to pollution of industrial and artisanal mining origin. This presents a potential health hazard to the inhabitants.

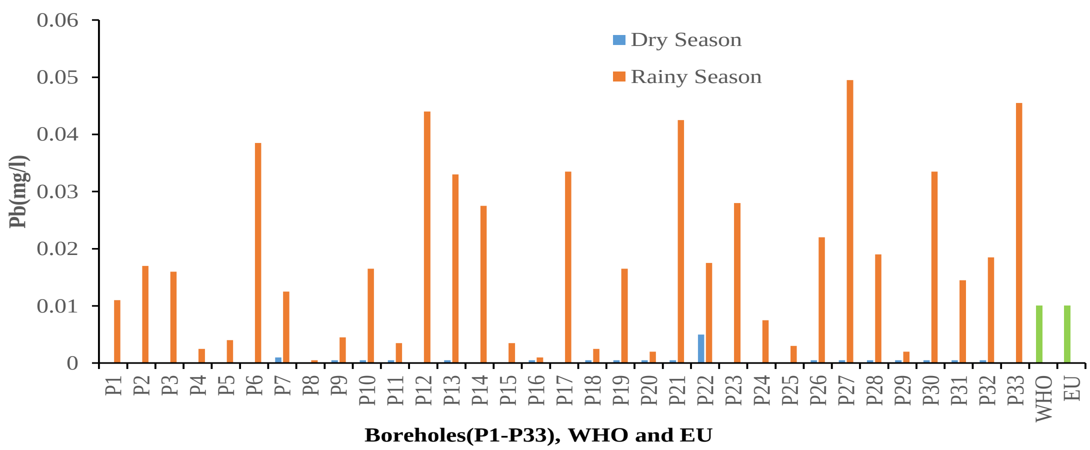

Figure 4. The evolution of Pb concentration

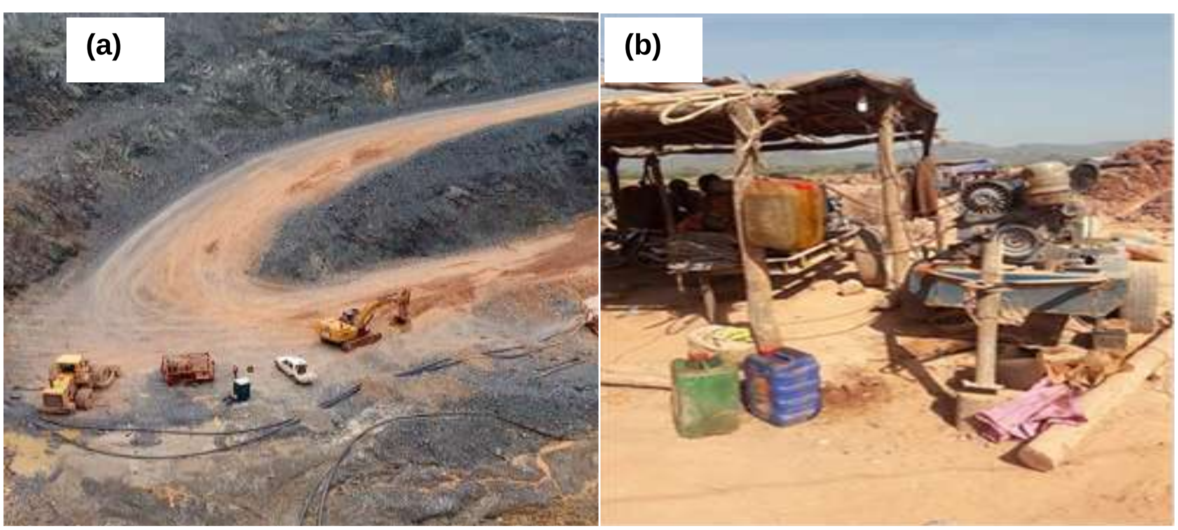

Figure 5. Industrial and artisanal mining activities. *(a)* Heavy and light machinery; *(b)* Semi-crusher

Figure 6. Acid mine drainage

Cu is a reddish, malleable, and ductile metal that conducts heat and electricity well. It is a metal that occurs naturally in ore deposits, but only at very low concentrations in most soils and rocks. Figure 7 shows the evolution of Cu concentration. Almost all the samples for Cu were in good agreement with guideline standards and this observable pattern was in agreement with the study reported by Ligate et al., (2021).

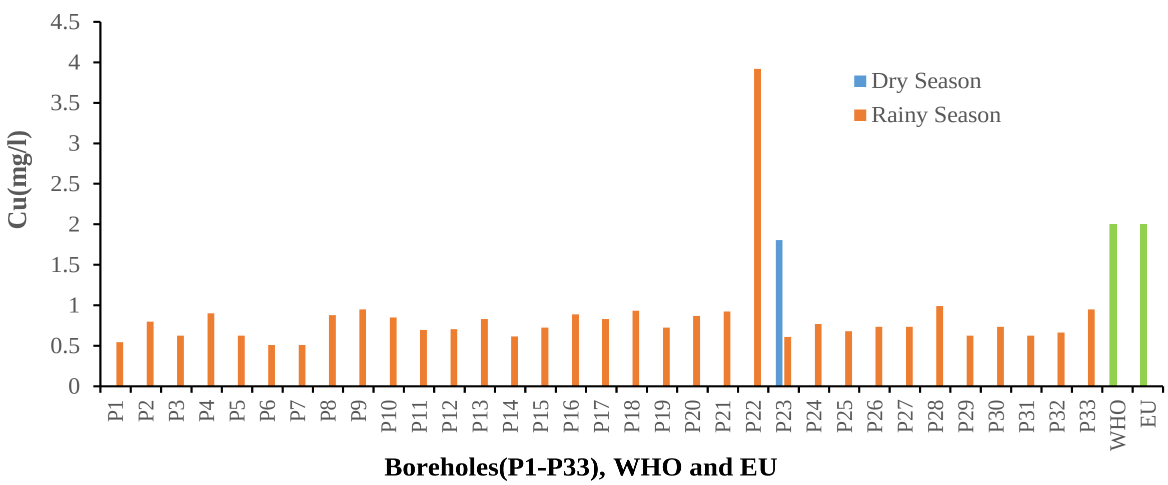

Figure 7. The evolution of Cu concentrations

As is a metalloid that occurs naturally at low concentrations in rocks, soils, animals, and plants. Long-term exposure to As in drinking water has been associated to cancer (Ayantobo et al., 2014). Skin cancer has been linked with long-term exposure to arsenic through drinking water (Ayantobo et al., 2014).
The environmental impacts of gold mining are mainly severe because of the chemical processes often utilize to extract gold (Abdul-Wahab and Marikar, 2012). Figure 8 displayed the evolution of As concentration. From Figure 8, it can be viewed that the values of As at both seasons in the villages of Amina and Lero respectively were higher than the permissible limits for drinking water quality. Elevated doses of As observed in these villages can be harmful to public health on persistent exposures through consumption. The presence of high concentrations of As in groundwater could be explained by probable

contamination following the leaching of mining waste deposited nearby for decades and by the geological nature. Similar study was also presented by Soro et al., (2019) and assumed that the contribution of As to the contamination of neighboring ecosystems would be due to leachate. Bamba (2012) exhibited that the presence of a high As content in the wells sampled in Burkina Fasso would come from contamination of the water table by these toxic elements probably coming from the mining heritage. Heriarivony et al.,(2015) specify that the high As content of groundwater is generally linked to the geological nature of the underground, which is partly composed of gold mineralization and volcano-sedimentary rocks of the Birimian. These undergrounds contain ores such as arsenopyrite in which the proportion of As elements is relatively high. Following the same idea, Ayantobo et al., (2014) concluded that the As concentration could be due to mineral dissolutions such as pyrite oxidation. Also, Ligate et al., (2021) mentioned that the most important geogenic source of As in groundwater systems is the presence of iron oxides, sulfide minerals such as pyrite, arsenopyrite, and chalcopyrite.

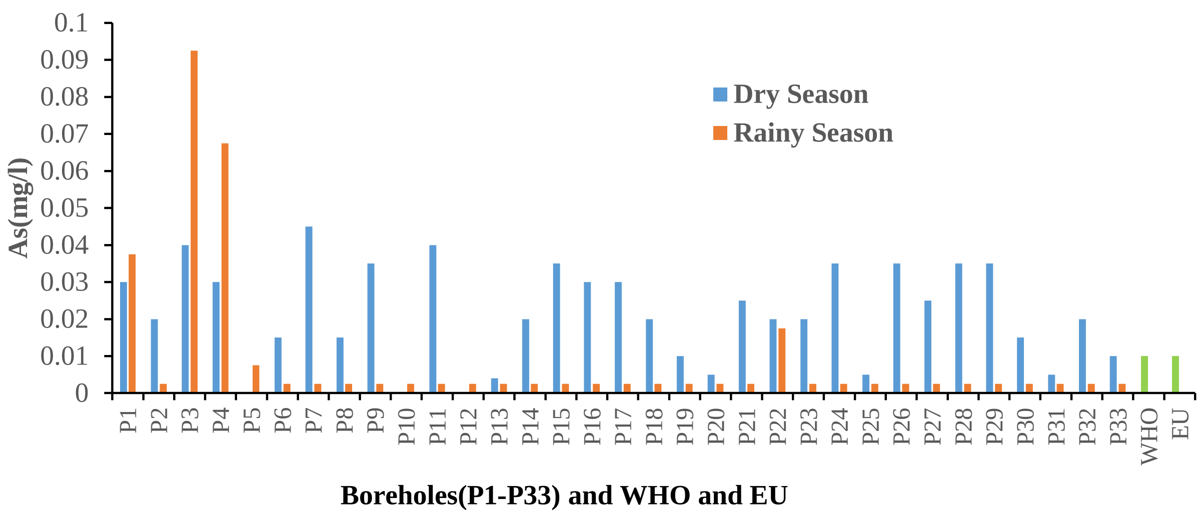

Figure8. The evolution of As concentrations.

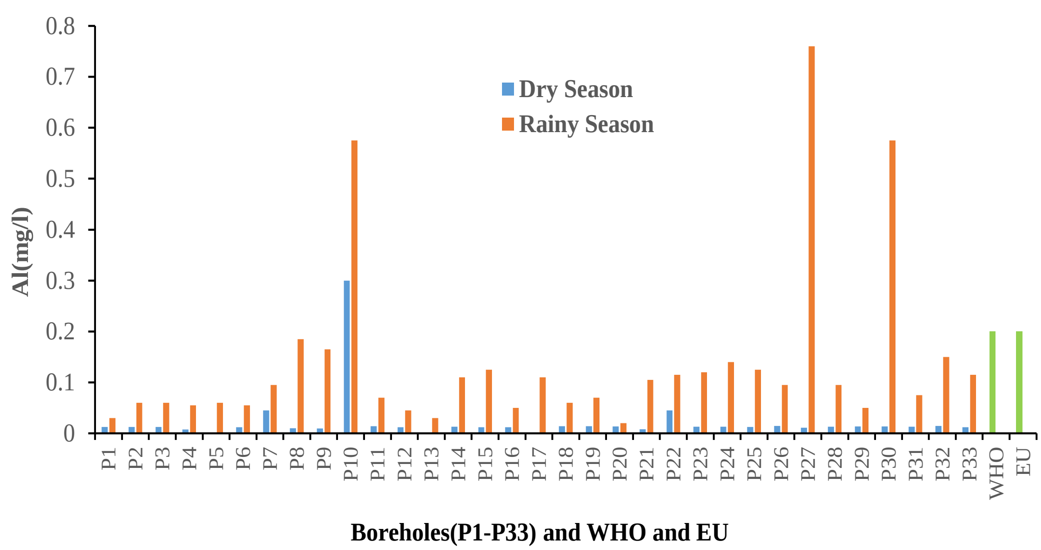

Figure 9. The evolution of Al concentrations.

Figure 9 shows the evolution of Al concentrations. It can be seen in Figure9 that about 4 and 10 % respectively of the dry and rainy season were above the WHO maximum acceptable limits. The variations of the values in the well P10, P27 and P30 respectively in Lero and Siguirini of the rainy period seem to follow a seasonal tendency, that is to say that it was high during the rainy period and low during the dry period. However, the concentrations in the well P10 at Lero remain almost constant suggesting seasonal independence (Kortatsi, 2006).

CONCLUSIONS

Studies on the characterization of groundwater in the Sub-prefecture of Baraka (Siguirni) of the Prefecture of Siguiri, through heavy metals analysis and statistical analyzes have made it possible to determine the characteristics, of the groundwater of Baraka and their potability. The concentrations of Zn, Al and Cu in some of the boreholes comply with WHO guideline values. However, the concentrations of Cd, As, and Pb are generally not within the WHO standard. The heavy metal abundance in sampled groundwater within the Baraka is in the order: Cd > As > Pb> Al > Cu > Zn for well water. High metal waters can cause contamination in the local groundwater through the solubilisation of toxic metals. Consequently, groundwater use from the study area could have negative impacts on the health of the population.

The limitation of this study is due to a lack of hydrochemical data over a long period based on advanced analytical chemical methods. For a depth analysis of water quality in Baraka area, the monitoring and analysis should be done for a longer period of time to ensure that gold extraction and processing do not impact drinking water sources. Test samples (raw ore, soils, discharges, surface water, and groundwater) should be collected for laboratory analysis or by using probes. The industrial and artisanal miners, and the entire community should be educated on the health risk linked with human exposure to toxic metals.

REFERENCES

Anim-Gyampo M, Berdie BS, Bessah E, Agodzo SK (2021) Effects of Illegal Artisanal Gold Mining Operations on Groundwater Quality in Ghana: The Case of Ahafo-Ano South District. In: Dunea, D. , editor.*Water Quality, IntechOpen; Available from: https://www.intechopen.com/chapters/79006 doi: 10.5772/intechopen.100242*

Abdul-Wahab SA and Marikar FA(2012) The environmental impact of gold mines: pollution by heavy metals *Cent. Eur. J. Eng. 2(2)304-313 DOI: 10.2478/s13531-011-0052-3*

Ayantobo OO, Awomeso JA, Oluwasanya GO, Bada BS and Taiwo AM (2014) Gold mining in Igun-ijesha, southwest Nigeria: impacts and implications for water quality. *American Journal of Environmental Sciences 10 (3): 289-300*

Armah FA, Obiri S, Yawson DO, Onumah EE, and Yengoh GT (2010) Anthropogenic sources and environmentally relevant concentrations of heavy metals in surface water of a mining district in Ghana: A multivariate statistical approach. *J. Environ. Sci.Health Tox. Hazard. Subst. Environ. Eng., 45: 1804-1813. DOI: 10.1080/10934529.2010.513296*

Belle G, Fossey A, Esterhuizen L, & Moodley R (2021) Contamination of groundwater by potential harmful elements from gold mine tailings and the implications to human health: A case study in Welkom and Virginia, Free State Province, South Africa. *Groundwater for Sustainable Development, 12, 100507.*

Bamba Y (2012) Evaluation des impacts de l'exploitation de la mine d'or de bonikro (côte d'ivoire) sur les ressources en eau (Mémoire). *2iE, Burkina Fasso*.

Dissmeyer GE (2000) Dissmeyer, Drinking Water from Forests and Grasslands, Southern Research Station, USDA Forest Service, Ashville, North Carolina, USA

Dorleku MK, Nukpezah D, Carboo D (2018) Effects of small-scale gold mining on heavy metal levels in groundwater in the Lower Pra Basin of Ghana. Appl Water Sci 8, 126.

Heriarivony SC, Razanamparany B & Rakotomalala JE (2015) Physico-chemical and bacteriological characteristics of drinking water (wells) in the Rural Commune of Antanifotsy, Vakinankaratra Region, Madagascar. *log larhyss , 1112-3680.*

International Trade Center for Development, CECIDE (2010) Effects of the operations of the Dinguiraye mining company / crew gold on the enjoyment of the social and economic rights of the community of Lero and Siguirini . (Memorandum). CECIDE, Guinea.

Kamunda C, Mathuthu M, & Madhuku M (2016) Health risk assessment of heavy metals in soils from Witwatersrand Gold Mining Basin, South Africa. *International Journal of Environmental Research and Public Health, 13(7), 663.*

Konan S, Goue DL, Yao MJ, Kouame KI, Lazare ,and Kouamé, BD (2018) Chemical quality of the drinking water of the populations of the commune of Soubre (south-west, Ivory Coast). *International Journal of Advanced Research* http://dx.doi.org/10.21474/IJAR01/6185 .

Kouassi MA, Ahoussi KE, Koffi YB, Ake YA, Biemi J (2012) Caractérisation hydrogéochimique des eaux aquifères fissurés de la zone Guiglo- Duekoué (Ouest de la Côte d'Ivoire). *Int. J. Biol. Chem. Sci., 6(1): 504-518.* DOI: http://dx.doi.org/10.4314/ijbcs.v6i1.45

Kouassi Serge G, Séraphin KK, Lazare KK, Alexis BL, Félix KK & Dongui, BK (2020) Evaluation of the chemical contamination of groundwater by anthropogenic activities: case of the area of ity-floleu sub-prefecture of zouanhounien , west of the ivory coast. *European Scientific Review, 16(6), 1857-7881.*

Kortatsi BK (2004) Hydrochemistry of groundwater in the mining area of Tarwa-Prestea, Ghana**.** *Ph.D. Thesis, University of Ghana, Legon-Accra, Ghana***.**

Kortatsi BK (2006).Concentration of trace metals in boreholes in the Bassin d'Ankobra, Ghana. West Africa *J Appl Ecol 10: 73–87*

Kubier A, Wilkin RT, Pichler T. (2019) Cadmium in soils and groundwater: A review. Appl Geochem. Sep 1;108:1-16. doi: 10.1016/j.apgeochem.2019.104388. PMID: 32280158; PMCID: PMC7147761.

Ligate F, Ijumulana J, Ahmad A, Kimambo V, Irunde R, Mtamba JO (2021) Groundwater resources in the East African Rift Valley: understanding the geogenic contamination and water quality challenges in Tanzania. *Scientific African, 13.*

Lebrun EO (2016) 4D evolution of the gold district Siguiri Orogen , Guinea (West Africa*). PhD Thesis ,School of Earthof Earth and Environment, University of Western Australia. Australia.*

Matini L, Moutou JM & Kongo -Mantono MS (2009) Evaluation hydro-chimique des eaux souterraines en milieu urbain au Sud-Ouest de Brazzaville, Congo. *Africa science, 05(1) 82 - 98 17.*

Mahamane A and Guel B(2015) Caractérisations physico-chimiques des eaux souterraines de la localité de Yamtenga (Burkina Faso),*International Journal of Biological and Chemical Sciences, 9, 517-533.*

Idrees N, Tabassum B, Abd Allah EF, Hashem A, Sarah R, Hashim M(2018) Groundwater contamination with cadmium concentrations in some West U.P. Regions, India, *Saudi Journal of Biological Sciences,25 (7), 1365-1368, ISSN 1319-562X*

Oluwasanya GO and. Martins O (2006) Assessment of heavy metals in groundwater case study of Ogun State-Southern Nigeria. Asset Series A, 6:309-321.

Souley Moussa R, Malam Alma MM, Laouli MS, Natatou I & Habou I (2019) Characterization physico-chemical waters of the Continental Intercalaire / Hamadien and Continentalsiems Terminal aquifers in the Zinder region (Niger), *International Journal of Biological and Chemical Sciences, 12(5), 2395-2411.*

Soro G, Soro TD, Fossou NM-R, Adjiri OA & Soro N (2019) Application des méthodes statistiques multivariées à l'étude hydrochimique des eaux souterraines de la région des lacs (centre de la Côte d'Ivoire). *International Journal of Biological and Chemical Sciences, 13(3), 1870-1889.*

Tay CK, Hayford EK and Hodgson IOA (2017) Application of multivariate statistical technique for hydrogeochemical assessment of groundwater in the basin Lower Pra , Ghana. *Applied Water Sciences 7, 1131–1150.*

Tay CK, Dorleku M, and Louis Korbla Doamekpor LK(2019) Human Exposure Risks Assessment of Heavy Metals in Groundwater *West African Journal of Applied Ecology, vol. 27(1), 2019: 23 - 41*

Tetteh GM and Asante NY(2016). Petrography and geochemistry of mineralization auriferous Birimian from the Siguiri Basin ,Guinea. *International Journal of Geology, Earth Sciences and the Environment. 6 (2) 8-17.*

World Health Organization (WHO) (2011) Guidelines for Drinking Water Quality, *WHO Press, Geneva, Switzerland, 4th edition.*