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RESEARCH ARTICLE

IMPACT OF ARTISANAL PERMA GOLD MINING ON GROUNDWATER QUALITY

L.A.S. Tometin[1,3], W.K. Chouti[2,3], A. Aboubakari[2], I. Agani[1], M. Dannon[2], J.K. Fatombi[1] and D. Mama[2]

1. Kabba Laboratory for Research in Chemistry and Applications (LaKReCa), UNSTIM / ENS- Natitingou.
2. Applied Hydrology Laboratory, National Water Institute (INE), University of Abomey-Calavi 01 BP: 526 Cotonou, Benin.
3. Laboratory of Inorganic Chemistry and the Environment, Faculty of Science and Technology (FAST), University of Abomey-Calavi, BP: 4521 Cotonou, Benin.

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Abstract

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The artisanal exploitation of gold in Perma is not without impact on the environment and even the quality of groundwater. For this, three gold panning sites were selected. Samples of water (surface and underground) and sediments were taken during the rainy season between the months of August and September 2021. The results from the physico-chemical analyzes show that the waters are slightly acidic (6 < pH < 7.42), weakly mineralized and conductive (21 < EC < 448 µS/cm); the water temperature varies between 27.7 °C and 30.8 °C. The concentrations of cyanides and zinc vary respectively from 0 µg/L and 30 µg/L and from 0.01 and 0.5 mg/L. With regard to the sediments, the physico-chemical analyzes show the following results: the water pH is close to neutral [6.79; 6.98] and the KCl pH is slightly acidic [6.42; 6.53]. Sediments from the Kouaterna site record high concentrations of total phosphorus 7934.00 meq/kg, total carbon 1.1094%, NTK 1200 mg/kg and organic matter 1.91%. As for the exchangeable K and the cation exchange capacity, they evolve respectively between 0.0859 meq/kg and 0.1791 meq/kg and 4.360 meq/kg < CEC < 6.160 meq/kg. Groundwater in the area is weakly mineralized, of good quality and has no impact on consumption, unlike unsuitable surface water.

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Introduction:-

The practice of artisanal gold mining, also called gold panning, is an activity that has appeared for a very long time throughout the world. This practice involves several million people in 70 countries around the world (UNEP, 2014). Although it is practiced with bygone means and even very little mechanized and sometimes not, it injects the yellow metal into the global gold network (Abdou, 2020). Indeed, 10 to 20% of the quantity of gold circulating in the world comes from artisanal mining (USAID, 2017). Gold panning not only contributes to the fight against poverty and rural exodus, it also has an economic advantage in the world (Tomicic et al., 2011). In Africa, most rural populations live at the expense of natural resources. However, this access is sometimes weakened in several areas due to increased competition, the reasons for which stem from population growth and other factors (Keita et al., 2001). The main reason for this dependence on natural resources is human poverty. However, this anarchic exploitation of natural resources does not allow people to get out of poverty (Hadonou et al., 2019). Apart from agriculture, livestock, fishing and other low-income activities, mining is part of one of the activities carried out on the

Corresponding Author: - Lyde A.S. Tometin
Address**:-** Laboratoire Kabba de Recherche en Chimie et Applications (LaKReCa), ENS-Natitingou. National University of Sciences, Technologie, Engineering and Mathematics (UNSTIM) - Abomey

environment and which do not remain without effect on the latter. It has become an essential source of additional income for many African countries over the past two decades. According to Rutherford et al. (2014), several million Africans pin their hopes on small-scale artisanal mining to be able to meet their needs. According to the Minamata Convention on Mercury, Artisanal Small-Scale Mining (ASM) is defined as “the mining of gold by individual miners or small enterprises with limited investment and production” (UNDP , 2014). Gold panning is a significant reality in rural areas in the same way as agriculture and livestock (Affessi et al., 2016). In view of the economic benefits of mining in general, gold mining in particular favors the settlement of the auriferous zone by individuals of various origins in search of gold (Hue and al, 2020). Unfortunately, it is not done without having consequences for the human and natural environment (Bohbot., 2017). According to (Keita, 2001), gold panning works cause the general deterioration of the living environment. For Jaques et al., 2003, artisanal gold mining has impacts on natural resources, health and even socially. In Benin, this activity is also practiced in the north of the country in Perma and more precisely in Kouaterna. According to the work of Arouna et al. (2016) in this area, intensive agriculture and gold panning activities degrade the landscape, thus promoting the regression of natural formations in favor of anthropogenic formations, not to mention the filling of watercourses. of the area. The changes caused by land use have a negative impact on the ecological balance of the landscape (Arouna et al., 2016). The mines were the subject of several concessions and exploitation before being abandoned to "wild" exploitation by the surrounding populations and from elsewhere (Hadonou et al., 2019). Indeed, very few research activities on the quality of water in this area have been carried out. However Tohngodo, (2008) had made a study on the evaluation of the ecotoxicological risk of mineral trace elements of the Perma gold perimeter. This study, which was carried out on the surface waters, soil and sediments of the gold-bearing zone, showed the presence of mercury, arsenic, lead and cadmium in its compartments. Unlike organic pollutants that can be degraded in the environment, Trace Metal Elements (TMEs) are persistent and can accumulate in sediments and biota (Hanane et al., 2014). Thus, this artisanal gold mining that pollutes surface waters is likely to also pollute groundwater because of the interconnection that exists between groundwater and surface water. This is what motivates us to work on the impact of this artisanal gold mining on the quality of groundwater.

Material And Methods:-

Study framework

The gold-bearing basin of Perma is located southeast of the commune of Natitingou in the department of Atacora in Benin, between the meridians 1°26'45" and 1°33'15" of longitude East and the parallels 10°11'00" and 10°14'00" north latitude (**Figure 1**). The morphology of the Perma deposit consists of the vein deposit and the alluvial deposits. These deposits are located in the Perma River, at Sinaissiré, and at Sarga. The alluvial gold reserve is estimated at 400 kg with a gravel content of 1 g/m2 (Kirov et al., 1984). In addition, this study area is largely crossed by the Perma River (Kirov et al., 1984).

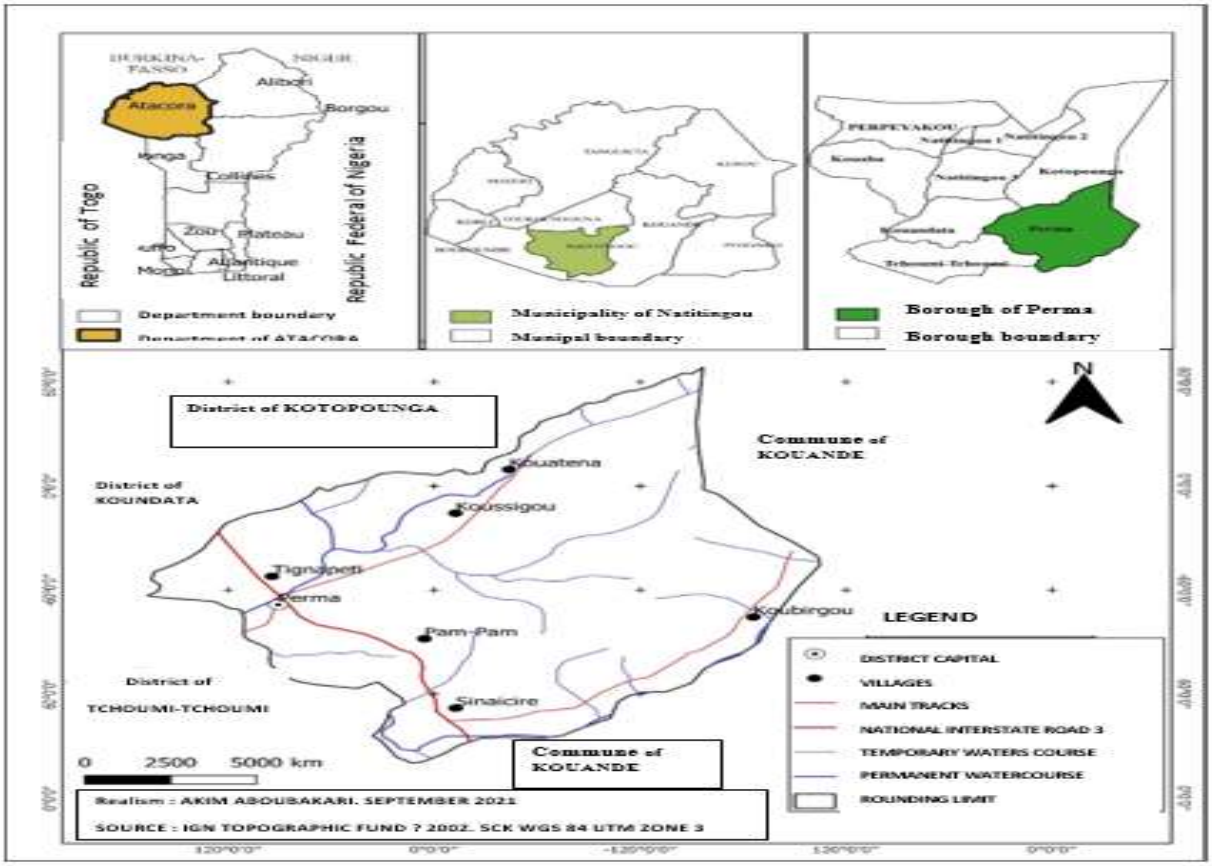

Figure 1:- Location of the study area.

This study is particularly interested in the sites of the villages of Koussigou, Kouaterna, and Gnamgnammou where the gold panning activity is more developed.

Sampling and determination of physico-chemical parameters

As part of our study, sampling was done during the rainy season (August, September 2021). The sampling sites were selected taking into account gold panning activities on the one hand, and the use made of water from wells and boreholes on the other. We therefore chose a total of three gold panning sites (Koussigou site, Kouaterna site, Gnamgnammou site) including eight water sampling points and three sediment sampling points.

In the waters, the pH and the temperature were measured in situ by the HANNA brand pH-meter; nitrites and nitrates were measured using the VWR spectrophotometer (UV-1600PC); cyanides and zinc were determined respectively by the pyrazalone-pyridine method (method 8027; Hach, 2005 and the zincone method (method 8009; Hach, 2005).

For the sediments, the pH of the sediment and the KCl pH were measured by the HANNA brand multi-parameter conductivity meter according to standard NF X 31-103; the nitrates were read using program 351 of the DR 3900., the dosage of total phosphorus and Nitrogen NTK was done according to the mineralization with HACH for the dosage of phosphorus and the neutralization of the mineralized with NaOH 5N. The total carbon was determined by the titrimetric method with H_2SO_4 0.01N. The method used for the determination of the CEC is the METSON method or the ammonium acetate pH 7 method.

Assessment of groundwater quality

The quality of groundwater was assessed according to the study of the pollution parameters and the interpretation of a simplified grid (table 2) namely the electrical conductivity and the chloride ions which provide information on the mineralogical quality of the waters then the nitrates which are indicators of groundwater pollution (Nordine Nouayi *et al*, 2015).

Table 1:- Simplified grid for global groundwater quality assessment.

	Parameters		
	Electrical conductivity µS/cm	Chlorides mg/L	Nitrates mg/L
Excellente	< 400	< 200	□ 5
Good	400-1300	200-300	5-25
Average	1300-2700	300-750	25-50
Bade	2700-3000	750-1000	50-100
Very bade	> 3000	> 1000	>100

The organic pollution index (IPO) of Leclercq (2001) was used to assess the organic load of the water analyzed. Its principle is to distribute the values of the polluting elements into 05 classes (Table 3 and Table 4). This index is obtained by means of the values of ammoniums, nitrites and phosphates. The principle of the calculation is to divide the values of the three polluting elements into five classes and to determine, from the values obtained in the study, the corresponding class number for each parameter using the average data from the table. The final organic pollution index is the average of the pollution classes for all the parameters.

Table n°2:- Grid of organic pollution index classes (Leclercq, 2001).

Class Parameters	Ammonium (mg/L)	Nitrites (µg/L)	Phosphates (µg/L)
5	< 0.1	5	15
4	0.1 – 0.9	6 – 10	16 – 75
3	1 – 2.4	11 – 50	76 – 250
2	2.5 – 6	51 – 150	251 – 900
1	>6	>150	>900

Table 3:- Grid of organic pollution index classes (Leclercq, 2001).

Class average	Characterization of organic pollution
5 – 4.6	Nul
4.5 – 4	Weak
3.9 – 3	Moderate
2.9 – 2	Strong
1.9 - 1	Very strong

Results and Discussion:-

Physicochemical parameters

Table I:- Variation of the physical parameters of water between August and September 2021.

Parameters		Temperature		pH		TDS		CE		NTU	
Sites	Code	Aug	sept	Aug	sept	Aug	sept	Aug	sept	Aug	Sept
Koussigou borehole	S1	30.7	30.9	6.23	6.42	125	130	245	262	6.32	5.87
Koussigou well	S2	31.1	30.6	6.28	6.94	58	65	117	130	90	73
Kouaterna F1	S3	29.3	28.7	6.18	6.00	88	88	170	175	1.5	0.8
Kouaterna F2	S4	29.6	29.7	6.49	6.48	131	142	262	285	2.09	1.22
Kouaterna well	S5	28.8	29.5	6.22	6.5	12	10	24	21	45.8	10.9
Gnamgnammou E-r	S6	27.7	27.5	7.55	7.62	16	16	32	32	4.11	2.68
Gnamgnammou E-Ri	S7	29.2	29.4	7.19	7.42	23	14	47	29	198	153
Perma	S8	30.8	31.8	6.33	6.12	176	225	350	448	1.75	2.38

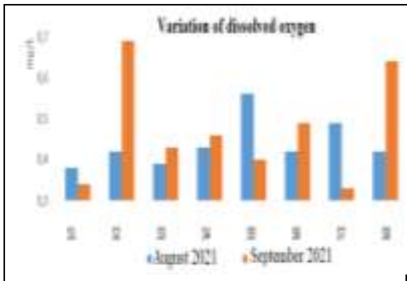

Figure 2 : Variation of dissolved oxygen in water

Figure 3 : Variation in the concentration of cyanide ions.

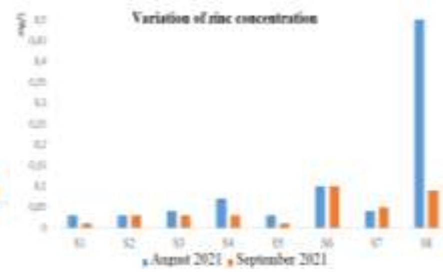

Figure 4 : The concentration of zinc in water samples

Table II:- Presents the concentration of ions (chlorides, calcium, magnesium, nitrites and nitrates) between August and September 2021.

Parameters	Period	S1	S2	S3	S4	S5	S6	S7	S8
Cl^-	Aug	6	10.01	8	12.01	14.02	10.01	12.01	64.07
	Sept	12.01	17.02	12.01	20.02	12.01	10.01	12.01	66.07
Ca^{2+}	Aug	56	36	36	40	32	38	20	60
	Sept	28	20	20	26	14	16	16	44
Mg^{2+}	Aug	48	14.4	22.8	14.4	28.8	9.6	12	12
	Sept	14	9.6	22.8	20.4	6	20.4	12	18
NO^{2-}	Aug	0.045	0.35	0.044	0.067	0.22	0.05	0.38	0.044
	Sept	0.054	0.28	0.047	0.047	0.068	0.049	0.21	0.048
NO^{3-}	Aug	0.45	4.96	0.99	2.77	0.66	8.35	1.023	13.37
	Sept	0.55	3.6	0.8	5.1	0.64	0.07	1.09	18.67

Physico-chemical parameters of sediments

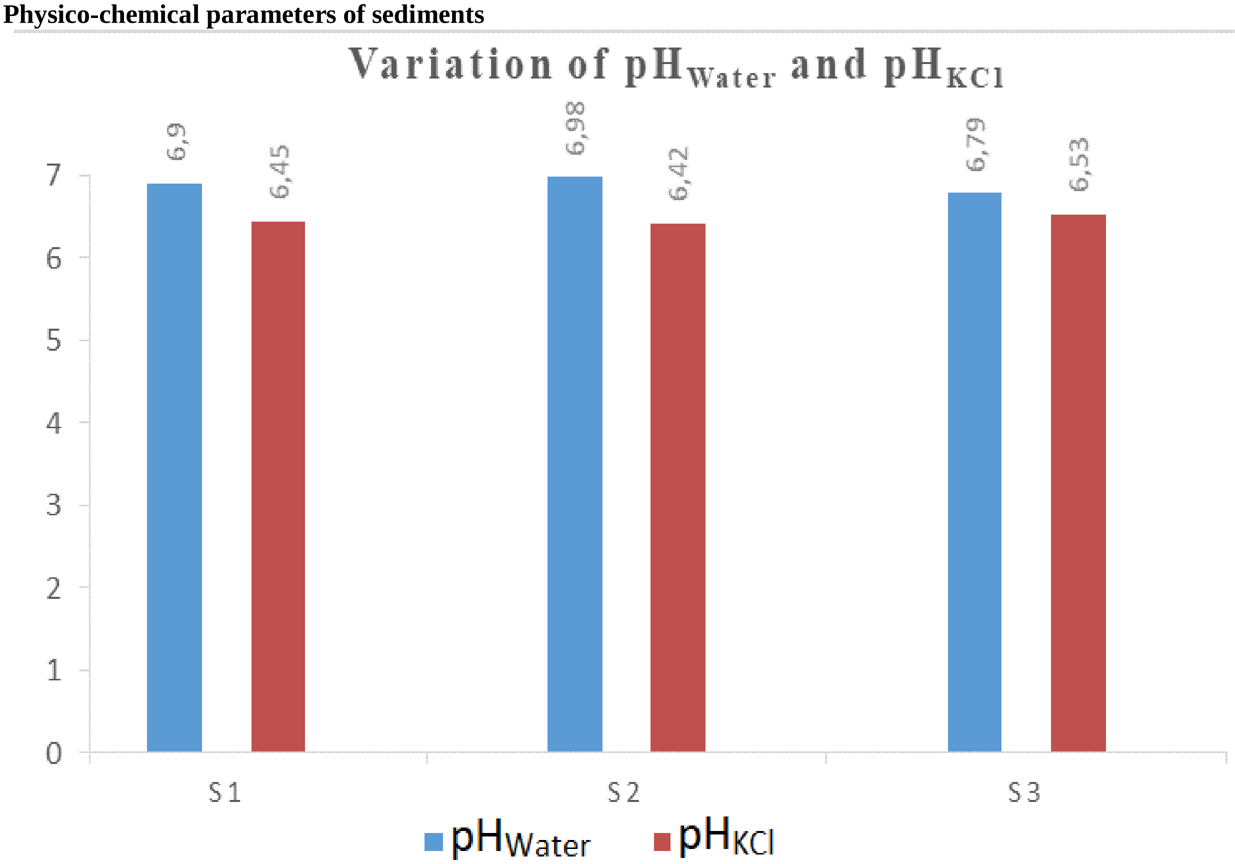

Figure 5:- Variation of pH_{eau} and KCl pH_{KCl}

Table III:- Variation of physicochemical parameters of sediments.

Parameters	K1		K2	G
Total Phosphorus, mg/kg	4906.00		3794.41	7934.00
NTK, mg/kg	300.00		898.20	1200.00
Total Organic Matter %	0.309		0.781	1.913
Total carbon %	0.1794		0.4530	1.1094
K exch meq/100g	0.0859		0.1005	0.1791
CEC meq/100g	4.360		4.560	6.160

Discussion:-

The pH measures the acidity or basicity of a solution. It is a parameter that determines the chemical activity of hydrogen ions in solution (IBGE, 2005). The pH of our study medium varies between 6.18 and 6.45. These pH values are not within the tolerable limit of the Beninese standard [6.5, 8.5], which reflects the acid nature of the waters. The pH values recorded are similar to those found by Tohngodo (2008) in the same study medium [5; 6.5]. These same values are consistent with those found by Atangana *et al.* (2019) on the degraded mining site in the Bétaré-Oya sector in eastern Cameroon. From the point of view of temperature, it varies between 27.7°C to 30.8°C with an average of 29.64°C. These values are higher than the Beninese standard for the potability of surface water (25°C). These results obtained are higher than those found by Atangana et al (2019) [24.8 and 31°C]. The waters are very mediocre from a temperature point of view.

Turbidity is a parameter that measures the presence of suspended solids in water. The waters analyzed have a turbidity between 1.22 NTU to 198 NTU. The turbidity decreases from the waters of the river (198 NTU) to the boreholes (less than or equal to 6.32 NTU) passing the wells (less than 2,198 NTU). The low level of turbidity observed at the level of the boreholes is explained by the fact that these structures are more protected compared to the waters of the river used for washing ores. The values found are lower than those found by Bawa *et al.* (2006) in the effluent waters of the textile industry of Datcha and the phosphate production industry of Kpémé in Togo. In general, industrial effluents are much more loaded with suspended particles and other toxic and colored substances. This will explain the difference observed with the turbidity of the waters of our study environment. The TDS, which designates all the total dissolved solids, has values below the standard recommended by the WHO (1000 mg/L). The maximum recorded value is 225 mg/L. These results do not agree with those found by Matini, (2009) in groundwater south-west of Brazzaville in Congo (less than 210 mg/L) and Niamke *et al*., (2020) in waters from an environment mining in the center of the Ivory Coast. Indeed, the underground waters of the South-West of Congo Brazzaville are those used for the drinking water supply of the population. On the other hand, the waters of a mining environment in the center of the Ivory Coast studied by Niamke *et al.* (2020) have a much higher TDS rate. The difference observed could lie in the different effluents that mining activities bring to water resources. High TDS value is not so bad for health (Maoudo *et al*., 2021) but can have undesirable effects and can also indicate the presence of harmful pollutants like iron, manganese, sulphate, bromide etc…

The electrical conductivity as well as the chloride and nitrite ion contents are parameters used to assess the quality of the water. Electrical conductivity is the ability of water to allow an electric current to pass through it. The maximum value (448 µS/cm) recorded in our study environment is at the level of the Perma well which is close to the Perma river. The high rate of conductivity could be due to the influence of the waters of the river which suffered the impact of gold panning. The chloride ion content is less than 200 mg/L. The nitrate level is less than 5 mg/L for the S1, S3, S5, S7 sites and greater than 5 mg/l for the S2, S4, S6, S8 sites. These results suggest that the groundwater of sites S1 S3 S5 S7 are of excellent quality while those of sites S2 S4 S6 S8 are of good quality. The waters of the study area are low in mineral content compared to the waters of the mining site in the Divo department (608.4 µS/cm) in the center-west of Côte d'Ivoire (Aristide *et al.*, 2020).

Furthermore, the nitrite content for all the S2 S3 sites is between 11 and 50 mg/L; that of the S1 S4 S6 S8 sites is between 50 and 150 while that of the S5 S7 sites is greater than 150 mg/L; which reveals the total absence of organic pollution. These results suggest that not all sites have the same level of organic pollution. S2 S3 sites are moderately polluted in organic matter; S1 S4 S6 S8 are strongly while S5 S7 are very strongly. These observations are too higher and disagree with Nitrite levels expected to be much lower than 3.3 mg/litre (US EPA, 1987). In the USA, naturally occurring levels do not exceed 4–9 mg/litre for nitrate and 0.3 mg/litre for nitrite (US EPA, 1987) Nitrite levels in drinking-water in the Netherlands are usually below 0.1 mg/litre. In 1993, a maximum value of 0.21

mg/litre was detected (RIVM, 1993).Absorbed nitrite is rapidly oxidized to nitrate in the blood. Nitrite in the bloodstream isinvolved in the oxidation of Hb to metHb: the Fe^{2+} present in the haem group is oxidized to itsFe^{3+} form, and the remaining nitrite binds firmly to this oxidized haem. The Fe3+ form doesnot allow oxygen transport, owing to the strong binding of oxygen (US NationalResearch Council, 1995). Therefore, methaemoglobinaemia can lead to cyanosis. But nitrite itself is not carcinogenic to animals (Speijers et al., 1989;WHO, 1996).With respect to chronic effects, JECFA recently re-evaluated the health effects ofnitrate/nitrite, confirming the previous ADI of 0–3.7 mg/kg of body weight per day for nitrate ion and establishing an ADI of 0–0.06 mg/kg of body weight per day for nitrite ion (WHO,1995).

On the other hand, dissolved oxygen is an important biological parameter in the evaluation of water quality because of its influence on living organisms. The solubility of oxygen in water decreases with temperature and salinity. The higher the temperature, the lower the dissolved oxygen.

Total phosphorus represents all the phosphorus in a sample in the form of phosphates in the water. They come from the leaching of certain minerals and the decomposition of organic matter. The value of total phosphorus in our study medium oscillates between 0.026 and 2.200 mg/L. These values are different from those found by Bawa *et al.* (2005).

Naturally, cyanides are absent in the waters. Their presence in the water is a source of anthropogenic pollution. Cyanides were analyzed in all water samples. The highest value (30 µg/L) is recorded in river water. Slightly lower than the WHO standard (50 µg/L), the high rate at this point is explained by the use of cyanide in the exploitation of the vein gold. Namoussi *et al.*(2019) had found different results from those found in our study environment. Indeed, Zinc is the only metal analyzed in our study. The maximum concentration 0.5 mg/L is obtained in a well at Perma. It does not present a danger for the moment because the value of the concentration of the assayed samples is lower than the Beninese standard which is 3 mg/L.

Indeed, chemicals released into the environment following various anthropogenic activities can penetrate aquatic ecosystems and become part of suspended matter. These particles settle over time on bottom materials, where contaminants can accumulate. Sediment can therefore constitute, through the phenomenon of salting out, an endogenous source of pollution of watercourses (Dimon *et al.*, 2014). In order to assess the level of sediment contamination in our study area, certain physico-chemical parameters were studied. For sediments, the pH represents a factor whose role is crucial for the mobility of metal ions Chouti *et al.*, (2018), because it influences the number of negative charges that can be dissolved. In our study environment, the water pH is slightly neutral, the highest value 6.98 is obtained at S2 and the lowest 6.76 at S3. Regarding the pH_{KCl}, it is slightly acidic and varies between 6.45 and 6.53. The largest value 6.53 is observed at S3. According to Chouti et al, 2018, pH_{KCl} is always lower than water pH. These two parameters make it possible to know the evolution of the degree of acidity in the sediments and soil. The greater the difference, the more the sediments have a reserve acidity and the more easily they can acidify. The difference pHwater - pH_{KCl} is positive in our study environment and varies from 0.26 to 0.56 in the present work. This differs with the results of Tohngodo (2008). For (Thiam, 2012) it is a low reserve acidity.

Total phosphorus represents all the phosphorus present in a sample in the form of phosphates or organophosphorus compounds. The high value of total phosphorus of 7934.00 mg/kg observed in the sediment of the Kouaterna site would be of anthropogenic origin and this is explained by the use of detergents for washing minerals and the laundry of artisanal gold miners along the rivers. The watering of local Fulani herds and the agriculture practiced near the site could also increase the total phosphorus content. Indeed, according to Chouti *etal.* (2011), phosphorus is not toxic for aquatic organisms but the contribution of this element in an environment causes the phenomenon of eutrophication which depletes the dissolved oxygen necessary for the monitoring of aquatic organisms. With regard to Total Kjeldahl Nitrogen or NTK which represents all the reduced forms of nitrogen contained in sediments and waters, i.e. the sum of organic nitrogen and ammoniacal nitrogen. The high value is also obtained at the Kouaterna site 1200 mg/kg. This nitrogen of anthropogenic origin can have serious consequences on the receiving environment because the degradation of organic nitrogen consumes oxygen with the associated risk of anoxic shock.

Total organic matter and total carbon, which were also analyzed, show varying percentages in the sediments. The highest values observed at the gold panning site of Kouaterna result from the pressure made by the gold washers in this site by cutting trees and throwing all kinds of solid waste. The agriculture and livestock farming practiced on the outskirts of the site also contribute to the deposit of these elements in the sediments of the river.

As for exchangeable potassium, it is dependent on many soil, climatic and agricultural factors which lead to a great variability of the observed contents. Potassium evolves in the soil in the form of K^+. It can be attached to clays, absorbed on the cation exchange capacity (CEC) and soluble in soil water.

The cation exchange capacity is an important parameter in the analysis of sediments and makes it possible to know the fixing power of the sediments with respect to cations. It makes it possible to know the total number of cationic charges that a mass of earth can retain in an exchangeable state by weak bonds of the electrostatic type according to the pH. In the study environment, the CEC is high and varies from one point to another, resulting in the retention of cations in the sediments. This explains their low rate observed in groundwater. These results differ from those found by Chitou *et al.* (2018).

Conclusion:-

In the Perma gold zone, gold mining is alluvial and vein types. This exploitation involves the use of chemicals such as mercury, cyanides and detergents.

The analysis of groundwater from the operating site reveals the presence of zinc and cyanide at low concentrations. The very low concentrations of these elements in groundwater compared to surface water can be explained by the anthropogenic nature of the pollution. The analysis of the sediments shows an anthropogenic pollution which results from the artisanal exploitation of gold on the one hand and from the agriculture and the breeding exercised around the site on the other hand.

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