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Research Article

WATER QUALITY ASSESSMENT OF PERMA GOLD BASIN IN THE NORTHWEST OF BENIN [THROUGH PRINCIPAL COMPONENT ANALYSIS (PCA)]

***Moussaga Alphonse SEKO OSSINRA[1, 3], Éric Alain M. TCHIBOZO [1], Christophe KAKI[2] & Placide F.G.A. CLÉDJO [3]**

[1]*Laboratory of Geomatic Applications and Environmental Management (LA2GE/FASHS), University of Abomey-Calavi (UAC), Benin*

[2] *Laboratory of Geology, Mines and Environment (LGME/FAST), University of Abomey-Calavi (UAC), Benin*

[3]*Ecole Doctorale Pluridisciplinaire, Université d'Abomey-Calavi (UAC), Bénin*
**Author for Correspondence: sekoalphonse@yahoo.fr*

ABSTRACT
The following research/study evaluates the physico-chemical quality of water in the gold basin of Perma Region where intense gold mining activities have been carried out for several decades in addition to agriculture. It is carried out on 24 physico-chemical parameters of three water sources (boreholes, traditional wells and River in Perma) taken in March-April 2020 and submitted to physico-chemical analyses and then submitted to the Principal Component Analysis (PCA). The physico-chemical parameters of water indicate their acidity with an average pH of 6.09. The relevant water are weakly mineralized with a strong colour (270.66) and turbidity (112.33), exceeding Benin guidelines. The presence of iron (1.5) and ammoniacal nitrogen (1.213) in the river is higher than Benin and WHO standards. Cyanides (CN--), mercury (Hg^{2+}), and lead (Pb^{2+}) are present in wells used as drinking water with concentrations of 0.059; 0.384; 0.005 respectively, which are above WHO standards. These heavy metals used by gold miners pollute water sources. The PCA carried out on the 20 physico-chemical parameters shows that the two factors account for 100% of the total variance with 69.97 % for the F1 factor and 30.03% for the F2 factor. Parameters such as pH, colour, turbidity, chlorides (Cl-), nitrites (NO2-), sulphates (SO_4^{2-}), ammoniacal nitrogen (NH_4^+), total iron (Fe /Fe^{2+}/Fe^{3+}) and fluoride (F) are positively correlated with F1 and then negatively correlated with alkalinity and bicarbonates (HCO). As for the F2 factor, it is positively correlated with temperature, color and Calcium (Ca^{2+}), and negatively correlated with Nitrates (NO3-) and Phosphates ($PO_4^{3-).}$

Keywords: *Perma, Water Pollution, Physico-Chemical Parameters, PCA*

INTRODUCTION
In West Africa, the exploitation of mineral resources has been booming since the 19th century (Koffi, 2015). In recent decades, Benin has particularly experienced artisanal gold mining in its northern part, in Perma region. This activity disrupts the quality of water resources which was already threatened by the use of inputs in agriculture. As water is essential for human health and other living beings, access to drinking water by rural populations for consumption has become a crucial problem due to the pollution of natural sources by anthropogenic activities. Water pollution, defined as physical, chemical or biological degradation resulting from human activities, also disrupts the balance of ecosystems, thus compromising their various uses. Perma gold basin has experienced remarkable economic growth in recent decades thanks to the development of gold mining activities. However, these activities have had a negative impact on the quality of the environment, especially on water resources. The chemical composition of water from the natural environment generally depends on the geological nature of the soil from which it originates and also on the reactive substances that affect it during its flow (Ahoussi *et al.*, 2010). If artisanal gold mining seems to be a lucrative actinity because of the strong

interest it generates, it however has many negative impacts, both socially and biophysically (*Goh, 2016*). Gold mining activities lead to silting of rivers in Perma gold basin, causing water shortage during the dry season. In addition to this silting, water pollution from agricultural gold mining activities is a permanent threat. Thus, waters from Perma gold basin show physico-chemical parameters of wells, boreholes and rivers which is out of phase with the standards of the Republic of Benin and those of the WHO. As the consumption of these waters can be fatal to human health, this study analyses their physico-chemical quality in order to contribute to a better understanding of this natural resource.

PRESENTATION OF THE STUDY AREA

Location of the study area

Perma Gold Basin is in south-east of the commune of Natitingou in the Department of Atacora in Benin, between meridians 1°26'45" and 1°33'15" east longitude and parallels
10°11'00" and 10°14'00" north latitude. It extends over an area of 13502 ha and covers the district of Perma and part of the districts of Kotopounga in the North-East, Kouandata in the East and is limited to the West by the district of Kouandata and to the South and East by the commune of Kouandé.
The present study is conducted particularly on the sites of Koussigou, Kouaterna, Tchantangou and Gnagnanmou villages where gold mining activity is more developed (Figure 1).

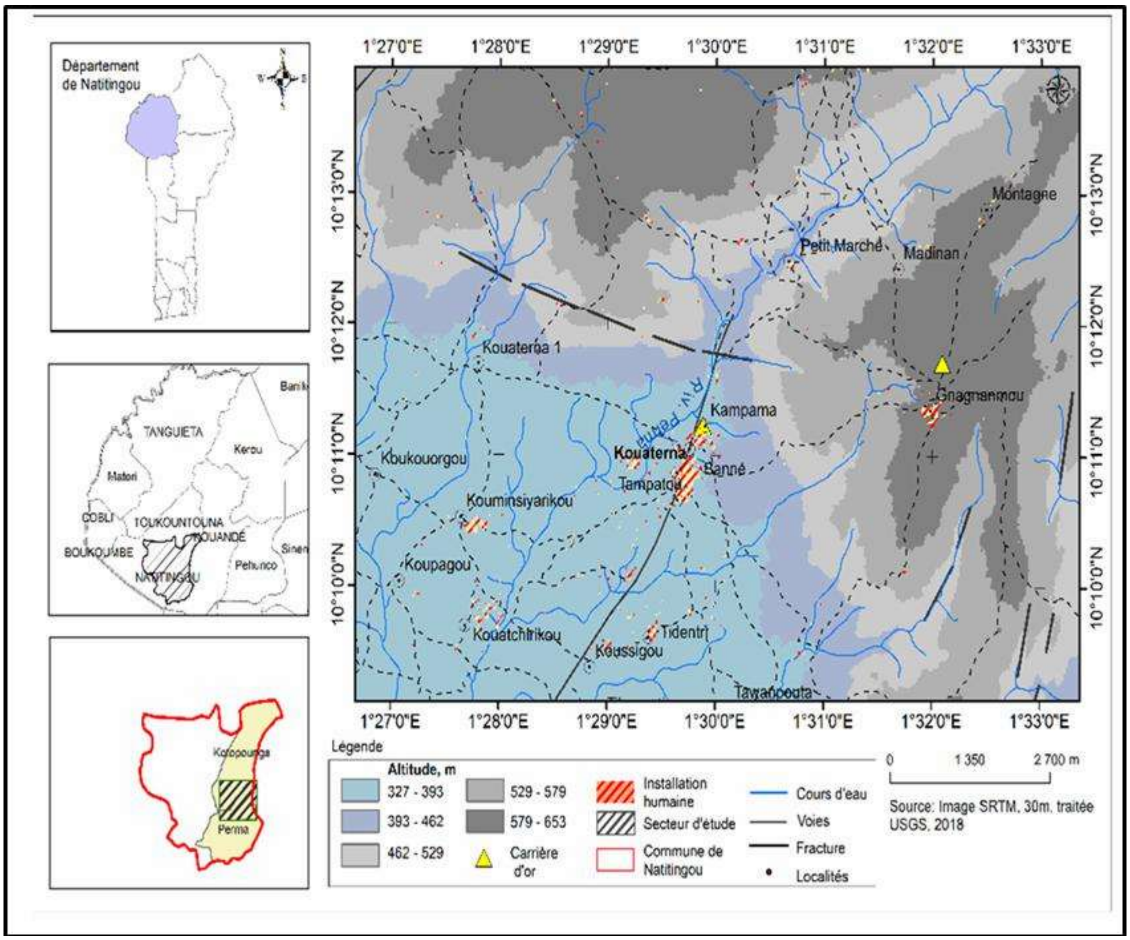

Figure 1: Geographical location of the study area

Climatic aspects

The area is characterized by a Sudano-Sahelian type climate and the average annual rainfall calculated from 1980 to 2010 is 1,173.4 mm; this shows that the study area receives an important rainfall with a peak of 1,400 mm of water per year. Rainfall amounts are especially high in July, August and September with average values of 189.7 mm, 272 mm and 239.3 mm respectively, compared to 108 mm, 103.6 mm and 106.2 mm respectively for potential evapotranspiration. The highest evapotranspiration values are recorded in March (153.1 mm) and April (148.5 mm).

Geomorphological and geological context

The geomorphology of the study area is typically that of an old, already eroded mountain range. The valleys are steeply incised and benefit from breaks to cross the folded quartzite ridges. The relief is made up of old mounds not higher than 400-450 m, slightly undulating with notches often of the small ravine type, dug by rivers (Perma, Sinaissiré, Kota, Irikouako, Sarga etc.). Erosion mainly concerns formations of Precambrian age on rocks of unequal resistance (quartzites and micaschists), which has a direct influence on the present relief with links in the quartzites and depressions due to erosion in the micaschists. Geologically, the area consists mainly of quartzites, shales and conglomeratic sandstones (Figure 2).

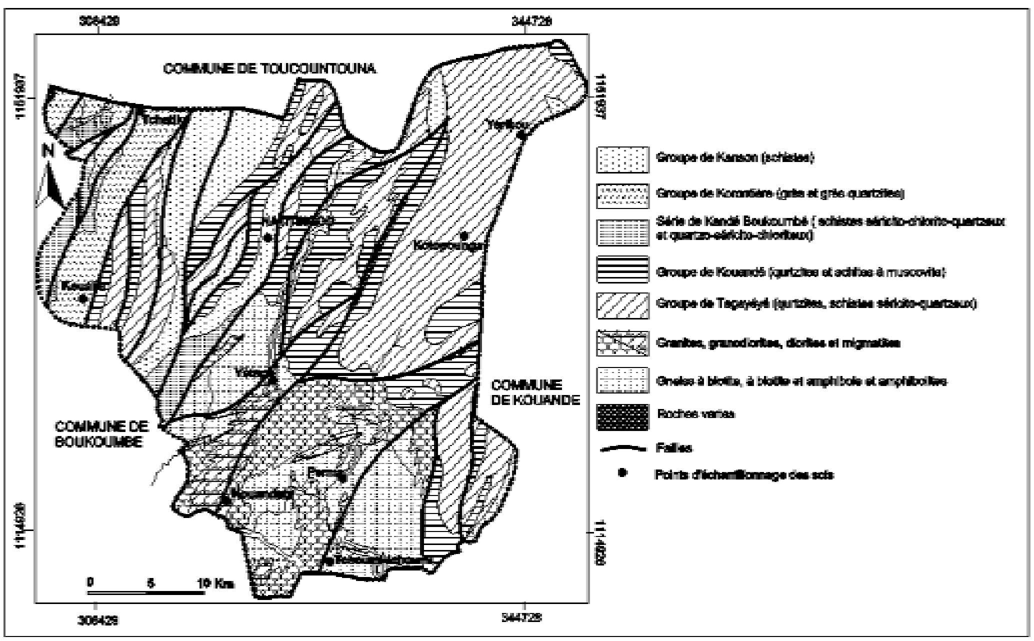

Figure 2: Geological Map of the Research Area

(Source: Extracted from the map of geology and useful minerals at 1/200 000th, Natitingou sheet. IGN-Paris, 1972)

From the hydrogeological point of view, the exploited productive aquifers are connected to the fracturing and alteration layer.

Socio-economic activities

The Perma River basin is a highly agricultural area due to the fertility of the depression soils in the Perma River watershed. It is also rich in gold resources known and exploited since colonial times. This gold exploitation was redeveloped from the 1990s with the arrival in Benin of gold miners from the West African sub-region. Currently, this gold basin which economy has long been based on agriculture, is now moving towards the exploitation of its subsoil relegating the agricultural sector to the second place.

MATERIALS AND METHODS

METHODOLOGICAL APPROACH TO WATER ANALYSIS

Water Sampling Methods

In order to characterize the water pollution of Perma Basin, sampling campaigns were carried out in March-April 2020 in Perma Gold Basin on boreholes, traditional wells and Perma River. The location of the sampled water points was identified with the Garmin 72 H GPS. The Central Laboratory of the DG Eau (Water Management Office) was used for the analysis of the physico- chemical parameters of the waters and the metallic trace elements (MTE) were analyzed at the Laboratory of Applied Hydrology (LHA) of the University of Abomey-Calavi (UAC). Figure3 shows the sampling points.

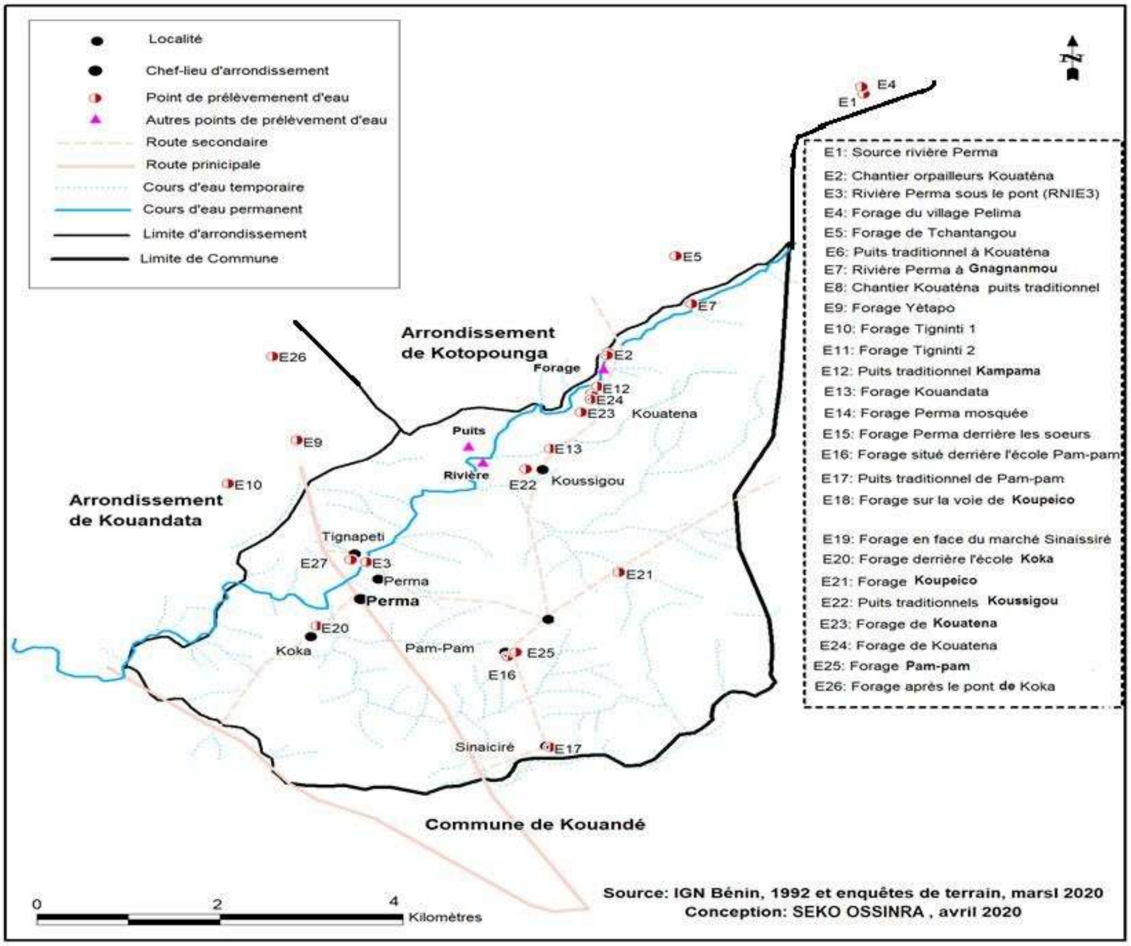

Figure 3: Spatial Distribution of Water Sampling Points

Water Analysis Methods for Perma gold basin

Water samples previously taken for physico-chemical analysis were taken using a 1.5 L plastic bottle. The determination of the different concentrations of physicochemical parameters and metal trace elements was measured using analytical methods. For conductivity, temperature, pH of the water with a Potentiometer HANNA HI 98191; TDS with a Conductivity Meter HANNA HI 98 192 ; colour with the Spectrometer HACH LANGE DR
5000; turbidity with a Turbidimetry HACH 2100 N, Alkalinity with the Alkalometric NF T0-
036 ; Hardness, Magnesium, Calcium, Chloride, Bicarbonates with the Titrimetry Method; Ammonium, Nitrates, Nitrites, Phosphates, Total Iron, Sulphates, Fluoride, Iodide with the Spectrometer HACH Lange DR 5000; Cyanides with the Spectrophotometer HACH DR2800; Lead, Mercury and Cadmium

with the portable Meta-yser HM1000.
Among the water samples taken, a particular was given to three of them. Thus focussed on water from Kouaténa borehole (E1), the traditional well of Koussigou (E2) and Perma River on the gold mining site of Kousssigou (E3). The analytical results of these samples taken on the sites of intense gold mining activities were used for statistical analysis (Principal Component Analysis).

Statistical analysis of the physico-chemical parameters of water in Perma gold basin

The statistical study was based on Principal Component Analysis (PCA). The intermediate correlation matrices, the correlation coefficients between the variables and the two axes F1 and F2 and the projection of the variables in the space of the F1 and F2 axes were obtained with XLSTAT 2008.1.01 software. During the study period, the hydro-chemical state of the water is apprehended from the measurement of 20 physicochemical variables. The Principal Component Analysis is performed on a data matrix composed of three sampling sources. Principal Component Analysis (PCA) is a multivariate analysis method that allows the simultaneous study of a large number of variables which total information cannot be visualized because of a space with more than three dimensions. This method would make it possible to specify the relationships between the variables and the phenomena at the origin of these relationships. The objective is to have information concentrated on a minimum number of axes. This method is widely used to interpret hydro-chemical data. The PCA is therefore a tool that offers the possibility of simplifying the study on the assessment of water quality in the Perma gold basin and to reduce the costs by reducing the number of variables to be taken into account.

RESULTS AND DISCUSSION

Physico-chemical quality of the waters of the Perma gold basin.

The results of the physico-chemical analyses carried out on water samples are shown in Tables 1 and 2.

Table 1: Results of analysis of the physico-chemical parameters of Perma water

Settings	**Units**	**Water samples taken**			**Beninese standards**	**WHO Standards**
		Drilling (E1)	**Well (E2)**	**River (E3)**		
		Analysis results				
Hydrogen potential (pH)	pH	**6.24**	**6.03**	**6.01**	6.5≤PH≤8.5	6.5≤PH≤8.5
Total Dissolved Solids (TDS)	mg/L)	83.91	12.84	16.44	2000	500
Conductivity (Cond)	µS/cm	168	26	33	2000	2000
Temperature (T)	°C	28	27.8	27.9	≈25°C	< 25
Color (Colour)	uc	06	**166**	**640**	15	15
Turbidity (Turb)	FTU	01	**95**	**241**	5 ,0	05
Alkalinity (Alca)	mg/L	30	20	10	-	-
Hardness (TH)	mg/L	106	04	10	200	500
Magnesium (Mg2+)	mg/L	14.59	0.486	0.9728	50	50
Calcium (Ca2+)	mg/L	18.44	10.42	20.841	100	100
Chloride (Cl-)	mg/L	8,875	7.1	17.75	250	250
Bicarbonates (HCO-3)	mg/L	18.3	12.2	9.15	-	_
Ammonium (NH4+)	mg/L	0.129	0.309	**1.213**	0,5	05
Nitrates (NO3-)	mg/L	2.658	4.873	0.0	45	45
Nitrites (NO2-)	mg/L	0.009	0.023	0.99	3.2	3.3
Phosphates (PO43-)	mg/L	0.12	0.23	0.011	05	05
Iron (Fe / Fe2+/Fe3+)	mg/L	0.04	0.29	**1.5**	0.3	0.3
Sulphates (SO42-)	mg/L	01	01	03	500	500
Fluorides (F-)	mg/L	0.13	0.0	0,0	-	1.5
Iodide (I-)	mg/L	0.10	0.11	0.34	-	-

Source: *Water Management Office Laboratory, March 2020*

The results of the physico-chemical analyses indicate that the pH of water is acidic with values between 6.01 and 6.24 for an average of 6.12. Below 6.5, water is corrosive and above 8.5 there is a risk of scaling. This water acidity is very close to that measured by Bawa, et *al,* (2008). Water in Perma River has colour and turbidity values that exceed the standards recommended by Benin and WHO. Wells and river water is coloured and turbid. The total iron and ammonium levels in river water exceed those recommended by Benin and WHO guidelines. Iron plays the decisive role in our bodies. The presence of iron atoms in each molecule of the haemoglobin of the red blood cells ensures the transport of oxygen from the lungs to all other organs and then exchanges it for carbon dioxide. In total, the waters of the Perma gold basin are corrosive since the analysis of these waters has shown that the majority of the concentrations obtained are below the guidelines of Benin and the World Health Organization (WHO).
Metallic trace elements were analysed for inorganic chemical parameters (Table 2).

Table 2: Trace Metal Elements (TME) analysis results for Perma water

parameters	**units**	**Water samples taken**			**Benin standards**	**WHO Standard**
		Drilling (E1)	**Well (E2)**	**River (E3)**		
Cyanides (CN)	mg/L	0.001	**0.059**	0.001	0.2	<0.05
Lead (Pb)	mg/L	<0.005	**0.384**	<0.005	0.05	<0.01
Mercury (Hg)	mg/L	<0.005	<0.005	<0.005	0.001	<0.001
Cadmium (Cd)	mg/L	<0.003	<0.003	<0.003	0.005	<0.003

Source: *Laboratory of Applied Hydrology of the University of Abomey-Calavi, April 2020*

Table 2 presents the results of inorganic chemical parameters for the Perma Basin. Parameters such as mercury, cyanides and lead are present in water from wells. That water is for human consumption. The goundwater of koussigou could be polluted if we reffer to the test result. It is therefore inferred that the population of this area is favourable to water-borne diseases. The presence of these metallic trace elements is due to gold mining activities, as these heavy metals are used by gold miners for various operations during the extraction of the yellow metal.

Table 3: **Correlation matrix (Pearson (n)) of the different water quality parameters of boreholes, wells and rivers sampled in Perma.**

	pH	**TDS**	**Cond**	**T**	**Coul**	**Turb**	**Alc**	**TH**	**Mg**	**Ca**	**Cl**	**HCO**	**NH4**	**NO3**	**NO2**	**PO4**
pH	**1**															
TDS	-0,460	**1**														
Cond	-0,461	**1,000**	**1**													
T	0,000	**0,888**	**0,887**	**1**												
Coul	**0,970**	-0,662	-0,663	-0,243	**1**											
Turb	**0,921**	-0,769	-0,770	-0,389	**0,988**	**1**										
Alc	-0,866	**0,843**	**0,843**	0,500	-0,961	-0,992	**1**									
TH	-0,454	**1,000**	**1,000**	**0,891**	-0,657	-0,765	**0,839**	**1**								
Mg	-0,473	**1,000**	**1,000**	**0,881**	-0,673	-0,779	**0,850**	**1,000**	**1**							
Ca	**0,678**	0,340	0,339	**0,735**	0,480	0,339	-0,220	0,347	0,326	**1**						
Cl	**0,988**	-0,317	-0,318	0,156	**0,921**	**0,850**	-0,778	-0,310	-0,331	**0,784**	**1**					
HCO	-0,756	**0,929**	**0,930**	**0,655**	-0,892	-0,951	**0,982**	**0,926**	**0,935**	-0,032	-0,645	**1**				
NH4	**0,988**	-0,593	-0,594	-0,156	**0,996**	**0,971**	-0,933	-0,587	-0,605	**0,556**	**0,952**	-0,849	**1**			
NO3	-0,891	0,007	0,009	-0,454	-0,754	-0,645	0,545	0,000	0,022	-0,938	-0,951	0,376	-0,810	**1**		
NO2	**1,000**	-0,471	-0,472	-0,012	**0,973**	**0,926**	-0,872	-0,465	-0,484	**0,669**	**0,986**	-0,764	**0,990**	-0,886	**1**	
PO4	-0,865	-0,048	-0,046	-0,502	-0,717	-0,602	0,498	-0,055	-0,033	-0,956	-0,932	0,325	-0,776	**0,998**	-0,859	**1**
Fe	**0,987**	-0,597	-0,598	-0,160	**0,996**	**0,972**	-0,935	-0,591	-0,608	**0,552**	**0,950**	-0,851	**1,000**	-0,807	**0,989**	-0,773
SO4	**1,000**	-0,461	-0,462	0,000	**0,970**	**0,921**	-0,866	-0,454	-0,473	**0,678**	**0,988**	-0,756	**0,988**	-0,891	**1,000**	-0,865
F	-0,500	**0,999**	**0,999**	**0,866**	-0,695	-0,797	**0,866**	**0,999**	**1,000**	0,297	-0,359	**0,945**	-0,629	**0,052**	-0,510	-0,003
I	**0,999**	-0,493	-0,494	-0,037	**0,978**	**0,935**	-0,884	-0,486	-0,506	**0,651**	**0,981**	-0,780	**0,993**	-0,874	**1,000**	-0,846

3.2 Statistical analysis of physico-chemical water parameters

The statistical analysis of the physico-chemical data was carried out on a data matrix consisting of 20 variables from 3 water sources distributed in the Perma basin. The XLSTAT

2008.1.01 statistical software was used to process the data. The correlation matrix gives a first idea of the existing associations between the different variables such as Turbidity and Color. The turbidity of the analyzed water is between 1 and 241 while the norm is 5. Water from wells and river is therefore unsafe to drink. These parameters are relatively well correlated with each other (Table 3).

The eigenvalues of the correlation matrix are used to measure the percentage of variance explained by each factorial (Table 3). The eigenvalue histogram shows that the factorial plan, consisting of the F1 and F2 axes, accounts for 100% of the total inertia. It proves to be very sufficient to reflect most of this inertia, because if we look at the distribution of eigenvalues, we can see that the main decay occurs just after the first two values, which means that the first two axes are sufficient to represent the information as a whole.

Table 3 shows important correlations between Ph and colour, turbidity, chlorides, ammonia nitrogen, nitrite, sulphate, iron, iodide and most of the variables. Total Dissolved Solids (TDS) are strongly correlated with conductivity, hardness, magnesium, bicarbonates, fluorides. Conductivity is correlated with conductivity, hardness, magnesium, bicarbonates and fluorides. These strong correlations between these variables show the similarity of the phenomena causing the circulation of these ions in water. The results of the PCA allow the choice of the different factors necessary for the interpretation of the different data.

However, the analysis of the results shows that most of the information is explained by the first two factor axes. In the F1xF2 factorial plan, the eigenvalues of the two components F1 and F2 and their contribution to the total inertia are shown in Table 4. The two axes taken into consideration to describe the correlations between the variables related to spatial structures, hold alone 100% of the total information with respectively 69.97% for axis 1 and 30.03% for axis 2 (Figure 4).

Table 4: **CPA own values and percentages expressed for the main axes**

	F1	**F2**
Own value Variability (%)	13.993	6.007
	69.967	30.033
cumulative%	69.967	100.000

The two factors reflect the main information we need and make it possible to represent the scatter plot in a meaningful way, since the sum of the variance expressed by these factors is 100%. The contribution of the different variables in defining the main factors is given in Table 5. Each factor is defined by a certain number of essential variables in highlighting the water mineralis Sation mechanism. Table V shows that the most important factor F1 is defined by the parameters : turbidity (r = 0.998), colour (r = 0.996), NH4+ (r = 0.985), Fe $^{2+/}$Fe $^{3+}$ (r = 0.985), NO2- (r = 0.949), I- (r = 0.957), SO2- (r = 0.945); pH (r = 0.945) are positively correlated while HCO-3 (r = - 928), Alc (r = - 982), Mg2+ (r = - 0.735), TDS (r = - 0.725), Conductivity (r = - 0.726) are correlated to a lesser extent.

Table 5: Correlation between variables and factors

	F1	F2
pH	**0.945**	0.327
Total Dissolved Solids (TDS)	-0.725	**0.689**
Conductivity (Cond)	-0.726	**0.688**
Temperature (T)	-0.326	**0.945**
Color (Colour)	**0.996**	0.087
Turbidity (Turb)	**0.998**	-0.067
Alkalinity (Alk)	-0.982	0.190
Hardness (TH)	-0.720	**0.694**
Magnesium (Mg2+)	-0.735	**0.678**
Calcium (Ca2+)	0.401	**0.916**
Chloride (Cl-)	**0.883**	0.469
Bicarbonates (HCO-)	-0.928	0.372
Ammonium (NH4-)	**0.985**	0.175
Nitrates (NO3-)	-0.694	-0.720
Nitrites (NO2-)	**0.949**	0.315
Phosphates (PO43-)	-0.653	-0.757
Total iron (Fe/Fe2+/Fe3+)	**0.985**	0.171
Sulphates (SO42-)	**0.945**	0.326
Fluorides (F-)	-0.755	**0.655**
Iodides (I-)	**0.957**	0.291

The different physico-chemical parameters of water measured in Perma basin are distributed on the F1 and F2 axes. When two variables are far from the centre of the graph, then they are positively correlated if they are close to each other; they are uncorrelated if they are orthogonal to each other; they are negatively correlated if they are symmetrically opposite with respect to the centre of the graph. The Principal Component Analysis performed on the
20 physico-chemical parameters shows that the two factorial axes account for 100% of the total variance (the first axis explains 69.97% and the second axis 30.03% of this variance). Axis 1 is positively correlated with pH, colour, turbidity, chlorides, nitrites, sulphates, ammonium, iron and iodide. Turbidity measurements may therefore be sufficient to predict water quality for the above parameters. This provides a simpler and faster means of monitoring water quality in the Gold Basin of Perma. Axis 1 is also strongly negatively correlated with alkalinity and bicarbonates. Conversely, axis 2 is positively correlated with temperature, colour and calcium and negatively correlated with nitrates and phosphates. This axis expresses less water mineralization compared to axis 1 (Figure 5). The analysis of Figure 5 allows the characterization of three types of water : Kouaterna wells are poor in pH, and rich in TDS, Conductivity, Temperature, Color, Turbidity, Mg^{2+}, Ca^{2+}, Cl, HCO^{3-}, NH^{4+}, NO_3^-, NO_2^-, $PO4^{3+}$, $Fe/Fe^{2+}/Fe^{3+}$, SO_4^{2+} , F- , I- , Hardness , Alkalinity and the water from those wells is classified as corrosive water; the koussigou wells also contains the same chemical components as the borehole water and is considered corrosive. This water is unsafe for human consumption because of the high content of Colour, Turbidity, Iron which exceed the standards recommended by Benin and WHO. River water contains the same physico- chemical elements but is also unsafe for consumption due to the high content of Colour and Turbidity and the ammonium and iron content which exceed the Benin guidelines. The typological structure shown by the F1*F2 plan (Figure 6) shows the individualization of three different groups according to their hydro-chemical quality. Group 1 is formed by borehole surveys characterized by high mineralization and very high organic load. Group 2 plays the role of intermediary, formed by the wells records, however this water gains the organic pollution. Group 3 is formed by the surveys of the Perma River and is characterized

by an organic load. This distinction of groups clearly shows the separation of the characteristics of the three water points (Figure 7). The factorial map of the samples confirms that the water taken from the borehole is distinct from other samples, especially from the well and the river. The well and river waters are the richest in different organic and inorganic forms of pollution. Hence, there is a pollution gradient in well and river water sources.

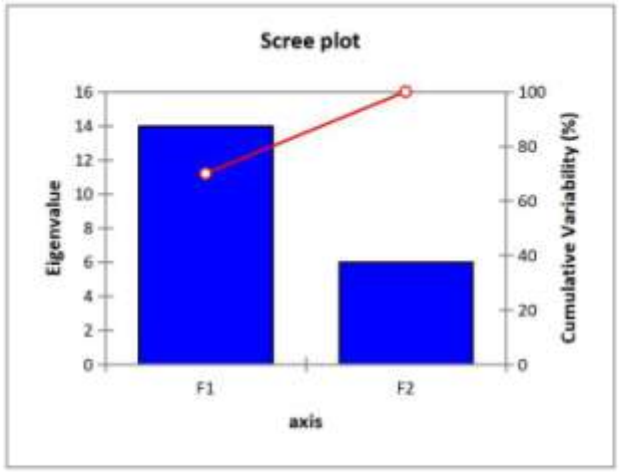

Figure 4: Distribution of inertia between the axes

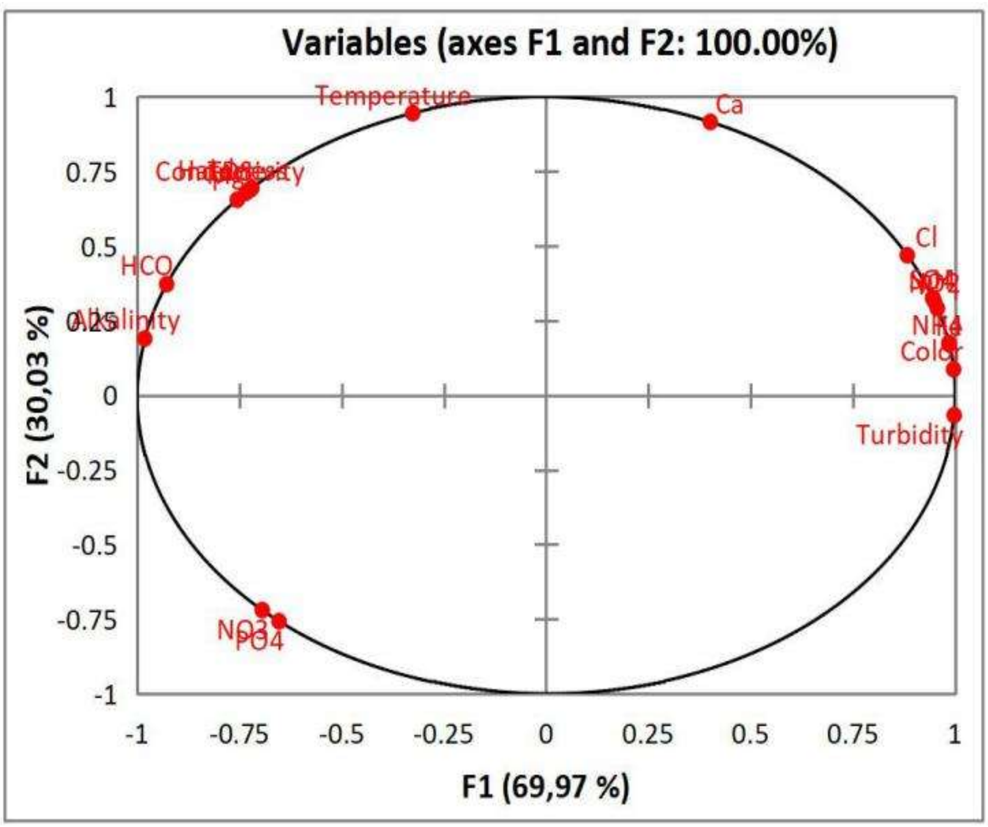

Figure 5: Projection of the physico-chemical parameters of well water on the first two axes of the PCA

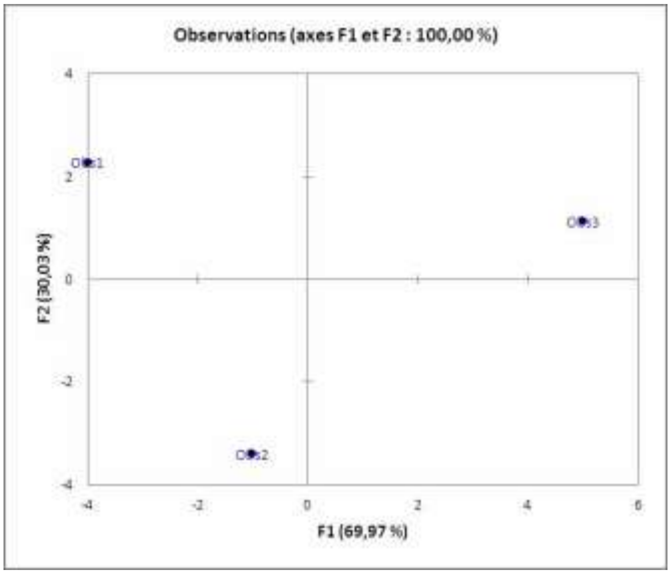

Figure 6: Representation of the borehole, well and withdrawal river on the F1 and F2 factorial plane

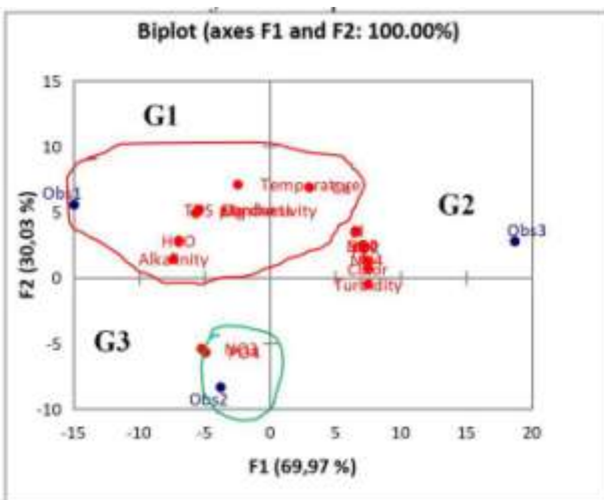

Figure 7: Projection of the twenty-one variables onto the reduced CPA master plan

Discussion

The results of the analysis of water in the gold basin of the Perma indicate the acidity of these water with an average pH of 6.09. They are weakly mineralized with a strong colour, very high turbidity, iron and ammoniacal nitrogen content in Perma River water; similarly, colour and turbidity are present in the Koussigou wells. The concentration of these physico-chemical parameters in the different water sources is higher than Benin and World Health Organization (WHO) standards. The pollution of that water is the result of anthropic pressure on the gold mining sites, which concentrate several thousand gold miners per km2 , especially in the dry season. These results confirm those of (N'tcha *et al.*, 2020) who evaluated the Hydrogeochemistry of Groundwater in the Basal Aquifers of the Commune of Natitingou in Benin and found that anthropogenic input influences mineralization by polluting the water of the region. Sambienou *et al.*, (2018) concurs by assessing the hydrogeochemistry of groundwater in the watershed of Pendjari in the northwest of Benin and reports that water of Perma is polluted under the influence of anthropogenic activities. For Lagnika *et al.*, (2014), water pollution would be linked to anthropogenic activities, especially the infiltration of wastewater and the use of chemical fertilizers in agriculture in Pobè. It constitutes a health risk for the populations which depends onwater from wells for their needs which is located in the anchorage of agricultural and gold mining activities. Heavy metals, namely cyanides (CN^-), mercury (Hg^{2+}), and lead (Pb^{2+}) are present in the wells of Koussigou serving as a source of drinking water with concentrations respectively of 0.059; 0.384; 0.005 which are higher than the WHO standards. These heavy metals used by gold miners pollute water sources. The PCA carried out on the 20 physico-chemical parameters shows that the two factors account for 100% of the total variance with 69.97% for the F1 factor and 30.03% for the F2 factor. The following parameters: pH, colour, turbidity, chlorides (Cl-), nitrites (NO_2^-), sulphates (SO_4^{2-}), ammoniacal nitrogen (NH_4^+), total iron (Fe /Fe2+/Fe3+) and fluoride (F-) are positively correlated with F1 then negatively correlated with alkalinity, bicarbonates (HCO-). With respect to the F2 factor, it is positively correlated with temperature, color and Calcium (Ca^{2+}), and negatively correlated with Nitrates (NO_3^-) and Phosphates (PO_4^{3-}).

CONCLUSION

Water of the Perma Gold Basin, with an average pH of 6.09, is weakly mineralized with a strong colour, turbidity, iron and ammoniacal nitrogen content. The concentration of these physico-chemical parameters in the different water sources is higher than Benin and World Health Organization (WHO) standards.

In short, one of the issues to be addressed in the Perma Gold Basin is the quality of drinking water. Physico-chemical analyses carried out have shown that wells and river water is polluted and borehole water is corrosive. The degradation of the quality of that water is linked to anthropic activities specifically related to gold mining. It constitutes a health risk for the population that depends on water from wells with a high lead and cyanide content for their needs. In view of that unhealthy water, appropriate measures should be taken by the municipal and governmental authorities in close collaboration with development partners to provide good quality water supply to the population of Perma basin in order to safeguard human health which is a guarantee for sustainable development.

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