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## Assessment of Arsenic Presence in Some Water Points in Different Areas of Benin

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**Abstract** Arsenic is a metalloid that appears in water naturally or after human activities. Above 10 µg/L recommended by WHO (2004), this element is toxic for human being. In Benin, the areas where the contents are considered to be higher have been the subject of this research. These include the gold area of Kouatena, the volcanic and sediment areas of Daho-Mahou and Pako and the iron area of Madecali. The common elements in water and the elements that have affinity with arsenic have been mixed and speciation of arsenic has also been done. At the end of analysis the arsenic contents in the volcano-sedimentary zones are below the guide value but with maxima very close to this one (8.20 µg/L for Daho Mahou and 9.30 µg/L for Pako). Elevated concentrations were recorded in the gold (with a maximum of 16.02 µg / L) and ferruginous (with a maximum of 11.03 µg / L) zones. After the speciation, the amount of As (III) is higher than As (V) in all samples of water. The speciation is function to pH and redox potential.

**Keywords** Arsenic, water–speciation, characterisation, Benin

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### 1. Introduction

Due to human mining activities, and various biological, geological and chemical processes, the arsenic can dissolve in water and ends up in aquifers and water sources [1-4]. In the beginning of twentieth century, everywhere in the world and particularly in developing countries such as Bangladesh, several cases of hard contaminations by arsenic have been registered.

In Benin volcano-sedimentary formation areas (Daho-Mahou et Pako), ferruginous (Loubou-Loubou et Madékali) and gold extraction (Kouaténa) areas are likely to have significant levels in the drinking water exhibiting thus populations with health problems including dermal, respiratory, pulmonary, cardiovascular, gastrointestinal, hepatic, renal, neurological, immunological, mutagenic and carcinogenic modifications when the arsenic content exceeds WHO reference guide which is 10 µg/L [5].

This work aims to investigate the state play of localities mentioned above to evaluate the concentrations of the elements with high affinity with the arsenic to determinate concentrations of total arsenic in consummation waters. It's also a draft of arsenic speciation in the water of these localities.

### 2. Material and methods

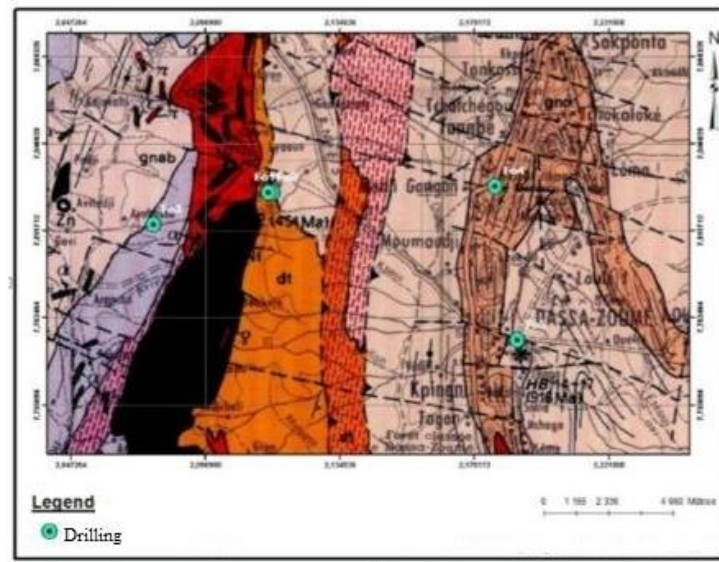
#### 2.1. Study area presentation

The different sites of sampling are indicated on the following table:



**Table 1:** Water sampling sites

N°	Village	Borough	Nature of the work	Elevation	Code
1	Mahou	Dassa	Drilling	192 m	Fo 1
2	Mahou	Dassa	Drilling	195m	Fo 2
3	Akpari	Dassa	Drilling	120 m	Fo 3
4	Perma	Perma	Drilling	332 m	Fo 6
5	Kouatéma	Perma	Drilling	389 m	Fo 7
6	Kouatéma	Perma	Career	388 m	Ec
7	Kouatéma	Perma	River	382 m	R1
8	Kouatéma	Perma	River	382 m	E1
9	Kouatéma	Perma	River	392 m	R2
10	Kouatéma	Perma	Well	393m	P1
11	Kouatéma	Perma	Well	384m	P2
12	Koussigou	Perma	Drilling	366 m	Fo 8
13	Kouampongou	Perma	Drilling	351 m	Fo 9
14	Djindégabi	Garou	Drilling	172 m	Fo 10
15	Garou Tédji	Garou	Drilling	169 m	Fo 11
16	Garou Tédji	Garou	Well	166 m	P3
17	Madécali	Madécali	Drilling	167 m	F 12
18	Madécali	Madécali	Well	167 m	P 4
19	Madécali	Madécali	Drilling	163 m	Fo 13
20	Sampeto	Founougo	Well	268 m	P 5
21	Sampeto	Founougo	Drilling	272 m	Fo 14
22	Sampeto	Founougo	Drilling	272 m	Fo 15
23	Babanga	Founougo	Well	304 m	P6
24	KpakoSouakpika	Founougo	Well	284 m	P7
25	Modji Gangan	Dassa	Drilling	175 m	Fo 4
26	Dassa	Dassa	Drilling	193 m	Fo 5

**Figure 1:** Location of water sampling points of Daho-Mahou volcano-sedimentary complex

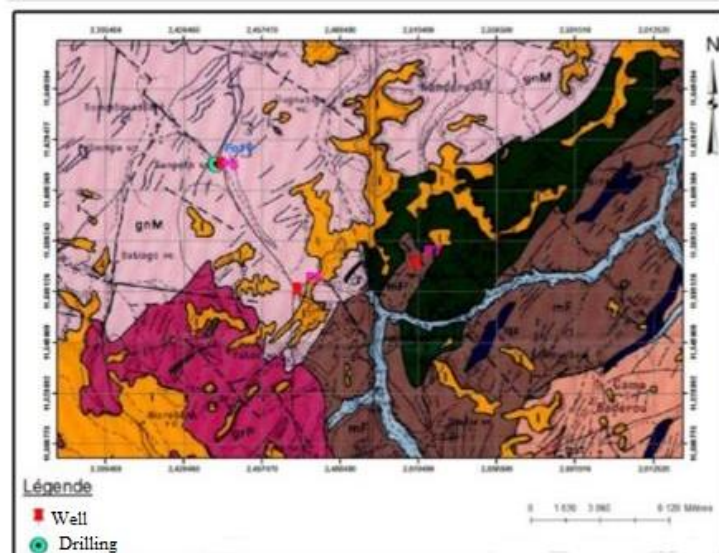


Figure 2: Location of water sampling points of Pako volcano –sedimentary complex

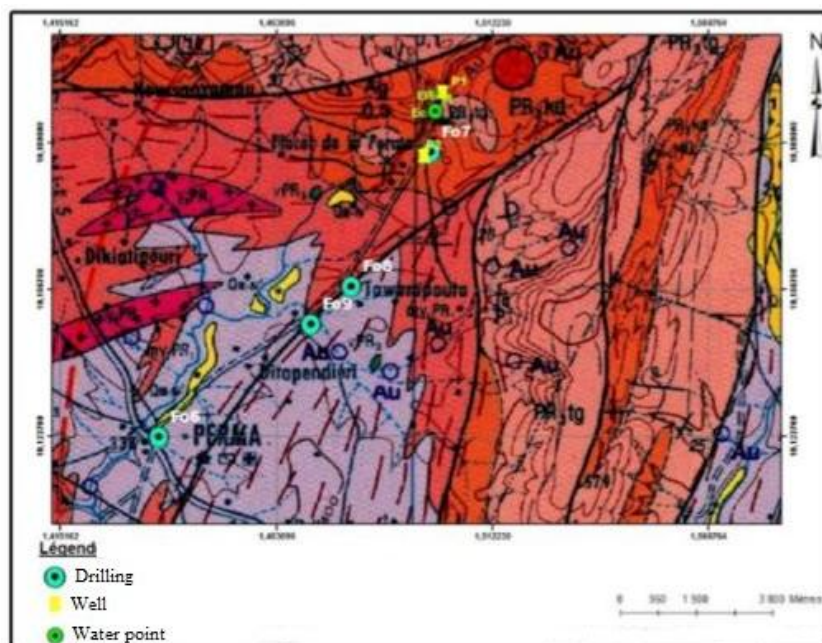


Figure 3: Location of water sampling points of the ferruginous area of Madecali

## 2.2. Sampling material

The bottles used for water sampling were rinsed thoroughly with tap water and then filled for 24 h with water to be sampled. Then they were rinsed with distilled water.

## 2.3. Sampling mode

Type of sampling depends of water origin. For drillings, samples were taken after 30mn of pumping. For wells and rivers the waters samples were taken at 50 cm deep from the surface far from banks and the approaches natural or artificial obstacles avoiding the deposits resuspension. During the sampling, the bottles were completely filled to avoid air bubble presence.

Twenty six waters points were sampled and Fo 4 et Fo5 are considered as witnesses. The friability of speciation's results were warranted by acidifying the samples with HCl 0,1% and their transport at low temperature (4-6°C) in aluminium packages to the laboratory. This precaution is destined to slow down considerably the oxidation of As (III) to As(V).



Water's temperature, pH, color, electric conductivity and potential redox were measured in situ. Others global chemical characterization parameters were determined at laboratory by standards methods [6]. Arsenic test were done by using Arsenator kit. Totalarsenic and Arsenic (III) concentrations were researched by atomic absorption spectrometry after generation of hydride.

### 3. Results and Discussion

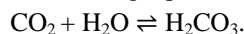
**Table 2:** Values of parameters measured in situ

Code	Village	Borough	Color (UcV)	pH	Cond (μS /cm)	T°C	Eh (V)
Fo 1	Mahou	Dassa	0	6.87	934	29.6	0.05
Fo 2	Mahou	Dassa	0	6.57	1146	29.9	0.05
Fo 3	Akpari	Dassa	0	6.80	706	31.1	0.04
Fo 6	Perma	Perma	50	6.12	454	25.0	0.06
Fo 7	Kouatéma	Perma	0	4.90	46	30.3	0.07
Ec	Kouatéma	Perma	292	4.34	30	27.7	0.08
R1	Kouatéma	Perma	1800	5.23	15	25.0	0.06
E1	Kouatéma	Perma	1270	5.24	3	29.1	0.05
R2	Kouatéma	Perma	8360	5.29	15	25.0	0.04
P1	Kouatéma	Perma	84	4.45	187	30.3	0.09
P2	Kouatéma	Perma	1060	5.04	10	28.8	0.09
Fo 8	Koussigou	Perma	128	6.22	288	30.2	0.01
Fo 9	Kouampongou	Perma	31	6.43	224	31.7	0.01
Fo 10	Djindégabi	Garou	122	5.15	150	32.7	0.08
Fo 11	Garou Tédji	Garou	57	5.35	135	32.4	0.08
P3	Garou Tédji	Garou	57	5.49	320	30.7	0.08
F 12	Madécali	Madécali	79	5.17	94	32.5	0.07
P 4	Madécali	Madécali	29	5.91	237	26.0	0.06
Fo 13	Madécali	Madécali	3	6.03	194	32.0	0.06
P 5	Sampeto	Founougo	96	6.00	422	28.7	0.05
Fo 14	Sampeto	Founougo	5	6.08	293	26.0	0.06
Fo 15	Sampeto	Founougo	0	6.24	292	26.0	0.07
P6	Babanga	Founougo	2495	5.74	102	28.0	0.07
P7	Kpako	Founougo	1455	4.78	48	26.0	0.09
	Souakpika						
Fo 4	Modji Gangan	Dassa	0	6.67	412	29.4	0.06
Fo 5	Dassa	Dassa	0	6.82	1871	29.7	0.05

#### 3.1. pH

Daho Mahou volcano-sedimentary complex waters values are slightly less than 7 indicating their non aggressiveness character. Those from Pako volcano-sedimentary have pH values range from 4.78 to 6 showing their acid character essentially due to sulphide minerals presence.

The pH of the waters of the Kouatena gold zone, between 4.45 and 6.43, would be explained by the leaching of the gold sediments thus making the water aggressive. The acidic character of the waters of the ferruginous zone of Madecali with pH values range from 5.15 to 6.03 could be due to trapping of the OH<sup>-</sup> ions by the calcium ions thus resulting in a decrease of the pH. Acid character noticed in waters could also be explained by anthropogenic activities witch principals are agriculture and breeding thus produce important quantities of CO<sub>2</sub> wich transform in water in carbonic acid by the following equation:



#### 3.2. Electrical conductivity

The electrical conductivity values of water at Dassa are highest and range between 706 μS.cm<sup>-1</sup> and 1146 μS.cm<sup>-1</sup>. The important mineralization in this area and rocks dissolving with important liberation of minerals in water can explain these values. On the other sites, water electrical conductivity varies from medium to low.



### 3.3. Color

According to the guide indication (15 U<sub>c</sub>V), the lowest values are recorded at the level of drillings at valcano-sedimentary zones while the highest values are noticed at gold areas.

Debris from the leaching of gold sediments could be the source of this pollution. In addition, the worrying values in the Madcali area could be due near this region of the Niger river, the object of various pollution. Also, the shallow wells of the Founougo region as well as the geological nature (presence of sedimentary rocks) of the environment could explain the values of the color of the waters.

### 3.4. Major water contents

The concentrations of water in Calcium, Sodium, Magnesium, Ammonium, Potassium, Chloride, Nitrate, Nitrite, Bicarbonate, Phosphate and Fluoride are mentioned on table below.

**Table 3:** Waters contents in major elements

Code	HCO <sub>3</sub> <sup>-</sup>	F <sup>-</sup>	Cl <sup>-</sup>	NO <sub>2</sub> <sup>-</sup>	NO <sub>3</sub> <sup>-</sup>	PO <sub>4</sub> <sup>3-</sup>	SO <sub>4</sub> <sup>2-</sup>	NH <sub>4</sub> <sup>+</sup>	Ca <sup>2+</sup>	Mg <sup>2+</sup>	Na <sup>+</sup>	K <sup>+</sup>
Fo1	89,98	1,53	239,63	0,29	42,68	1,60	38,00	0,08	148,30	9,73	50,00	30,00
Fo2	77,78	0,92	244,06	0,21	102,52	2,20	42,00	0,21	152,30	14,59	49,00	32,00
Fo3	96,08	0,94	221,88	0,01	3,96	2,50	1,00	0,03	72,14	29,18	43,00	37,00
Fo6	41,18	0,31	244,06	0,00	0,00	1,80	35,00	0,19	51,30	10,21	83,00	78,80
Fo7	7,63	0,00	130,00	0,01	4,84	9,00	0,00	0,08	5,61	2,43	63,20	54,00
Ec	3,05	0,00	24,41	0,00	8,36	0,21	2,00	0,61	1,60	0,97	18,00	4,00
R1	15,25	0,00	26,00	0,00	189,00	0,17	0,00	2,53	4,01	2,43	62,60	50,80
E1	30,50	0,00	248,50	0,39	73,48	0,00	11,00	1,55	32,06	24,32	93,40	79,20
R2	30,50	0,00	89,00	0,00	45,32	0,29	0,00	4,97	4,01	2,43	60,00	40,00
P1	30,50	0,00	134,00	0,05	76,12	0,19	1,00	2,03	8,02	2,43	82,80	72,20
P2	6,10	0,35	23,08	0,33	3,52	0,15	4,00	1,14	1,60	0,49	17,00	5,80
Fo8	183,00	0,46	14,20	0,01	2,20	0,38	1,00	0,41	32,87	4,86	30,00	20,00
Fo9	38,13	0,49	35,00	0,01	7,48	0,71	1,00	0,13	19,24	8,27	7,00	3,00
F10	26,00	0,00	30,00	0,02	5,72	0,11	1,00	0,18	20,84	2,92	4,00	3,50
F11	22,88	0,00	35,00	0,01	6,16	0,10	1,00	0,14	21,64	1,46	8,00	4,60
P3	13,73	0,00	71,00	0,12	49,28	0,17	15,00	0,21	21,64	6,81	35,00	19,60
F12	9,15	0,00	27,96	0,01	30,80	0,26	2,00	0,01	11,22	2,43	14,30	9,50
P4	12,20	0,00	31,30	0,05	77,88	1,00	1,00	0,05	29,66	7,30	10,40	5,40
F13	13,73	0,00	31,00	0,00	51,48	0,18	1,00	0,00	21,64	4,86	12,80	4,60
P5	10,68	0,09	68,78	0,05	121,00	0,04	1,00	0,00	35,27	11,67	33,40	13,60
F14	48,80	0,41	55,00	0,01	5,28	0,43	4,00	0,00	32,06	8,76	8,00	5,70
F15	53,38	0,45	52,00	0,00	1,32	0,36	5,00	0,00	31,26	10,21	6,10	4,90
P6	10,68	0,00	23,00	0,17	356,00	0,79	139,00	5,22	11,22	6,81	150,00	120,00
P7	6,10	0,00	52,81	0,07	22,00	0,42	3,00	2,57	8,82	0,00	29,00	19,00
Fo4	65,00	8,60	48,00	0,02	4,84	0,34	6,00	0,00	40,88	6,81	13,00	10,50
Fo5	177,00	3,18	300,00	0,39	96,36	0,94	489,00	1,07	228,46	48,64	148,00	125,00

#### 3.4.1. Calcium and magnesium

The values obtained for Ca<sup>2+</sup> and Mg<sup>2+</sup> concentrations are comply to beninese drinking water standards which are respectively are 100 mg/L for Ca<sup>2+</sup> and 50 mg/L for Mg<sup>2+</sup>. Furthermore the lowest values are recorded in the gold area of quartz formation. In fact calcium and magnesium come from silicated minerals hydrolyse such as dolomite [CaMg(CO<sub>3</sub>)<sub>2</sub>], ankerite [Ca (Fe,Mg,Mn)(CO<sub>3</sub>)<sub>2</sub>], bentonite [(Ba,Sr)<sub>6</sub>(Ca, Mn)<sub>6</sub>Mg(CO<sub>3</sub>)<sub>13</sub>], huntite [CaMg<sub>3</sub>(CO<sub>3</sub>)<sub>4</sub>], etc. the absence of these minerals in quartzite's could explain the lowess of Ca<sup>2+</sup> and Mg<sup>2+</sup>.

#### 3.4.2. Sodium

The concentrations registered are lower than the standard (150 mg/L). However the concentrations are higher in valcano-sedimentary formation areas than elsewhere. This can be explained by the presence of Na<sup>+</sup> ions from minerals alteration, in crystalline and sedimentary rocks.

#### 3.4.3. Chloride

Despite high values recorded in certain areas all of the chlorides concentrations comply with the drinking water standard (250 mg/L) and their presence could be linked to anthropogenic activities in particular urine and washing and cleaning products.



### 3.4.4. Sulfate

All the samples analyzed have sulphate concentrations are lower than the standard which is 500 mg/L. This is usually brought about by residues of fertilizers contained in runoff waters. Also oxidation of arsenopyrite in gold area could train release of sulfates ions into the water.

### 3.4.5. Nitrate

Nitrate concentrations recorded in many samples are higher than drinking water standard (45 mg/L). Nitrate ions presence could be natural as it can come from organic plant matter's decomposition and agricultural activities which use mineral fertilizers.

### 3.4.6. Fluoride

The highest values are obtained at rocky area of Dassa and could come from minerals such as fluorine ( $\text{CaF}_2$ ), fluo apatite  $\text{Ca}_5\text{F}(\text{PO}_4)_3$  and micas, dissolution in waters. All values obtained in other areas are below the guide value (1.5 mg/L) for drinking water.

## 3.5. Correlation matrices of major elements

In order to appreciate the link between the different elements and to deduce their probable origins, correlation matrices have been established. These are presented in the table below.

**Table 5:** Correlation matrix of the major elements of the volcano-sedimentary zones

	$\text{HCO}_3^-$	F	Cl	$\text{NO}_2^-$	$\text{NO}_3^-$	$\text{PO}_4^{3-}$	$\text{SO}_4^{2-}$	$\text{NH}_4^+$	$\text{Ca}^{2+}$	Mg <sup>2+</sup>	$\text{Na}^+$	$\text{K}^+$
$\text{HCO}_3^-$	1											
F	<b>0,93</b>	1										
Cl	0,86	0,90	1									
$\text{NO}_2^-$	0,24	0,52	0,51	1								
$\text{NO}_3^-$	-0,47	-0,39	-0,30	0,40	1							
$\text{PO}_4^{3-}$	0,82	0,74	0,89	0,39	-0,10	1						
$\text{SO}_4^{2-}$	-0,22	-0,14	-0,14	0,57	<b>0,92</b>	0,09	1					
$\text{NH}_4^+$	-0,61	-0,55	-0,49	0,22	0,79	-0,21	0,80	1				
$\text{Ca}^{2+}$	0,78	0,89	<b>0,93</b>	0,69	-0,19	0,74	-0,02	-0,48	1			
Mg <sup>2+</sup>	0,70	0,49	0,61	-0,19	-0,22	0,72	-0,21	-0,46	0,37	1		
$\text{Na}^+$	-0,24	-0,17	-0,08	0,50	<b>0,93</b>	0,17	<b>0,95</b>	0,82	-0,06	-0,07	1	
$\text{K}^+$	-0,22	-0,18	-0,11	0,42	0,90	0,19	<b>0,94</b>	0,84	-0,12	-0,03	<b>0,99</b>	1

The coefficients in bold indicate the strong correlations i.e  $\geq 0.92$ . The value obtained ( $r = 0.99$ ) between sodium and potassium indicates that these two elements could have the same origins.

**Table 6:** Correlation matrix of the major elements of the iron zone

	$\text{HCO}_3^-$	F	Cl	$\text{NO}_2^-$	$\text{NO}_3^-$	$\text{PO}_4^{3-}$	$\text{SO}_4^{2-}$	$\text{NH}_4^+$	$\text{Ca}^{2+}$	Mg <sup>2+</sup>	$\text{Na}^+$	$\text{K}^+$
$\text{HCO}_3^-$	1											
F	-	1										
Cl	-0,12	-	1									
$\text{NO}_2^-$	-0,23	-	<b>0,93</b>	1								
$\text{NO}_3^-$	-0,75	-	0,19	0,39	1							
$\text{PO}_4^{3-}$	-0,45	-	-0,20	0,14	0,77	1						
$\text{SO}_4^{2-}$	-0,23	-	<b>0,98</b>	<b>0,93</b>	0,21	-0,20	1					
$\text{NH}_4^+$	0,63	-	0,63	0,58	-0,43	-0,36	0,57	1				
$\text{Ca}^{2+}$	0,17	-	0,12	0,28	0,50	0,61	-0,01	0,17	1			
Mg <sup>2+</sup>	-0,49	-	0,49	0,68	0,89	0,63	0,49	0,00	0,63	1		
$\text{Na}^+$	-0,49	-	<b>0,92</b>	0,86	0,38	-0,11	<b>0,95</b>	0,30	-0,07	0,55	1	
$\text{K}^+$	-0,43	-	0,90	0,87	0,26	-0,14	<b>0,96</b>	0,39	-0,19	0,44	<b>0,97</b>	1

The high correlation between sulphide, chloride, sodium and potassium ions indicates also that they could have the same origins.



### 3.6. Hydro chemical facies of water

The Piper diagram presented in the figure below is traced with the data related to the concentrations of major elements.

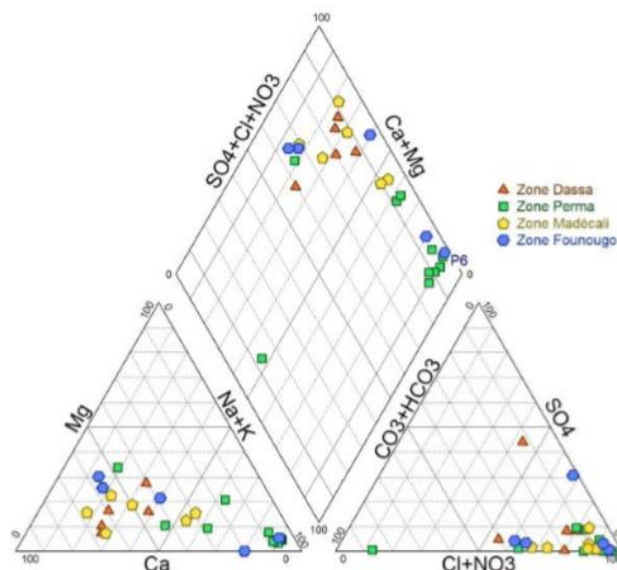


Figure 4: Piper diagram of major elements

On the diagram, we notice that samples of water from Dassa area present mainly a calcium chlorinated facies; those of Perma sector, a sodium chlorinated facies, those around Madecali a majority of calcium chloride facies and those of district Fonoungo have a sodium chloride facies.

### 3.7. Sulphide contents of waters

Due to its affinity with arsenic, sulphide has been measured to identify some areas with important content of this element. Figures below shows values obtained for sedimentary-volcano areas and gold areas.

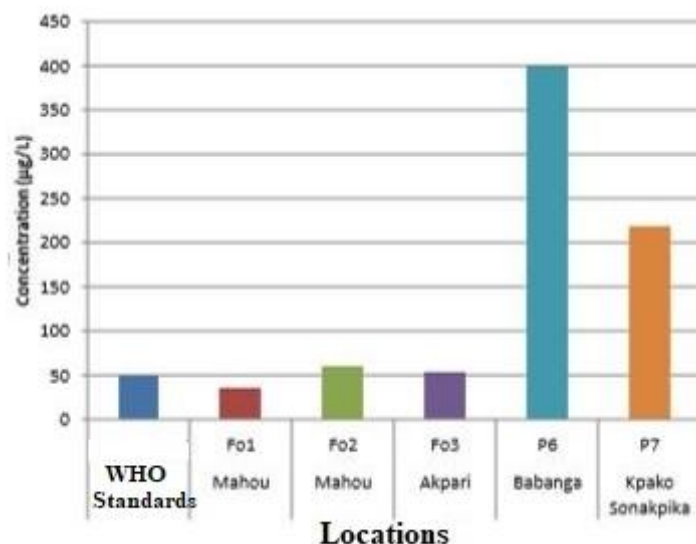


Figure 5: Sulphide concentrations in waters of volcano-sedimentary zones

The variations of sulphide concentrations in gold zone waters is presented in the figure below.

The dissociation of the different elements of arsenopyrite ( $\text{Fe AsS}$ ) may justify the high values recorded in gold zone. These high concentrations can be justified by the natural richness of volcano-sedimentary environments in sulphides.

In the immediate vicinity of the gold site, the effects of pollution are also noticeable at the water points and in particular in the wells. This explains why the content of  $\text{P}_2$  is slightly higher than the standard.



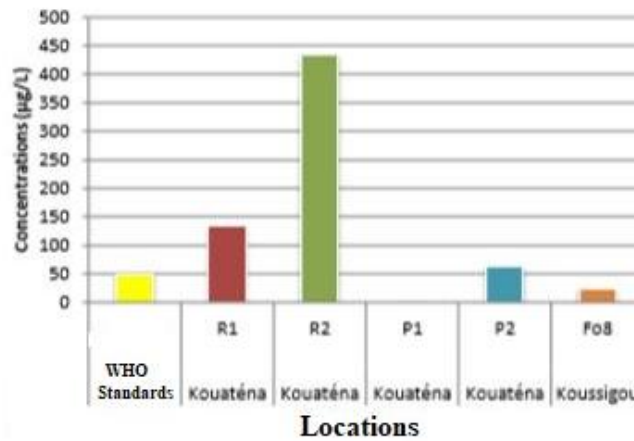


Figure 6: Sulphide concentrations in gold zone

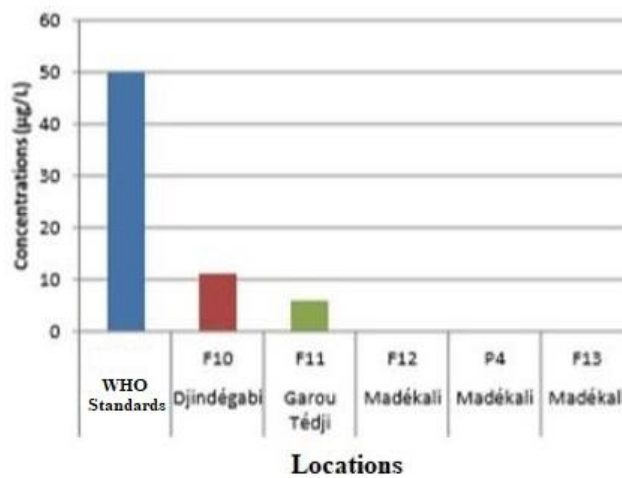


Figure 7: Sulphide content of the waters of ferruginous zone

In this region, the sulphide contents are very low. It has been necessary to carry out the essay of another element which has an affinity for arsenic for a conclusion as to the presence or not of this toxic element in this zone.

### 3.8. Iron contents

Iron is an element whose presence in water may indicate that of arsenic. The various analyses carried out made it possible to highlight a significant presence of this element in all the zones studied. Figures below show values obtained for sedimentary-volcano areas and gold areas.

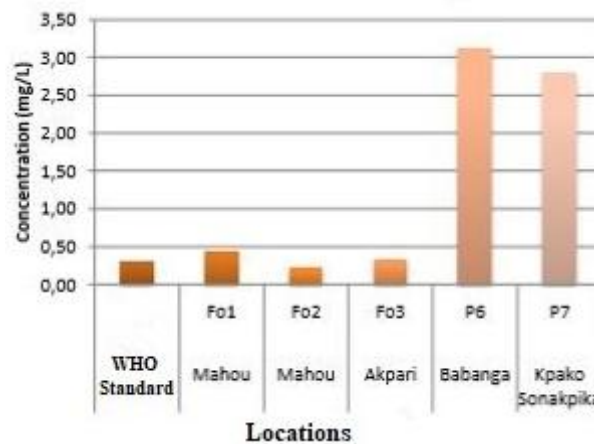


Figure 8: Iron contents of waters of volcano-sedimentary complex



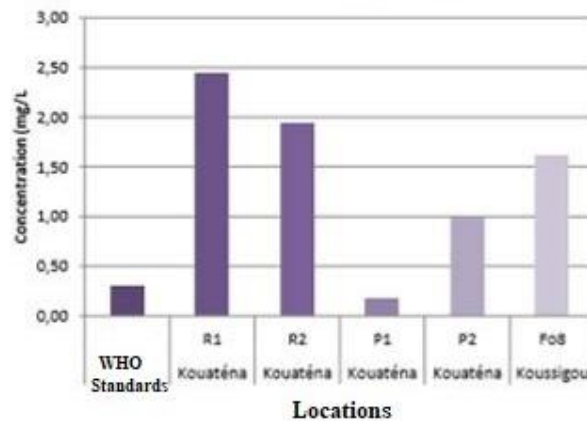


Figure 9: Iron contents of gold zones waters

In gold zones, the arsenopyrite is a major indicator of arsenic presence. The high values recorded could be due to dissociation of arsenopyrite and iron liberation in water.

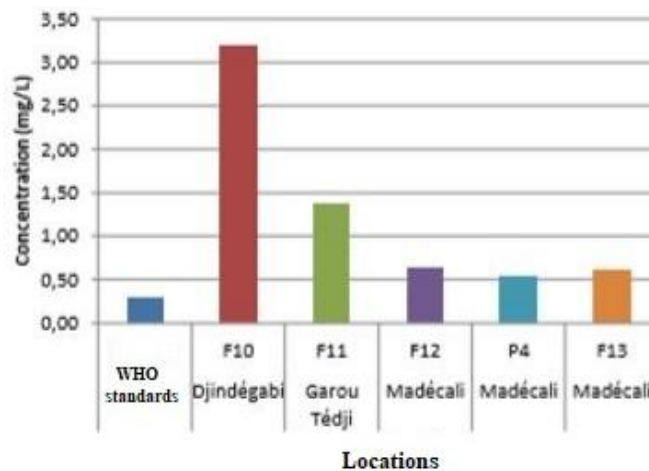


Figure 10: Iron contents in feruginous waters zones

The iron contents obtained confirms the nature of the zone

### 3.9. Arsenic contents in feruginous zones waters

Table 7 below indicates the results recorded on the samples which did not experience any significant interference in the direction of the transformation of As (III) into As (V) following three tests.

Table 7: Total Arsenic and Arsenic (III) contents in waters

Code	Total As		As (III)	
	Medium value	Standard deviation	Medium value	Standard deviation
Fo 1	8.19	0.02	6.45	0.13
Fo 2	5.89	0.03	5.28	0.02
Fo 3	6.22	0.02	4.37	0.08
R 1	10.73	0.12	10.25	0.20
R 2	15.89	0.22	14.32	0.49
P 1	13.24	0.19	10.33	0.25
P 2	8.49	0.03	6.75	0.05
Fo 8	10.23	0.06	10.16	0.06
F 10	11.05	0.04	9.23	0.07
F 11	5.07	0.04	4.54	0.40
F 12	7.52	0.01	6.21	0.02
P 4	6.02	0.02	5.38	0.02
F 13	6.88	0.04	5.88	0.02
P 6	9.25	0.07	7.18	0.05
P 7	7.31	0.01	4.25	0.04



Arsenic is a metalloid, the presence of which in water at levels exceeding a guide value should cause concern in view of its very toxic nature. The regulations only provide a guide value set at 10 µg /L by WHO for total arsenic [5]. Compared to this value, those recorded are various. The highest are registered in gold zone of Kouatena due to artisanal exploitation of gold which is mainly carried out by populations of this area.

### 3.10. Correlation matrices of dosed elements

Matrices presented below allow to appreciate relation between arsenic and others dosed elements. The values greater than or equal to 0.60 are significant and in bold.

**Table 8:** Matrix correlation of all of the elements dosed in volcano –sedimentary zones

	HCO <sub>3</sub> <sup>-</sup>	F <sup>-</sup>	Cl <sup>-</sup>	NO <sub>2</sub> <sup>-</sup>	NO <sub>3</sub> <sup>-</sup>	PO <sub>4</sub> <sup>3-</sup>	SO <sub>4</sub> <sup>2-</sup>	NH <sub>4</sub> <sup>+</sup>	Ca <sup>2+</sup>	Mg <sup>2+</sup>	Na <sup>+</sup>	K <sup>+</sup>	Fer Tot	S <sup>2-</sup>	As tot
HCO <sub>3</sub> <sup>-</sup>	1														
F <sup>-</sup>	0,93	1													
Cl <sup>-</sup>	0,97	0,93	1												
NO <sub>2</sub> <sup>-</sup>	0,17	0,46	0,27	1											
NO <sub>3</sub> <sup>-</sup>	-0,53	-0,50	-0,58	0,28	1										
PO <sub>4</sub> <sup>3-</sup>	0,92	0,73	0,88	-0,03	-0,38	1									
SO <sub>4</sub> <sup>2-</sup>	-0,43	-0,36	-0,49	0,42	0,98	-0,34	1								
NH <sub>4</sub> <sup>+</sup>	-0,89	-0,85	-0,94	-0,07	0,82	-0,78	0,75	1							
Ca <sup>2+</sup>	0,83	0,90	0,92	0,61	-0,37	0,70	-0,24	-0,80	1						
Mg <sup>2+</sup>	0,78	0,51	0,65	-0,35	-0,30	0,91	-0,30	-0,58	0,36	1					
Na <sup>+</sup>	-0,44	-0,43	-0,55	0,23	0,98	-0,32	0,97	0,79	-0,39	-0,19	1				
K <sup>+</sup>	-0,44	-0,47	-0,57	0,11	0,96	-0,30	0,94	0,80	-0,45	-0,12	0,99	1			
Fer Tot	-0,97	-0,91	-1,00	-0,20	0,58	-0,92	0,49	0,94	-0,89	-0,71	0,54	0,55	1		
S <sup>2-</sup>	-0,89	-0,87	-0,94	-0,11	0,82	-0,76	0,74	1,00	-0,81	-0,55	0,79	0,80	0,94	1	
As total	-0,54	-0,32	-0,63	0,37	0,68	-0,68	<b>0,73</b>	<b>0,74</b>	-0,43	-0,57	<b>0,73</b>	<b>0,70</b>	<b>0,66</b>	<b>0,71</b>	1

The observation of the matrix shows significant correlations between arsenic and iron in one hand ( $r = 0.66$ ) and arsenic and sulphide ( $r = 0.71$ ) on the other hand. This value confirms indeed that this zone has a volcano-sedimentary nature and therefore it is rich in sulphide. Significant affinities are also noticed between sulfates, ammonium, potassium sodium and arsenic.

**Table 9:** Correlation matrix of all the elements dosed in gold zones

	HCO <sub>3</sub> <sup>-</sup>	F <sup>-</sup>	Cl <sup>-</sup>	NO <sub>2</sub> <sup>-</sup>	NO <sub>3</sub> <sup>-</sup>	PO <sub>4</sub> <sup>3-</sup>	SO <sub>4</sub> <sup>2-</sup>	NH <sub>4</sub> <sup>+</sup>	Ca <sup>2+</sup>	Mg <sup>2+</sup>	Na <sup>+</sup>	K <sup>+</sup>	Fer Tot	S <sup>2-</sup>	As tot
HCO <sub>3</sub> <sup>-</sup>	1														
F <sup>-</sup>	0,66	1													
Cl <sup>-</sup>	-0,34	-0,68	1												
NO <sub>2</sub> <sup>-</sup>	-0,37	0,44	-0,27	1											
NO <sub>3</sub> <sup>-</sup>	-0,43	-0,71	0,07	-0,44	1										
PO <sub>4</sub> <sup>3-</sup>	0,88	0,41	-0,15	-0,53	-0,45	1									
SO <sub>4</sub> <sup>2-</sup>	-0,17	0,60	-0,30	0,97	-0,57	-0,39	1								
NH <sub>4</sub> <sup>+</sup>	-0,50	-0,77	0,49	-0,38	0,30	-0,04	-0,55	1							
Ca <sup>2+</sup>	0,99	0,64	-0,32	-0,37	-0,39	0,83	-0,16	-0,56	1						
Mg <sup>2+</sup>	0,89	0,26	-0,12	-0,75	-0,07	0,86	-0,58	-0,21	0,89	1					
Na <sup>+</sup>	-0,32	-0,88	0,80	-0,64	0,62	-0,18	-0,70	0,52	-0,28	0,09	1				
K <sup>+</sup>	-0,28	-0,83	0,77	-0,61	0,63	-0,21	-0,65	0,39	-0,22	0,12	0,99	1			
Fer Tot	0,09	-0,09	-0,57	-0,41	0,44	0,24	-0,50	0,35	0,03	0,24	-0,13	-0,19	1		
S <sup>2-</sup>	-0,28	-0,46	0,17	-0,29	0,07	0,18	-0,44	0,91	-0,38	-0,12	0,17	0,01	0,54	1	
As total	-0,16	-0,70	0,75	-0,61	0,12	0,25	-0,68	<b>0,86</b>	-0,19	0,15	<b>0,70</b>	<b>0,60</b>	0,04	<b>0,70</b>	1

For the samples analyzed, a significant correlation is noted between arsenic and sulfide. These two elements result from leaching of the gold sediments which then return to the water points. The link is also significant between ammonium, sodium, potassium and arsenic.



**Table 10:** Correlation matrix of all elements dosed in ferruginous zones

	HCO <sub>3</sub> <sup>-</sup>	F <sup>-</sup>	Cl <sup>-</sup>	NO <sub>2</sub> <sup>-</sup>	NO <sub>3</sub> <sup>-</sup>	PO <sub>4</sub> <sup>3-</sup>	SO <sub>4</sub> <sup>2-</sup>	NH <sub>4</sub> <sup>+</sup>	Ca <sup>2+</sup>	Mg <sup>2+</sup>	Na <sup>+</sup>	K <sup>+</sup>	Fer Tot	S <sup>2-</sup>	As tot
HCO <sub>3</sub> <sup>-</sup>	1														
F <sup>-</sup>	-	1													
Cl <sup>-</sup>	0,50	-	1												
NO <sub>2</sub> <sup>-</sup>	-0,15	-	0,01	1											
NO <sub>3</sub> <sup>-</sup>	-0,74	-	-0,19	0,56	1										
PO <sub>4</sub> <sup>3-</sup>	-0,50	-	-0,07	0,91	0,84	1									
SO <sub>4</sub> <sup>2-</sup>	-0,59	-	-0,67	-0,21	-0,07	-0,10	1								
NH <sub>4</sub> <sup>+</sup>	0,94	-	0,42	0,09	-0,71	-0,32	-0,45	1							
Ca <sup>2+</sup>	0,19	-	0,52	0,67	0,51	0,63	-0,84	0,18	1						
Mg <sup>2+</sup>	-0,46	-	-0,14	0,68	0,93	0,85	-0,33	-0,44	0,71	1					
Na <sup>+</sup>	-0,94	-	-0,36	-0,17	0,55	0,21	0,60	-0,96	-0,35	0,22	1				
K <sup>+</sup>	-0,76	-	-0,58	-0,05	0,17	0,12	0,96	-0,60	-0,67	-0,13	0,75	1			
Fer Tot	0,87	-	0,02	-0,09	-0,71	-0,46	-0,31	0,88	-0,03	-0,42	-0,90	-0,55	1		
S <sup>2-</sup>	0,95	-	0,24	-0,11	-0,79	-0,50	-0,38	0,95	0,02	-0,51	-0,94	-0,60	0,97	1	
As total	0,40	-	-0,58	-0,11	-0,38	-0,32	0,05	0,40	-0,26	-0,16	-0,50	-0,19	0,78	0,61	1

This table shows significant correlation between iron and arsenic ( $r = 0.78$ ) in one hand and between sulphide and arsenic on the other hand.

After analyzing all these matrices, it should be noted that arsenic has a significant affinity with iron and sulfide. This therefore confirms the fact that, failing to dose the arsenic due to the too high cost of the analysis, the knowledge of the iron and sulphide contents makes it possible to have an idea of its concentration in the studied areas.

### 3.11. Arsenic speciation analysis

In water, arsenic is at inorganic form with oxidation degrees III and V. The knowledge of total arsenic and arsenic III concentrations allow to calculate arsenic V concentration by formula:  $[As(V)] = [As\ total] - [As(III)]$

Figures below indicate As (V) concentration in waters on studied areas

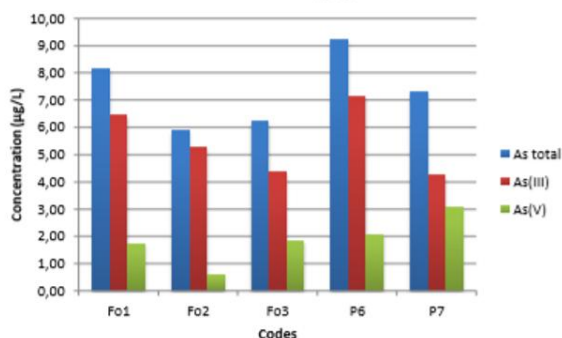


Figure 11: Arsenic contents in gold zones

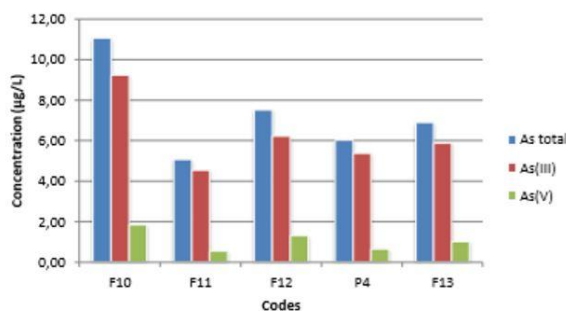


Figure 12: Arsenic contents in ferruginous zones

In oxidizing conditions ( $0.2\ V < EH < 0.5\ V$ ) and in the aerobic zone, arsenate is in the majority.  $H_2AsO_4^-$  predominates at  $pH < 6.9$  while  $H_2AsO_4^{2-}$  predominates at  $pH > 6.9$ . In the anaerobic zone, therefore under reducing conditions ( $0V < EH < -0.2\ V$  and  $pH < 9.2$  arsenite  $H_3AsO_3$  is the most stable form. When  $0V < EH < 0.2V$  and  $5 < pH < 9$  the three species listed above coexist [3].



The redox potentials noted in the samples are over all very low, close to zero and therefore indicate reducing conditions. As for the pH values, they are all less than 9.2.

From all of the above, the form to be expected is therefore arsenite ( $\text{H}_3\text{AsO}_3$ ). This observation is confirmed by the figures above.

### Conclusion

This work revealed the acid nature of most of waters analyzed, variables electrical conductivities and almost potential redox zero. Piper diagram obtained for waters after major elements dosage indicated on the whole a calcium chloride facies or a sodium chloride facies. The correlation matrices allowed understanding the origins of elements with high correlations and to explain the affinity between arsenic and iron on a hand and between arsenic and sulphide on second hand. Studying of Arsenic speciation indicated more As(III) than As (V) and their presence depend of pH and redox potentials values. Water resources in these localities are potentially polluted by arsenic and there is a need to regulate using of herbicides, pesticides and others pollutants.

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