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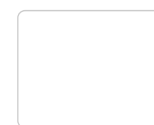
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RESEARCH ARTICLE

PHYSICO-CHEMICAL QUALITY AND METAL CONTAMINATION OF WELL WATER IN THE SIXTH NEIGHBORHOOD OF COTONOU, SOUTH BENIN

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Abstract

In this research work, we have studied the physico-chemical characterization and searched for twenty-six metallic elements in the well waters of the sixth neighborhood of Cotonou. Well water was sampled in ten neighborhoods of this neighborhood. Physico-chemical parameters such as pH, temperature, conductivity, total dissolved salts (TDS) and salinity were measured on site while ammonium, phosphate, chloride, nitrite and nitrate ions are determined in the laboratory. Twenty-six metallic elements were measured after acid digestion of the water samples using the inductively coupled plasma source mass spectrometer (ICP-MS). The results showed that groundwater in the sixth neighborhood is in a degradation of its physico-chemical quality. The conductivity values varying between 2.06 and 1270 $\mu\text{S}/\text{Cm}$ with an average of 872.41 and a standard deviation of 393.90 show that these waters are highly mineralized (the WHO qualifies waters with a conductivity greater than 200 $\mu\text{S}/\text{Cm}$ of very highly mineralized water). Ammonium and nitrite ions varying respectively between 0.6 and 7.1 mg/L with an average of 2.21 mg/L and 0.02 and 0.61 mg/L with an average of 0.22 mg/L are at abnormal concentrations in groundwater. The ammonium ion contents are beyond the standard value. As for metallic elements, aluminum, which is a trace element, is strongly present in water with an atypical observation of 5.008 mg/L. This value exceeds more than 25 times the standard defined by the WHO which is 0.2 mg/L. Iron is also present with an abnormal concentration of 2.711 mg/L as maximum value. Even if the values of the trace metals whose toxicities approved are lower than the standards, some atypical values are recorded and significant correlations established between these different chemical elements results from the common origins for the

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positively correlated metals and different origins for those which are negatively correlated.

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Introduction:-

Water is an essential element for life. It is even life because no one can do without it for several days and continue to live. The unavailability of quality water is the cause of the consumption by men of doubtful waters which are sources of diseases that can lead to death in the short, medium and long term. Water, designated as life, is therefore in terms of quantity and quality. Despite the water resources available on earth, man is faced with a serious problem of drinking water supply (Odoulami L., 2009). Indeed, in 1994, the United Nations Children's Fund estimated that among the 37 major diseases that plague developing countries, 27 are linked to water (73%). In the least developed countries, 15 million children die each year as a result of drinking contaminated water, lack of hygiene or malnutrition. WHO (1993) estimates that 80% of all such cases of illness are related to dirty water supply and inadequate sanitation. In sub-Saharan Africa, 42% of the population still does not have access to good quality sources (CNRS. France, 2004).

Benin has fully understood the potential danger represented by this drink of non-drinking water, which led it to set as an objective to be achieved in 2021: " 100% coverage for basic water supply " (SDG, water). To achieve these goals, it will need 94,146,667 dollars per year (SDGs, water). In Benin and more specifically in the sixth neighborhood of Cotonou, despite the existence of water from SONEB, a segment of the population continues to use well water for various needs, including drinking. This population is not spared from water-borne diseases such as diarrhoea, cholera and fever, which are very common in the outlying districts.

In the design of all drinking water supply projects today all over the world, in particular in many developing countries such as Benin, the aspect of physico-chemical quality is increasingly taken into account (Proulx- McInnis et al., 2016). The borough of Cotonou is not on the fringes of drinking water supply difficulties and more serious sanitation problems in the 6th neighborhood.

Indeed, the sixth neighborhood of Cotonou is confronted with frequent epidemics of diarrheal diseases, especially during the rainy season. This situation is often attributable to the poor management of municipal waste. The most important source of pollution is the Dantokpamarket, which alone generates more than 80% of the solid and liquid waste produced in this part of the borough. Populations whose capacities for efficient waste management are limited mostly opt for makeshift solutions consisting of burying waste in the immediate surroundings of the concessions. These waters are also polluted by elements of geochemical origin (Avocefouhou et al., 2017, Avocefouhou 2018). This unhealthy environment inevitably exposes the water table to the possible intrusion of all kinds of pollutants, thus posing a public health problem because a large segment of the population does not have access to drinking water and gets its drinking water from traditional wells fed by groundwater.

The objective of the study is to evaluate 26 metals and nitrogenous inorganic pollution indicators, phosphates and physical parameters to characterize the pollution of well water in the sixth neighborhood in order to determine the origins of this pollution.

Material And Methods:-

Study framework

The borough of Cotonou constitutes the coastal department located at the intersection of 6°20 and 6°23 North latitude and 2°22 and 2°30 East longitude. The economic capital of the country, Cotonou covers an area of 79km² with 13 neighborhoods and 144 neighborhoods. The sixth neighborhood is one of the 13 neighborhoods that make up this borough and is limited to the north by Lake Nokoué, to the south by the fifth neighborhood, to the east by the Cotonou lagoon, and to the west by the seventh, eighth and ninth neighborhood. This neighborhood comprises 19 neighborhoods, namely: Aïdjèdo I, II, III and IV, Agata, Towéta I and II, Gbèdjromèdé I and II, Ladjì, Dantokpa, Hindé I and II, Jericho I and II, AguéVossa, Djidjè I and II, 16,906 households with 75,336 inhabitants including 35,791 male and 39,545 female (Fourth General Census of Population and Housing 2013). It is a neighborhood which is located in the peripheral zone of Cotonou. Its marshes communicate with the lagoon and, depending on

their depth, are part of the lagoon system. (cf. PDC January 2008 p.18 quoted by Irma SM KEMAVO, 2010). Figure 1 shows the location of the commune of Cotonou.

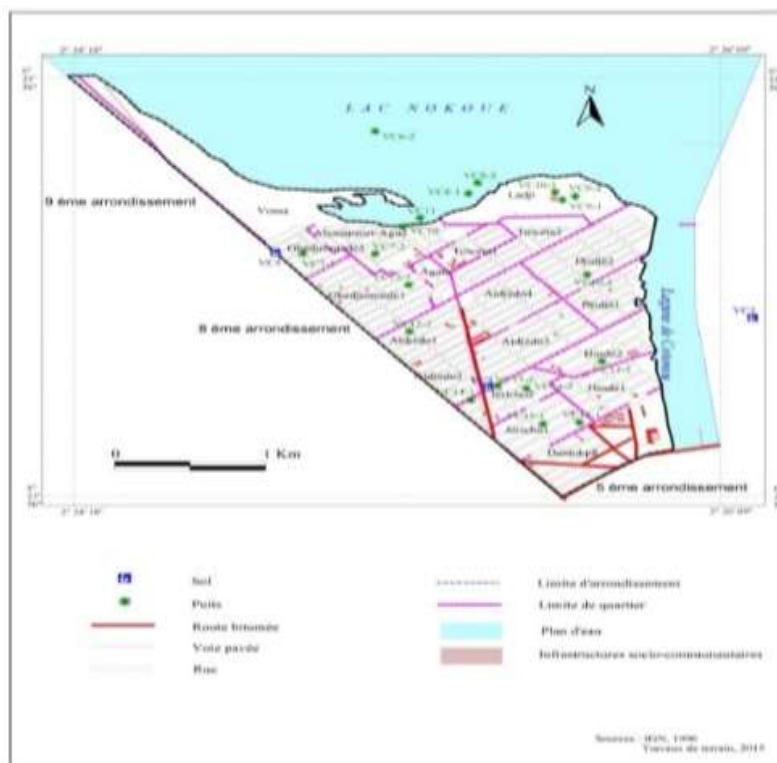


Figure 1:- Location of the study area.

Sampling

The selection criterion for sampling sites is based on the influx of households to these water points (wells). Ten neighborhoods have been identified, namely: Ahouansori, Aijedo, Dantokpa, Hidé, Jericho, Ladji, Towta and Vossa. Then we sampled twenty wells, two wells per neighborhood. A control well was sampled at Djadjo in the commune of Abomey.

Sample processing and analysis

Before sampling, 1.5L plastic bottles were rinsed with tap water and then with demineralized water for sampling. In the field, these materials were rinsed at least two to three times with the water to be sampled. Then, the sample was taken with the scoops usually used at each water point by the populations. Sampling was done during the small dry season (August). Thus, twenty (20) wells were sampled in ten (10) neighborhoods of Cotonou for physico-chemical and toxic metal analyses. The samples were kept in a cooler with ice packs and then transported to the laboratory where all the parameters were measured.

Parameters susceptible to modification during transport such as temperature, pH, electrical conductivity and total dissolved salts (TDS) were measured on site using a multi-parameter of the Testr marque.

Nitrate, nitrite, ammonium, phosphate, chloride ions and metallic elements were determined in the laboratory using appropriate methods (Rodier, 1984, Rodier, 2016).

The sodium salicylate method was used for the determination of nitrates. According to the principle on which the method is based, nitrates give, in the presence of sodium salicylate, sodium para-nitro-salicylate which, when colored yellow, is susceptible to colorimetric determination, the intensity of the color being a function of the nitrate concentration (Rodier, 2016).

Used in the context of this study for the determination of nitrites, the Zambelli reagent method was used. Based on the ability of sulphanic acid to form, in the presence of nitrite ions in a hydrochloric medium, in the presence of pure ammonia and phenol, a complex colored yellow whose intensity is proportional to the concentration of nitrites and likely to be measured colorimetrically.

The Nessler method was adopted for the determination of ammonium ions while the ammonium molybdate method based on the principle that in an acid medium and in the presence of ammonium molybdate, the ortho phosphates give a phospho -molybdic complex which, reduced by ascorbic acid, develops a blue color susceptible to a colorimetric assay was used for the assay of phosphate ions (Rodier, 2016).

In addition, the inductively coupled plasma source mass absorption spectrophotometer (ICP-MS) after acid digestion (H / NF EN ISO 15587-1 et 2 for the mineralization) (INERIS, 2003) of water samples was used for the determination of metals.

The results obtained were processed with SPSS descriptive statistics. Software such as Excel was used to obtain the graphs and Word for entering the text. We have used the SPSS descriptive statistics applied to major, minor and trace elements to determine percentile values and make a graph.

Results And Discussion:-

Physical parameters

Physical parameters such as temperature, pH, conductivity, dissolved solids (TDS) and salinity were measured on site. The results are presented in Table I below:

Table I:- Variation of physical parameters.

name of the site	T (°C)	pH	Cond (µS/cm)	TDS (ppm)	Salt (ppt)
VOSSA1	27.5	7.60	1133	800	564
VOSSA2	27.8	5.50	1659	1180	835
GBEDJROMEDE1	28.2	6.70	620	445	307
GBEDJROMEDE2	27.4	6.73	1126	796	557
TOWETA1	28.5	7.03	1252	886	620
TOWETA2	27.7	7.05	2.27	1.55	1.16
LADJI1	28.1	7.95	2.06	1.47	1.06
LADJI2	28.8	7.51	1826	1290	938
AHOUANSSORI1	28.5	6.84	1258	894	626
AHOUANSSORI2	28.2	6.95	1321	831	645
HINDE1	28.8	7.92	857	603	420
HINDE2	28.1	8.01	941	668	464
JERICH01	29.6	8.01	647	459	315
JERICH02	29.7	7.58	808	574	397
TOKPA1	27.8	7.77	800	569	393
TOKPA2	28.1	7.63	1162	825	577
DJIDJE1	28.2	6.87	1270	915	643
DJIDJE2	29.0	9.05	1574	1120	792
AIDJEDO1	27.4	8.20	885	627	434
AIDJEDO2	28.5	6.75	613	435	298
F1	29.1	4.65	130	6.21	6.59
Minimum	27.4	5.50	2.06	1.47	1.06
Maximum	29.7	9.05	1826	1290	938
Mean	28.30	7.38	987.82	696.00	491.36

The temperature values obtained for all the well water are between 27.4 and 29.6 °C. Atypical values were recorded at the drilling level at Djadjo and at AIDJEDO. The pH value recorded at the borehole (control well) is atypical. The conductivities obtained are between 2.06 and 1270 µS/Cm with an average of 872.41 µS/Cm and a standard deviation of 393.90 µS/Cm. The distribution is elongated towards the low values of this parameter recorded at the level of the wells. These concentrations varied the same as these of Kanohin et al., 2017 and N'guettia et al., 2019.

As in the case of conductivity, the TDS distribution is elongated towards low values

As in the case of conductivity and TDS, the distribution of salinity is elongated towards low values.

Inorganic pollution indicators and chloride ions

Ammonium ion levels ranging between 0.6 mg/L and 7.1 mg/L with an average of 2.21 mg/L are above the standard value set by the WHO for drinking water (0.5mg/L). The highest value was recorded at DJIDJE while the lowest value is observed at JERICHO. Ammonium concentrations in these wells are greater than those obtained by Kanohin et al., 2017 which obtained concentrations below 0.5 mg/L (the WHO threshold value). N'guettia et al., 2019 has obtained lower concentrations of ammonium than those we have in this study.

On the other hand, the concentrations of phosphate and nitrate ions respectively 5 mg/L and 45 mg/L are well below the standard value set for drinking water. The highest value for nitrate ions is recorded at DJIDJE.

Table II:- Variation in levels (mg/L) of inorganic pollution indicators and chloride ions.

Sites	NH ₄ ⁺	PO ₄ ³⁻	NO ₂ ⁻	NO ₃ ⁻	Cl ⁻
VOSSA	0.97	0.20	0.02	0.30	178
GBÈDJROMÉDÉ	1.85	0.70	0.23	1.50	71
TOWETA	2.33	1.40	0.08	2.00	69
LAJI	1.77	0.10	0.25	2.00	177
DJIDJE	7.1	0.70	0.61	4.40	65
AHOUANSORI	2.57	0.80	0.53	1.70	31
AIDJEDO	0.66	0.40	0.1	1.20	151
HINDI	1.01	0.20	0.18	2.00	461
JERICHO	0.6	1.10	0.05	0.60	11
DANTOKPA	3.25	1.10	0.18	0.50	46
Minimum	0.6	0.10	0.02	0.30	11
Max	7.1	1.40	0.61	4.40	461
Avg	2.21	0.67	0.22	1.62	126
WHO	0.5	-	3	50	-
Benign	-	-	3.2	45	250
Canada¹	-	-	3.29	29.57	-
MSDA	0.05	-	0.01	25	20

As for nitrite ions, only the levels recorded in the localities of VOSSA, TOWETA, AÏDJEDO and JERICHO comply with the standard set by the WHO for drinking water. The levels recorded in the six other localities do not meet WHO standards and the highest value is recorded in DJIDJE (4.4 mg/L). The average is 0.22. These concentrations are well below the drinking water quality standards and the values obtained by Youssao (2011) and Ghazali et al., 2013. This could be explained by the fact that the nitrogen ions in the waters generally come from agricultural sources which are practically absent (Youssao et al. , 2011).

The chloride ion contents vary between 11 mg/L (JERICHO) and 461 mg/L (HINDE). Only the content recorded in the locality of HINDE does not respect the recommendation of the WHO quality guidelines for drinking water which is 250 mg/L; the average being 126 mg/L.

Metallic elements concentrations

The concentration of metallic trace elements in ten neighborhoods of the borough of Cotonou are grouped in Table III. It emerges from the analysis of this table that the low magnesium concentrations were found in VOSSA and LADJI respectively (11.1±0.3) mg/L and (24.8±0.8) mg/L while the highest values were recorded in eight other neighborhoods.

With regard to calcium, the high concentration was found in the well water of the borehole (F1). However, the concentration values of this chemical entity in the ten neighborhoods of Cotonou show its low presence.

¹Guide to the interpretation of the Regulation respecting the quality of drinking water, Quebec - Updated in 2021.

Iron was also quantified in well water in the ten neighborhoods. The values obtained indicate a strong presence of iron in the TOWETA and LADJI neighborhoods (2711 ± 65) $\mu\text{g/L}$ and (2079 ± 43) $\mu\text{g/L}$ respectively. On the other hand, there is a minority or trace presence of this chemical entity in the other neighborhoods. The lowest iron concentrations were found in the well water samples from HINDÉ, GBEDJROME1, JERICO and the borehole (F1) all below the quantification limit.

We also quantified Aluminum in the ten samples and the well water from the borehole. It should be noted that of the twenty-six metal trace elements quantified at TOWETA1, only Aluminum has a higher concentration (5008 ± 162) $\mu\text{g/L}$. On the other hand, iron concentrations in the JERICO and AIDJEDO2 neighborhoods are all below the quantification limit. In addition, we note the presence of elements such as Pt, Hg, Tl, Pb, Th and U in very small proportions or in traces. However, we noticed the presence of lead (2.82 ± 0.04) $\mu\text{g/L}$ in the borehole water (F1). But the lowest values were recorded in well water from the ten neighborhoods of Cotonou. In conclusion, we can say that the presence of these metallic trace elements in Cotonou well water would be due to various human activities (agriculture, industry, wastewater treatment, recycling of urban and industrial waste, etc.) which generate pollution, all sorts. In addition, it is important to note that most of these contaminants are either naturally present or are introduced into these well waters either directly or transported by waterways to reach the marine environment.

Correlations between metallic elements concentrations

Table IV presents the matrix of correlations between the metallic elements found in well water in the sixth neighborhood of Cotonou. Between the metallic elements present in the water, some of which have values lower than the WHO standard values, there are significant correlations at the threshold with $p < 0.05$, $p < 0.01$ and $p < 0.001$.

Thus we note a significant negative correlation between Fe and Mg ($r = -0.663$, $p < 0.05$); Mg and Pb ($r = -0.678$, $p < 0.05$); Mg and U ($r = -0.662$, $p < 0.05$); Mn and As ($r = -0.665$, $p < 0.05$); Cu and Tl ($r = -0.689$, $p < 0.05$).

For the significant positive correlations between the elements, we note:

- a positive and significant correlation between Co and Sn ($r = 0.670$, $p < 0,05$); Fe and Mn ($r = 0.674$, $p < 0.05$); Ca and U ($r = 0.674$, $p < 0.05$);
- a positively and highly significant correlation between Fe and Al ($r = 0.779$, $p < 0.01$); Cu and U ($r = 0.819$, $p < 0.01$); Be and Sn ($r = 0.873$, $p < 0.01$); Be and Al ($r = 0.880$, $p < 0.01$);
- a positive and highly significant correlation between Fe and Co ($r = 0.860$, $p < 0.001$); Cu and Pb ($r = 0.940$, $p < 0.001$); Fe and Be ($r = 0.978$, $p < 0.001$); Al and Sn ($r = 0.999$, $p < 0.001$).

The strongest significant correlation coefficient was noted between Al and Sn (0.999) and the weakest between Cu and Tl (-0.689). This affinity would be linked to the source of these metals which would come either from urban waste discharges for Al and Sn and conversely Cu and Tl would be of different origins. This reasoning can be extended to all the significant correlations noted in the table.

Table III:- Concentrations of major elements (Mg and Ca in mg/L), minor and trace elements (in $\mu\text{g/L}$).

	TOW ETA	HIND E	TOKP A	AHOU ANSO	GBEDJ ROME	VOS SA	LADJI	JERIC O	AIDJE DO	DJIDJ E	F1
Mg*	64.7 \pm 1 .3	4236 \pm 151	4909 \pm 159	7058 \pm 3 01	4333 \pm 10 0	11.1 \pm 0.3	24.8 \pm 0 .8	4432 \pm 115	7596 \pm 232	7950 \pm 319	808 \pm 2 4
Ca*	25.0 \pm 0 .6	63.5 \pm 1 .5	55.0 \pm 2 .2	65.4 \pm 2 5	45.3 \pm 1.2	104 \pm 3	109 \pm 4	61.5 \pm 2 .0	105 \pm 4	79.8 \pm 3 .3	9382 \pm 174
V	7.32 \pm 0 .16	13.9 \pm 0 .2	7.31 \pm 0 .16	17.8 \pm 0 3	8.52 \pm 0.1 0	12.9 \pm 0.2	10.4 \pm 0 .3	15.7 \pm 0 .1	6.82 \pm 0 .18	8.94 \pm 0 .24	0.85 \pm 0 .04
Cr	3.18 \pm 0 .06	4.25 \pm 0 .10	5.54 \pm 0 .24	0.49 \pm 0 02	<LOQ	2.97 \pm 0.03	3.42 \pm 0 .10	1.09 \pm 0 .03	<LOQ	<LOQ	<LOQ
Mn	72.7 \pm 2 .1	<LOQ	42.4 \pm 1 .2	29.0 \pm 0 6	70.2 \pm 1.7	<LO Q	98.6 \pm 3 .2	<LOQ	37.8 \pm 1 .1	56.4 \pm 2 .2	5.49 \pm 0 .02
Fe	2711 \pm 65	<LOQ	325 \pm 1 1	79.8 \pm 3 4	<LOQ	144 \pm 3	2079 \pm 43	<LOQ	37.8 \pm 1 .1	256 \pm 1 0	<LOQ
C	0.76 \pm 0	0.27 \pm 0	0.26 \pm 0	0.52 \pm 0	0.17 \pm 0.0	0.27 \pm	0.64 \pm 0	0.15 \pm 0	0.38 \pm 0	0.26 \pm 0	0.20 \pm 0

o	.02	.02	.01	.02	.01	0.03	.06	.01	.04	.01	.01
Ni	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
Cu	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	4.60±0.22	<LOQ	<LOQ	<LOQ	<LOQ	8.03±0.27
Zn	<LOQ	15.6±0.7	<LOQ	29.2±1.0	<LOQ	<LOQ	37.1±0.7	<LOQ	82.8±4.7	<LOQ	76.1±1.4
As	3.25±0.28	4.21±0.43	3.88±0.47	4.51±0.27	1.94±0.16	2.68±0.19	1.79±0.25	4.34±0.21	4.13±0.10	2.66±0.34	<LOQ
Se	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
Cd	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
Be	0.14±0.03	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	0.074±0.005	<LOQ	<LOQ	<LOQ	0.17±0.02
Al	5008±162	73.7±4.6	146±7	59.2±2.5	11.4±0.7	128±5	128±7	<LOQ	<LOQ	10.8±0.5	13.9±0.6
Sr	339±4	203±1	174±1	198±3	143±1	474±10	601±11	488±4	321±4	243±2	16.3±0.1
Mo	1.87±0.02	11.3±0.1	4.54±0.01	7.82±0.11	4.99±0.04	5.54±0.05	3.90±0.04	2.76±0.04	7.68±0.07	7.11±0.05	0.21±0.01
Ag	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
Sn	4.81±0.04	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
Ba	30.8±0.5	13.4±0.1	10.0±0.1	30.6±0.4	107±1	32.8±0.4	134±1	15.0±0.1	36.8±0.3	27.7±0.1	15.4±0.2
Pt	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
Hg	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
Tl	0.071±0.008	0.049±0.006	0.046±0.006	0.094±0.021	0.11±0.01	<LOQ	0.050±0.002	0.047±0.004	0.060±0.003	0.056±0.003	0.042±0.007
Pb	0.99±0.01	0.25±0.01	0.25±0.01	0.17±0.01	0.47±0.02	2.73±0.02	0.48±0.02	0.13±0.01	<LOQ	0.19±0.01	2.82±0.04
Th	<LOQ	0.70±0.04	0.84±0.05	0.73±0.04	0.58±0.01	0.71±0.13	0.64±0.05	0.59±0.04	0.57±0.02	0.55±0.02	0.54±0.03
U	0.41±0.01	0.44±0.01	0.30±0.01	0.19±0.01	0.047±0.004	3.18±0.07	2.12±0.01	0.18±0.01	0.61±0.01	0.22±0.01	0.17±0.01

Table IV:- Correlation between element concentrations.

	Mg	Ca	Mn	Fe	Co	Cu	Zn	As	Be	Al	Sn	Ba	Tl	Pb	Th	U
Mg	1	0.012	-0.203	-0.663*	-0.425	-0.460	0.309	0.478	-0.646	-0.475	-0.454	-0.362	0.387	-0.678*	0.332	-0.662*
Ca		1	-0.070	-0.183	-0.052	0.412	0.572	-0.200	-0.310	-0.578	-0.585	0.264	-0.529	0.209	0.469	0.674*
Mn			1	0.674*	0.561	-0.417	0.111	-0.665*	0.594	0.330	0.327	0.725	0.455	-0.208	-0.392	-0.055
Fe				1	0.860***	-0.101	-0.000	-0.380	0.978***	0.779**	0.768	0.362	0.027	0.144	-0.070	0.200

						50	42	1							00	
C					1	-	0.2	-	0.850	0.68	0.670	0.2	0.15	0.056	-	0.16
o						0.1	79	0.11		0	*	65	6		0.5	4
						68		5							73	
C						1	-	-	-	-	-	-	-	0.940	0.1	0.81
u							0.2	0.22	0.158	0.09	0.111	0.0	0.68	***	85	9**
							13	8		6		92	9*			
Z							1	0.22	-	-	-	0.1	0.10	-	0.1	0.05
n								5	0.067	0.22	0.213	86	1	0.337	0.06	9
A								1	-	-	-	-	-	-	0.1	-
s									0.291	0.03	0.031	0.7	0.01	0.369	0.53	0.44
										8		91	3			4
B									1	0.88	0.873	0.2	0.09	0.153	-	0.11
e										0**	**	70	1		0.8	2
															14	
Al										1	0.999	-	0.13	0.201	-	-
											***	0.1	2		0.9	0.10
												06			05	0
S											1	-	0.15	0.184	-	-
n												0.1	0		0.9	0.12
												09			17	2
B												1	0.31	0.016	-	0.29
a													9		0.0	4
															31	
Tl													1	-	-	-
														0.589	0.2	0.71
															39	5
P														1	-	0.80
b															0.0	4
															83	
T															1	0.17
h																4
U																1

* Significant correlation at the $p < 0.05$ threshold

** Significant correlation at $p < 0.01$

*** Significant correlation at the threshold $p < 0.001$

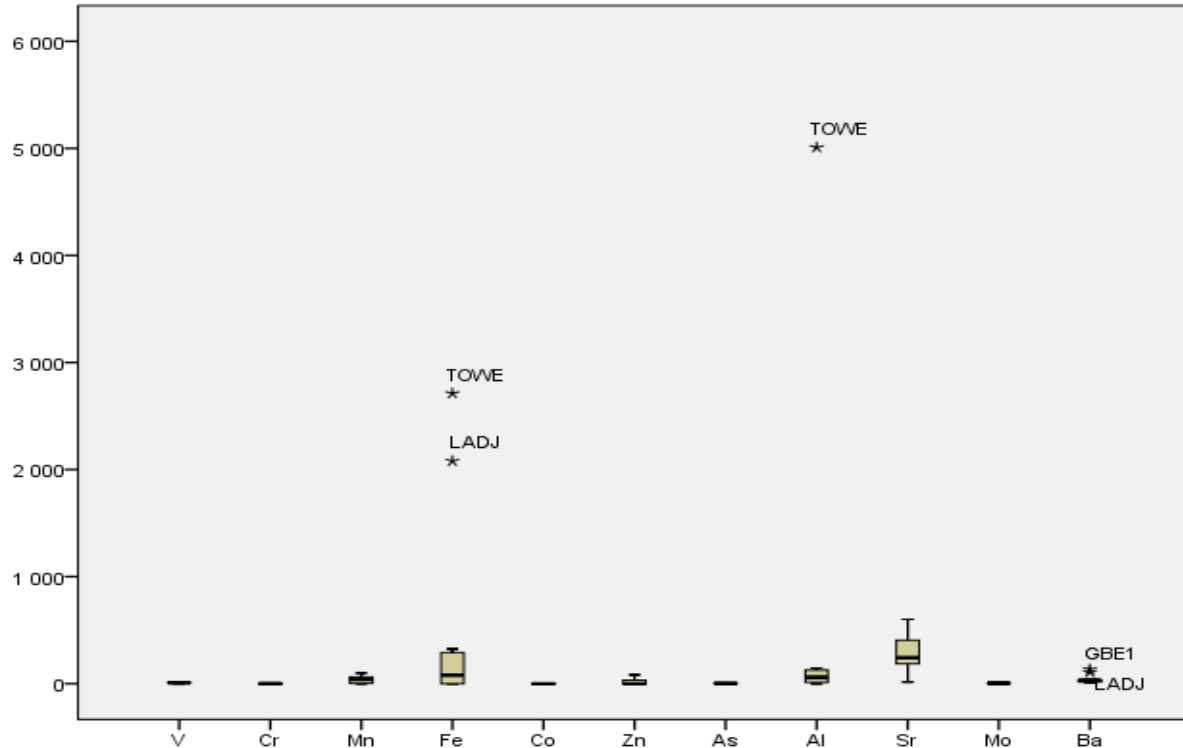


Figure 2:- Distribution of eleven minor and trace elements in well waters.

Aluminum is strongly present with an atypical observation in groundwater at TOWETA where a value of 5008 ± 162 $\mu\text{g/L}$ was recorded for an average of 507.18 $\mu\text{g/L}$ (Table 5). This atypical value exceeds more than 25 times that of the WHO which is 200 $\mu\text{g/L}$. This water would be dangerous to drink

Iron is also present with an atypical observation in groundwater at TOWETA where a value of 2.711 mg/L and an average of 0.56 mg/L was recorded.

Table V presents the concentration of metal trace elements quantified in the drilling water (F1), the minimum, the maximum, the average as well as the WHO guideline and the Beninese, Canadian and Swiss standards for the quality of the water. drinking water. From the analysis of this table, it appears that the majority elements present in the water are Calcium (Ca) and magnesium (Mg) whose concentrations are respectively 9382 and 808 $\mu\text{g/L}$. On the other hand, the average values recorded are Ca (917.77 $\mu\text{g/L}$) and Mg (3765.69 $\mu\text{g/L}$).

Other minor elements like manganese (5.49 $\mu\text{g/L}$), copper (8.03 $\mu\text{g/L}$), strontium (16.3 $\mu\text{g/L}$), aluminum (13.9 $\mu\text{g/L}$) and zinc (76.1 $\mu\text{g/L}$) were also quantified. In addition, we note the presence of elements such as chromium, vanadium, Iron, cobalt, Nickel, arsenic, selenium, cadmium, beryllium and molybdenum in very low concentration.

The highest concentration of aluminum was obtained at TOWETA1 and those of strontium and Ba at LADJI. As for lead and uranium, the highest concentrations were obtained respectively at Djadjo in the drilling water and at VOSSA in a well in the 6th neighborhood of Cotonou.

In short, the concentrations of these metallic trace elements are very low and below the recommended quantification limit. The highest levels recorded with Calcium (Ca) and magnesium (Mg) would be due to the abundance of these elements in the earth's crust or to their introduction into the waters during human activities.

Table V presents the reference standards, the quartiles, the averages and the minimum and maximum values of the concentrations in the waters of the 6th neighborhood of Cotonou and the concentrations of the elements in the water of the borehole chosen as a reference in Djadjo in the commune of Abomey- Calavi.

Table V:- Variations in concentrations of metallic elements in well water and drilling water.

Elements	Units	Drilling	Well water from the 6th neighborhood						Standards			
		F1	Q1	Q2	Q3	Minimum	Maximum	Mean	WHO	Benin ²	Canada	MSDA ³
Mg	mg/L	808.00	1107.53	4382.50	6520.75	11.10	7950.00	3765.69		50		50-125
Ca	mg/L	9382.00	56.63	64.45	97.95	25.00	9382.00	917.77		100		200
V	µg/L	0.85	7.62	9.67	13.65	0.85	17.80	10.04				
Cr	µg/L	<LOQ	0.12	2.03	3.36	<LOQ	5.54	1.90	50	50	50	1 (Cr ⁶⁺ /l)
Mn	µg/L	5.49	7.25	40.10	66.75	<LOQ	98.60	37.51	400	0.1		20
Fe	µg/L	<LOQ	9.45	111.90	307.75	<LOQ	2711.00	512.05		300		50
Co	µg/L	0.20	0.26	0.27	0.49	0.15	0.76	0.35				
Ni	µg/L	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	70	20		
Cu	µg/L	8.03	<LOQ	<LOQ	<LOQ	<LOQ	8.03	1.15	2000	2000	1000	20 (Cu ²⁺ /l)
Zn	µg/L	76.10	<LOQ	<LOQ	25.80	<LOQ	82.80	21.89		3000		100
As	µg/L	<LOQ	2.67	3.57	4.19	<LOQ	4.51	2.92	10	50	10	2
Se	µg/L	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	40	10	10	1
Cd	µg/L	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	3	5	5	0.5
Be	µg/L	0.17	<LOQ	<LOQ	<LOQ	<LOQ	0.17	0.03				
Al	µg/L	13.90	10.95	66.45	128.00	<LOQ	5008.00	507.18	200			50
Sr	µg/L	16.30	199.25	282.00	440.25	16.30	601.00	290.94				
Mo	µg/L	0.21	4.06	5.27	7.54	0.21	11.30	5.25	70			
Ag	µg/L	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ				
Sn	µg/L	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	4.81	0.44				
Ba	µg/L	15.40	18.18	30.70	35.80	1<LOQ	134.00	41.23	700	1000	1000	1300
Pt	µg/L	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ				
Hg	µg/L	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	6	1	1	0.1 (Hg ²⁺ /l)
Tl	µg/L	0.04	0.05	0.05	0.07	<LOQ	0.11	0.06				

²DECREE N° 2001-094 OF February 20, 2001 Setting drinking water quality standards in the Republic of Benin³Swissfoodmanual

	L											
Pb	µg/ L	2.82	0.18	0.25	0.48	<LOQ	2.82	0.77	10	50	5	1
Th	µg/ L	0.54	0.57	0.62	0.71	<LOQ	0.84	0.59				
U	µg/ L	0.17	0.20	0.36	0.57	0.05	3.18	0.72	30		20	

The average concentrations of magnesium and calcium largely exceed Benin and Switzerland in terms of drinking water quality and the minimum values (11.10 and 25.00 mg/L respectively for Mg and Ca are lower than these standards. reference (Table V). However, 75% of the sites have a magnesium concentration above 6520.75 (Q3) which is the value of the third quartile. This value is well within the reference standards of Benin and Switzerland. As for calcium, the value of the third quartile (97.95 mg/L) is close to the Benin standard (100 mg/L). So only 25% of the wells do not meet the Beninese standard while all the wells meet the Swiss standard in terms of drinking water quality. It should be noted that the borehole has the highest concentration of calcium (9382 mg/L) far exceeding the existing ones.

Vanadium (V) and Strontium (Sr) are found in well water respectively in the order of ten µg/L and a few hundred µg/L. However, these elements are not regulated in waters for human consumption. The maximum concentrations obtained for these elements are respectively 17.80 and 601 µg/L with a respective average of 10.04 and 290.94 µg/L.

Chromium (Cr), manganese (Mn), Iron (Fe) and aluminum (Al) presented respective average concentrations of 1.90 µg/L, 37.51 µg/L, 512.05 µg/L and 507.18 µg/L and quartiles (Q3) of 3.36 µg/L, 66.75 µg/L, 307.75 µg/L and 128 µg/L.

The chromium concentrations are lower than all the reference standards (50 µg/L) except for the Swiss standards for hexavalent chromium (1 µg/L). 75% of the wells sampled have concentrations of these elements above Beninese and Swiss drinking water quality for manganese and iron and above Swiss standards for aluminium. However, the average aluminum concentration is more than double the OS guideline and more than four times the Swiss standard.

As for the 13 elements, Cobalt (Co), Nickel (Ni), Arsenic (As), Selenium (Se), Cadmium (Cd), Beryllium (Be), Molybdenum (Mo), Sn (Tin), Ba (Barium), Tl (Thallium), Pb (Lead), Th (Thorium) and U (Uranium), the concentrations obtained are well below the standards except the Swiss standard for dissolved lead (Pb²⁺).

The following chemical elements, copper (Cu), zinc (Zn), Ag (silver), Pt (platinum) and Hg (mercury) have concentrations below the quantification threshold of the method.

The physico-chemical characterization of groundwater and the search for trace elements in these resources have been the concerns of many researchers in recent years (Dovonou et al., 2011; Lalêyè, 2015; Avocèfohou et al., 2017).

The well waters of the sixth neighborhood analyzed reveal that the values of physico-chemical parameters such as temperature, conductivity, TDS and salinity are high in certain localities. The high temperatures could be explained by the influence of the ambient heat on the water withdrawn and also by the geothermal gradient of the area. These values could be explained by the fact that the lake and the channel communicate with the sea water. The ions contained in these waters are carried away by the underground waters and by ricochet the wells. The conductivity values ranging between 0.2µS/Cm and 1270 µS/Cm confirm those obtained in certain Cotonou wells which were 718µS/Cm and (Dovonou, 2011) in certain Abomey- Calavi wells which varied between 69.8 µS/Cm and 651 µS/Cm.

Well water in the sixth neighborhood of Cotonou is contaminated with ammonium, nitrite and chloride ions. Nitrites (NO₂⁻) are ions that occur naturally in the environment. Their source is also attributed to human activities through animal husbandry, agriculture and others. They are the result of nitrification of the ammonium ion (NH₄⁺) present in water and soil, which is oxidized into nitrites by bacteria of the nitrosomonas genus (Health CANADA, 1992). This

explains the highest values of ammonium and nitrite ions recorded in the same locality (DJIDJE). This is because nitrites react with normal hemoglobin to form methemoglobin, thereby affecting the blood's ability to carry enough oxygen to the body's cells. Infants in the neighborhoods of GBÈDJROMÉDÉ, LADJI, DIDJÈ, AHOANSORI, HINDÉ and TOKPA are therefore exposed to the consequences linked to the presence of nitrites in the water.

Contrary to the results of the present study, Souley Moussa et al. (2018) had obtained nitrate contents in the upper Zinder wells.

Moreover, these waters are also contaminated by metals such as aluminum and iron. These two metallic elements presented an atypical observation in well waters collected at TOWETA. This explains the positively and highly significant correlation ($r = 0.779$, $p < 0.01$) between them (Table IV). These compounds produce very unpleasant effects on the aesthetic level, such as stains on clothing, sanitary appliances and household appliances, but do not necessarily have an impact on health. Even if the consequences linked to the consumption of water containing a high level of aluminum have not yet been fully proven on human health, it is advisable to monitor this element closely in drinking water.

Dovonou(2011) had recorded the total iron concentration of 0.5 mg/L and 40 % of the samples have total iron contents exceeding 0.3 mg/L in the Godomey wells. These values are lower than those recorded in the wells of the sixth district of Cotonou.

The other elements present in the groundwater of the sixth neighborhood of Cotonou with values lower than the standard values hide disparities that should be underlined. Indeed, Mn, Zn, Pb and Th have a more elongated distribution towards high values with atypical observations for lead at Vossa and Djadjo (control well) and for that TOWETA (Figures 9 and 10).

The toxic effects of this element appear only in case of absorption of very large quantities. If the diet is rich in calcium, the bioavailability of other absorbed minerals may be disturbed.

Magnesium concentrations ranging from 5 to 10 meq /L (6 to 12 mg/ dL) can alter heart rhythm. Skeletal muscle paralysis, reduced lung capacity, coma and death may occur at plasma magnesium concentrations of 15 meq /L (18 mg/ dL).

Dissolved manganese can form blackish particles in water and cause similar colored stains on appliances. High concentrations of dissolved iron in the wellbore can lead to the growth of iron bacteria. These bacteria can coat the inside of the casing or any other submerged part of the plumbing in the well and can cause problems.

The health effects of silver are: digestive disorders, gum line and bluish-gray discoloration of the skin. This dyschromia predominates on the face and uncovered parts, as well as on the nails (Rodier et al., 2016).

Aluminum causes Alzheimer's disease and parkinsonian syndromes as well as slight cerebral atrophy (Botta and Bellon, 2004, Parkinson et al., 1981). Acute aluminum poisoning can cause lip and mouth ulceration (Eastwood et al., 1990).

Health concerns result primarily from the ability of these chemical constituents to cause adverse health effects after prolonged exposure times.

Conclusion:-

Water is an essential resource that must be preserved at all costs. Drinking water presupposes, among other things, water that meets the standards, content of certain metals and some physico-chemical parameters. This study will have made it possible to know the quality of groundwater in the sixth neighborhood of Cotonou in relation to their content of twenty-six metallic elements and a certain number of physico-chemical parameters. To do this, it is necessary to know the quality of the water we consume in the world in general and in Benin in particular in order to consider adequate measures for good management. This water is polluted and not suitable for human consumption.

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