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WELLS AND BOREHOLES PHYSICOCHEMICAL WATER QUALITY EVALUATION IN THE ATAKPAMÉ COMMUNE UNDER AGRICULTURE AND MUNICIPAL WASTEWATER IMPACT

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ABSTRACT

Most of the drinking water supplies of Atakpamé town is assured by wells and boreholes. The quality of this water is threatened by human activities. This study is to evaluate the impact of agricultural techniques and wastewater management on the evolution of the physicochemical quality of well and borehole water, for an understanding of the acquisition of groundwater mineralization in this commune. The water was collected and analyzed and, the results submitted to statistical processing using the software *XLSTAT 2018.6* shows that the most downgrading physicochemical parameters are pH, conductivity and nitrates, compared to World Health Organization (*WHO)* standards. Factor analysis and correlation between the parameters explain the source of nitrate pollution which is linked to the farming and other human activities. The hydro chemical facies represented in the Piper diagram using the diagram software are in majority chlorinated, sodipotassic. Qgis software led to the spatial representation of the nitrate pollution. This pollution is high in Abotèssè, Aféyé-Kpota, Idiotsè and Ikotadi localities. The Hierarchical Ascendant Classification (HAC) of sampled water point gives four important homogeneous subgroups for future sampling selecting a point while representing the subgroup under surveillance.

KEYWORDS: Atakpamé, Anthropogenic, Chemistry, Facies, drinking.

1. INTRODUCTION

The accelerated development of cities in southern countries, including Togo, puts most households in certain neighborhoods outside the distribution of drinking water networks. Thus, accessibility to good quality water is becoming a permanent quest to prevent certain water-related diseases [1] [2] [3]. The observation is that in Atakpamé commune, which is plateau region administrative center of Togo, the autonomous sanitation system is the main process used for partial waste management. Thus, a good part of the grey water and sewage sludge is evacuated in the streets and open spaces. The lack of TdE (Water of Togolese) connections has negative consequences on economy, health and development of the population. The rate of access to public water networks is low due to high investment costs, which calls for the study of water quality in our cities for a proper use[4]. Improving living conditions, health and family well-being are the benefits inherent to the use of drinking water. To this end, the issue of availability of drinking water supply sources remains a major problem for the communes of Togo, particularly for Atakpamé commune, and inevitably involves controlling the quality of water from available sources, which is the subject of this work.

This study is to evaluate the impact of agricultural techniques and wastewater management on the evolution of the physicochemical quality of well and borehole water, for an understanding of the acquisition of groundwater mineralization in this commune.

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2. STUDY AREA, MATERIAL AND METHODS

2.1 Study area

Atakpamé commune is the administrative center of Ogou prefecture and the plateau region. It is located around 164 km north of Lomé, the Togolese capital. The city is built on a site formed by mountainous relief. The study area is 87 km^2.

It is marked by a tropical Guinean climate and includes four (04) seasons: two dry seasons (one long and one short) and two rainy seasons (one long and one short)**[5].** Annual rainfall varies between 995.6 and 1855.1 mm from 2003 to 2017. The average annual temperature is 26.34°C and with climate change, the study area has recorded a slight increase temperature.

Most of the geological layers that can explain Atakpamé massif predate the Cambrian. The massif of mica schist and Atakorian quartzite in the heart of which Atakpamé town is located rises like an island in the middle of gneiss terrains. The Dahomean basement is located east of the Atakpamé massif and is mainly composed of magnetic enclave granite and Granito-Gneiss**[6].** The hydromorphic soils spread in the town along the Eké stream and in the lowlands located east of the town are waterlogged during the rainy season. The alteration of quartzites produces more sand than clay **[7]** and would explain the exposure of the water table to the risk of pollution due to the low porosity of the sand. The vegetation cover has evolved from 24.25% to 30.55% from 1988 to 2015 [8]**.** The population of this city was 69,261 in 2010, the date of the last census[9]. The main economic activities are subsistence farming, market gardening, trade, handicrafts and livestock breeding. Fishing and the marketing of fish products from Nangbeto dam also play an important role in economy of Atakpamé community.

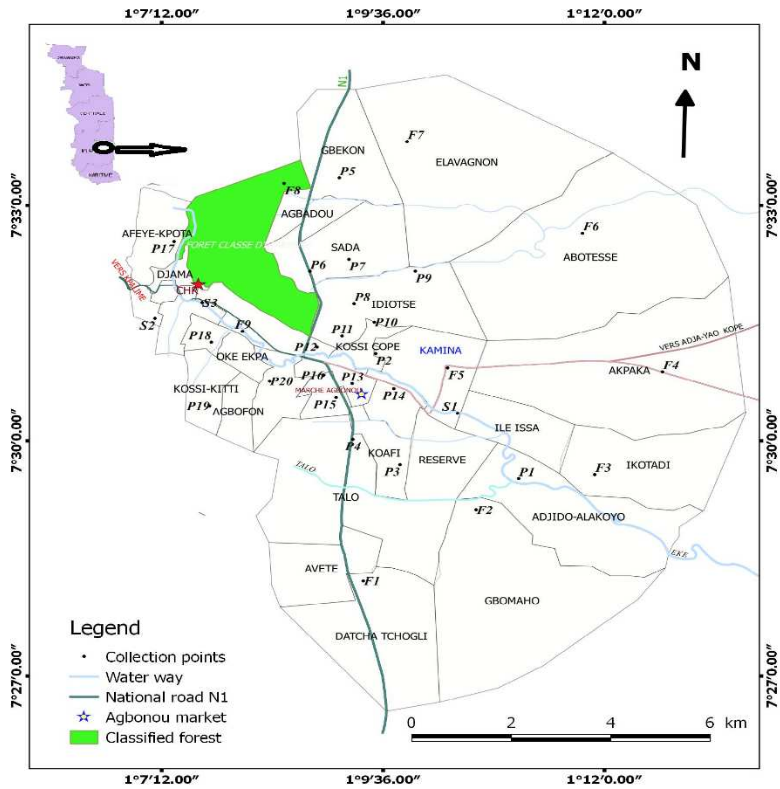

Figure 1: Map of study area

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2.2 Materials

Wells and boreholes were the sources of water collection. A multi-parameter HANNA apparatus, a spectrophotometer..., have allowed to measure the physicochemical parameters (temperature, conductivity, pH and TDS); to make the determinations (volumetric and spectrometric) of laboratory waters; Polyethylene plastic bottles (1.5 l) were used for water sampling; Adapted coolers were used to transport the collected samples to the laboratory immediately after sampling.

This study concerned a network of 32 water points which were identified according to their solicitation and/or their exposure to the probable sources of pollution thanks to data collection (presence of wild dumps, latrines, cesspools, raving animals, possible intrusion of surface water) on the immediate environment of these structures on the one hand and on the other hand the choice is made while considering one or two water point(s) as being representative of neighborhood according to the surface area and the density of the population. Figure 1 shows location of sampling sites. The designation of the sampling points was based on a nomenclature where the wells are represented by letter "p," the boreholes by letter "f" and the springs by letter "s" followed by the serial number assigned to the structure and their geographical coordinates were recorded.

Samples were taken from bottles described above, stored at 4°C in coolers and transported to the laboratory within hours of collection for physicochemical analysis. Bottles were rinsed twice with sample water. Boreholes were pumped to ensure collection of representative samples. Two bottles of each water point were collected; one bottle was filtered (0.45 µm) and acidified with two drops of nitric acid, (HNO_3) for cations determination. Acidification stops most bacterial growth, inhibits oxidation reactions and precipitation of cations.

The physical parameters (temperature, conductivity) were measured directly at each sampling site using HANNA multi-parameter.

Chemical parameters such as pH and TDS were also measured at the sampling site using the same multi-parameter. The other chemical parameters were measured in laboratory using volumetric and spectrophotometric dosage according to AFNOR (1986) protocol as mentioned in table 1. WHO [10], [11] standards were used to compare physicochemical values of the results in order to determine the quality of the studied water.

The statistical analyses of different variables was done using *XLSTAT 2018.6*. The analyses concerned factorial analysis between different physicochemical parameters and the existing correlations between the main components. The qgis and Diagram software were used to make the different distribution maps of each parameter and realization of piper diagram to identify different water families and to know proportion of major ions [12].

Table 1: Materials and methods used for the determination of physicochemical parameters

Parameters	Methods	AFNOR Standard	Methodes precision	Materials
pH	Electrometry	NFT 90-008	± 0,05	HANNA Multiparameter
(CE)	Conductimetry	NFT 90-031	±2%	HANNA Multiparameter
Ca^{2+}	EDTA complexometry	NFT 90-016	±0.5 mg/l	-
Mg^{2+}	EDTA complexometry	NFT 90-016	±0.24mg/l	-
Na^+	Atomic absorption spectrometry	NFT 90-20	± 0.04mg/l	Perkin Elmer model 2380 Spectrophotometer
K^+	Atomic absorption spectrometry	NFT 90-20	±0.02 mg/l	Perkin Elmer model 2380 Spectrophotometer
NH_4^+	Molecular absorption spectrometry	NFT 90-015	±0.3%	*METASH* UV 5200 Spectrophotometer
Fe_T	Molecular absorption spectrometry	NFT 90-017	±0.3%	*METASH* UV 5200 Spectrophotometer
Cl^-	Argentimetry	NFT 90-014	±0.5 mg/l	-
HCO_3^-	Acidimetry	NFT 90-036	±0.25 mg/l	-
SO_4^{2-}	Nephelometry	NFT 90-009	±0.3%	*METASH* UV 5200 Spectrophotometer
NO_3^-	Molecular absorption spectrometry	NFT 90-012	±0.3%	*METASH* UV 5200 Spectrophotometer

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3. RESULTS AND DISCUSSION

The results (Table 2) show that 81.25% of water samples analyzed have an ion balance less than or equal to 5%. Those with an unbalanced ion balance remain within an acceptable limit (between - 10% and + 10%) and are not taken into consideration in the statistical analyses. The temperature values recorded fluctuate between 24°C and 27°C.
Dissolved salt contents are moderately low, expressed through conductivity, they show low charged and conductive water, exceeding the potability standards. Conductivity lower than 200µS/cm characterizes fresh water.

The measured pH values vary between 4.59 and 7.56. A percentage of 46.87% of the water points have a normal pH according to WHO standards($6.5 < pH < 8.5$)[11]. These concentrations are spatially represented in Figure 2.

The hardness of water represents the content of alkaline earthy metal salts in water. Generally, the water of the Atakpamé commune has hardness values that vary between 1.4°f and 35.2°f and these values allow the classification of the water of this commune from soft to hard water. The hardness presents a great variation which would be related to the lithological nature of the aquifer formation and in particular to its magnesium and calcium composition. Figure 3 shows the spatial distribution in hardness of the sampled water.

Calcium and sodium are dominant elements in drinking water. A major component of water hardness, calcium concentrations vary between 0.8 and 89.6 mg/l. Although calcium is the major element in water, unfortunately, Atakpamé's water contains little calcium. Calcium and sodium ions have an average content of 17.97 and 71.40 mg/l respectively. The least represented major cation is potassium with an average content of 4.54 mg/l and is also the only major cation that exceeds the maximum allowable concentration (12mg/l)[11]. Magnesium concentrations in the groundwater of Atakpamé commune vary between 0 and 41.3mg/l. All values obtained meet WHO standard of 50mg /l.

Bicarbonate concentrations range from 6.1 to 75.25 mg/l. The presence of bicarbonates in study area water, would be due to the dissolution of carbonate formations by carbon dioxide laden water. Chloride concentrations do not exceed WHO standards and vary between 10.65 and 191.7 mg/l. The spatial distribution is shown in Figure 4.

The origin of this element would be mainly related to the dissolution of saliferous formations and to the wastewater discharged into the nature. Sulphate concentrations vary between 0 mg/l and 66.44mg/l not exceeding WHO standard (400mg/l). The sulphate concentration is below detection limit for many sampling points. Figure 5 shows the spatial distribution of sulphate levels in the Atakpamé commune.

Nitrogenous minerals were measured for nitrate and ammonium ions. The concentrations of ammonium ions are all inferior to the only detections of method used and are therefore not presented. Nitrate ion concentrations range from 0 to 244.57mg/l and the average content is 49.66mg/l. On the network of the 32 points studied, 12 points have their content higher than the WHO[11] standard (50mg/l), that is, a nitrate pollution rate of 32.5%. The spatial distribution of nitrate is shown in Figure 6 and thus shows the areas most affected by this pollution.

The concentration of total iron varies between 0.01 and 0.31mg/l. Only one (1) point out of the 32 has a concentration higher than the standard set by the WHO (0.3mg/l).

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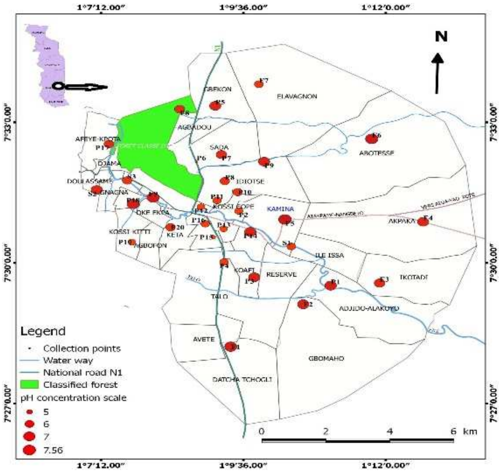

Figure 2.: Spatially representation of pH

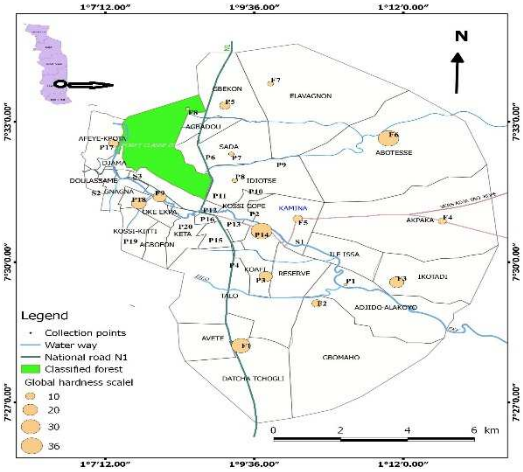

Figure 3.: Spatially representation of hardness

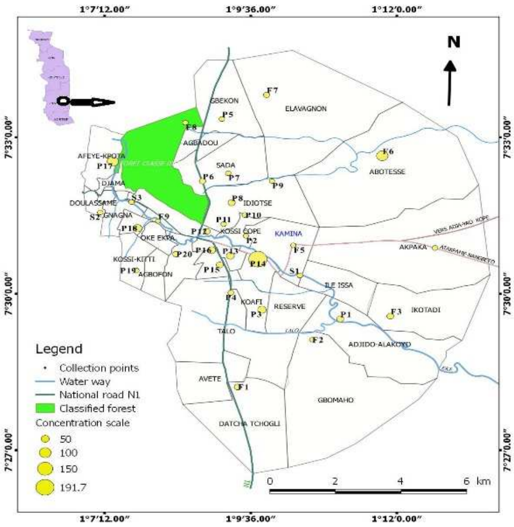

Figure 4.: Spatially representation of chloride

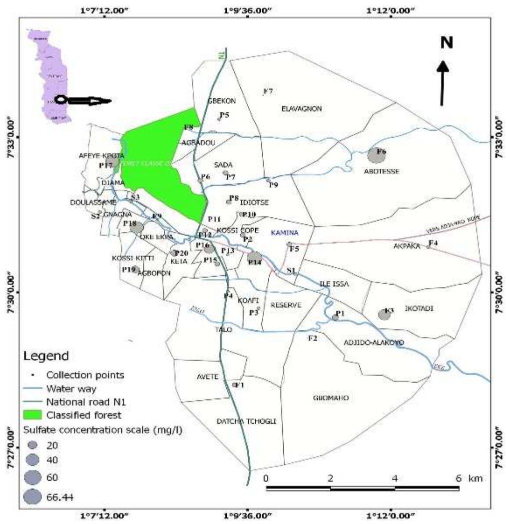

Figure 5.: Spatially representation of sulphate

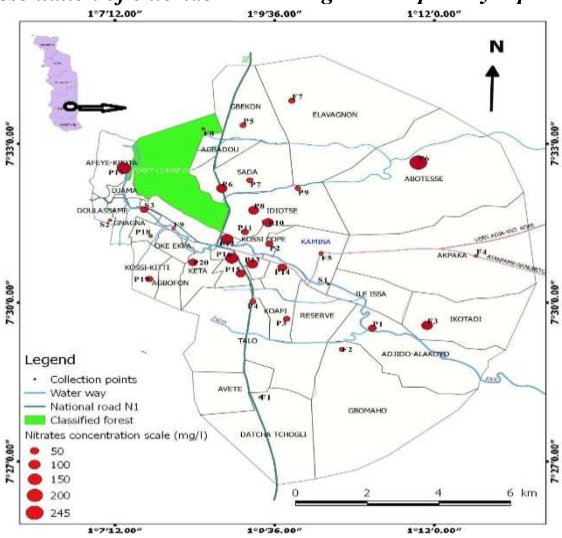

Figure 6.: Spatially representation of nitrate

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Analysis of table (Table 2) summarizing the results shows that parameters such as temperature, pH and total iron have standard deviations of less than 1. Potassium and bicarbonate ions have standard deviations of 2 order, while the other parameters have very high standard deviations. The low standard deviations show the low distribution compared to the mean.

Correlation matrix (Table 3) shows that a significant number of the parameters are well correlated with each other. The highest coefficients relate pH to (TDS ; C.E ; HCO_3^- ; TH ; Ca^{2+} ; Mg^{2+}) ; TDS to (C.E ; HCO_3^-; TH ;Ca^{2+}; Mg^{2+}; SO_4^{2-} Cl^- ; Na^{2+}) ; C.E to (HCO_3^- TH ; Ca^{2+} ; Mg2+ ; SO_4^{2-}; Cl^- ; Na^{2+}) ; HCO_3^- to (TH ;Ca^{2+} ; Mg^{2+}) ; TH to (Ca^{2+} ; Mg^{2+} ; SO_4^{2-}; Cl^-; Na^{2+}) ; Ca^{2+} to (Mg^{2+} ;SO_4^{2-};Cl^-) ; Mg^{2+} to (SO_4^{2-}; Cl^- ; Na^{2+}). In summary, almost all parameters have a strong correlation except for iron, temperature and nitrates which are not correlated with any other parameter.

Table 2: **Descriptive statistics of the physicochemical results of the aquifers of the Atakpamé commune**

Variable	Minimum	Maximum	Average	Standard deviation
Temperature	24.00	27.00	25.90	0.89
pH	4.59	7.56	6.39	0.75
TDS	60.00	762.00	232.12	177.26
C.E	120.00	1524.00	464.25	354.53
HCO_3^-	6.10	75.25	22.43	14.43
TH	1.40	35.20	8.65	9.84
Ca^{2+}	0.80	89.60	17.97	23.11
Mg^{2+}	0.48	41.30	10.27	12.75
Fe_T	0.01	0.31	0.07	0.06
NO_3^-	0.00	244.57	49.66	54.32
SO_4^{2-}	0.12	66.44	14.00	15.93
Cl^-	10.65	191.70	36.60	35.75
Na^+	10.40	136.00	71.40	23.01
K^+	0.300	14.000	4.54	2.47

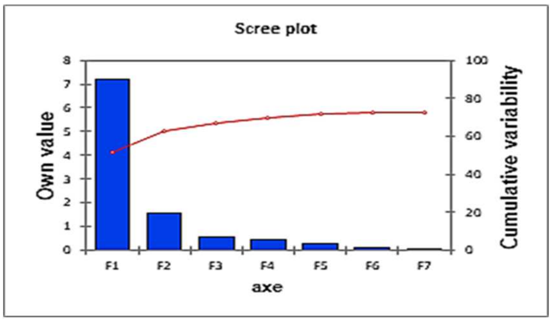
Table 3: Correlation matrix of parameters.

	T°C	pH	TDS	C.E	HCO_3^-	TH	Ca^{2+}	Mg^{2+}	Fe	NO_3^-	SO_4^{2-}	Cl^-	Na^+	K^+
T°C	1													
pH	-0.27	1												
TDS	-0.33	**0.57**	1											
C.E	-0.33	**0.57**	**1.00**	1										
HCO_3^-	-0.39	**0.54**	**0.61**	**0.61**	1									
TH	-0.27	**0.66**	**0.95**	**0.95**	**0.69**	1								
Ca^{2+}	-0.25	**0.58**	**0.87**	**0.87**	**0.60**	**0.91**	1							
Mg^{2+}	-0.24	**0.61**	**0.84**	**0.84**	**0.64**	**0.88**	**0.62**	1						
Fe_T	-0.02	-0.07	-0.29	-0.29	-0.30	-0.29	-0.23	-0.31	1					
NO_3^-	-0.08	-0.18	0.35	0.35	-0.21	0.21	0.29	0.06	-0.18	1				
SO_4^{2-}	-0.27	0.20	**0.70**	**0.70**	0.06	**0.61**	**0.60**	**0.50**	-0.18	**0.69**	1			
Cl^-	-0.16	0.17	**0.78**	**0.78**	0.18	**0.65**	**0.57**	**0.59**	-0.19	0.48	**0.76**	1		
Na^+	0.02	0.37	**0.68**	**0.68**	0.33	**0.59**	0.49	**0.59**	-0.36	0.15	0.41	**0.65**	1	
K^+	-0.31	0.31	0.40	0.40	0.19	0.36	0.19	0.48	-0.30	0.14	**0.52**	0.33	0.49	1

Principal Component Analysis (PCA) and varimax rotation analysis[13],[14], [15], [16], [17] carried out on the general table of "complete" analyses carried out on all the measuring points of the network (boreholes, wells and springs) allowed the identification of 2 main independent factors that influence the chemistry of the water of the commune, as well as the eigenvalues of the factors. The results are presented in Tables 4 and 5; Figures 7 and 8.

Table 4: Eigenvalues of factors.

	F1	F2	F3	F4	F5	F6	F7
Eigenvalue	7.880	1.928	1.165	0.923	0.667	0.480	0.389
Variability (%)	56.287	13.775	8.322	6.594	4.763	3.432	2.777
Cum	56.287	70.062	78.384	84.978	89.741	93.173	95.950



Figures 7: Variability of factors

Table 5: Factor coordinates for factors one and two.

	F1	F2
pH	**0.584**	-0.419
TDS	**0.994**	0.036
C.E	**0.994**	0.036
HCO_3^-	**0.631**	-0.611
TH	**0.981**	-0.142
Ca^{2+}	**0.850**	-0.043
Mg^{2+}	**0.868**	-0.195
Fe_T	**-0.301**	0.013
SO_4^{2-}	**0.776**	0.532
Cl^-	**0.727**	0.423
Na^+	**0.792**	-0.119
K^+	**0.691**	0.167
NO_3^-	0.310	**0.698**

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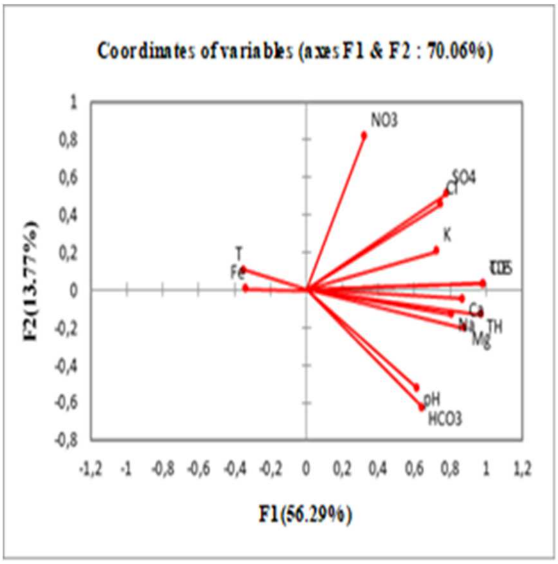
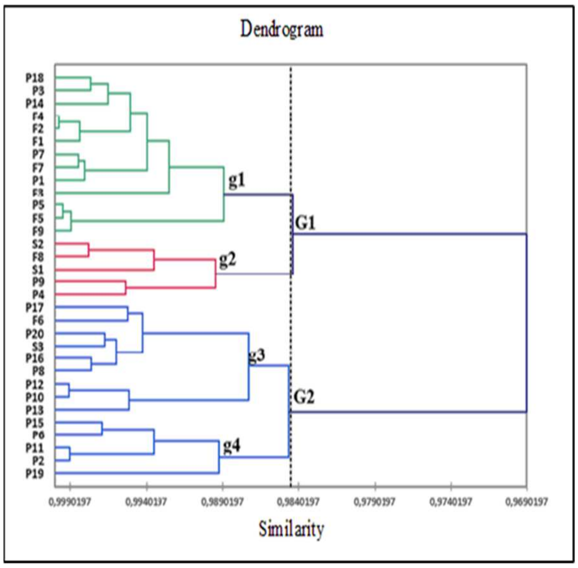
This study allowed the Hierarchical Ascending Classification (HAC) of the sampled an analyzed water point (Figures 9). In general, there are two groups that emerge (G1 and G2) and several subgroups with subgroups g1, g2, g3 and g4 directly following the two groups.



Figures 8: Space of the variables of the factorial plane F1×F2



Figures 9: Hierarchical Ascendant Classification

Analysis of the information collected around the sampling points shows that 53.12% of the network of 32 points have environments that are cultivated by the local populations. In addition to agriculture, raving animals are present around 59.37% of the sampling points; wastewater and household waste are present around 28.12% of the sampling points. The observation is that the wastewater discarded infiltrates into the soil and contributes to groundwater recharge as it is recharged from precipitation [18] which leaches from the soil surface, hence the likelihood of pollution. For this reason, the safety distance between water points and latrines/sump; 18, 75% of the points are at risk.

The study area is sparsely occupied by the population which is dense in places and especially in the valleys of the hills and in the villages surrounding city center. The rest of the surface which constitutes about 60% of the total area is exploited at 90% in agriculture by the population. It should be noted that the population uses the autonomous system for the management of wastewater and chemical fertilizers in agriculture and market gardening in times of drought along the Eké stream. Figures 10 shows the distribution of study area.

The Piper diagram (Figures 11) allows easy comparison of water samples. Piper diagram highlights the facies of the three main categories of water in the study: well water, spring water and borehole water. Spring water is sodium chloride, while borehole water has sodipotassium chloride facies. Well water has calcium and magnesium sulphate chloride facies. For the whole network of water points, 3 families can be identified: a sodipotassium chloride family for 78.125%, a sulphated calcium and magnesium chloride family for 18.75% of the samples. In addition to these two large families, we note the presence of a calcium and magnesian bicarbonate family.

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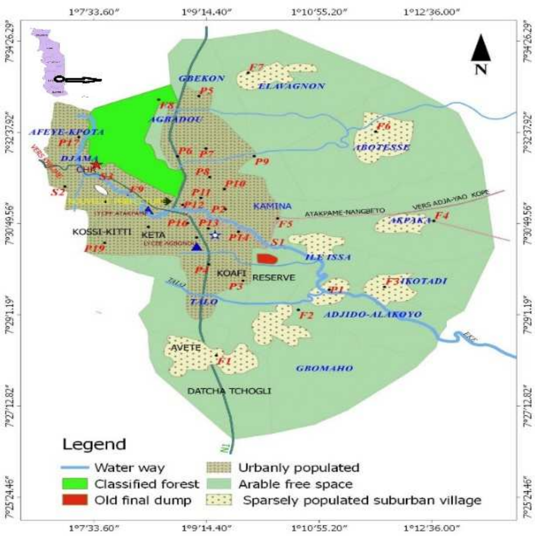
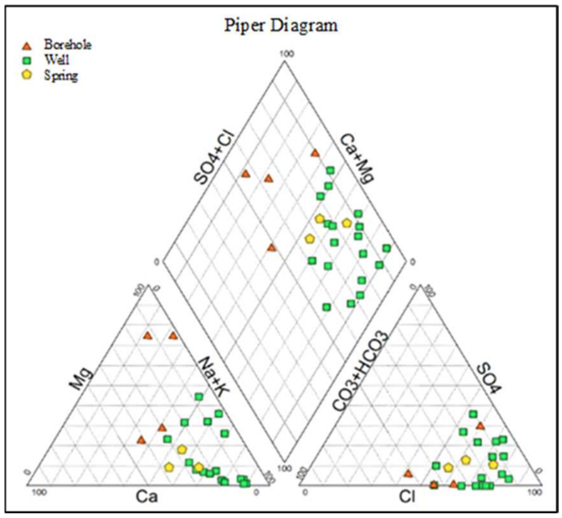


Figure 10: Representative land use map in the Atakpamé commune



Figures 11: Piper diagram

Control and preservation of water quality, resources that are under threat from anthropogenic activities is priority for many researchers around the world[12], [18], [19], [20], [21]. The temperature values recorded for water show slight fluctuations observed from one source to another due to: exposure, sampling time, depth of water table. Parameters such as pH, total iron have standard deviations of less than 1; which explains their low distribution around their mean and indicates the homogeneous character of Atakpamé's water in relation to these parameters. The other parameters analyzed have high standard deviations, which reflects their high variability around their mean. Usually these are the soluble elements (HCO_3^-;Ca^{2+} ; Mg^{2+}; SO_4^{2-};Cl^-; Na^{2+}…) and some physical parameters, whose concentration cannot be affected by processes of precipitation, dissolution, or ion exchange, which show high correlations[23], [24]**.** These correlations show that variations in dissolved ionic charges are entirely or partly related to variations in the contents of these different ions. This also indicates that the different parameters tend to evolve concomitantly either by concentration under the effect of evaporation or by contributions of ions from common sources for example. Nitrates show a very weak correlation with all the other parameters except for sulphates, which would perhaps explain the divergence of their sources.

The probable sources of pollution identified by the study are wastewater and lack of control of agricultural techniques[25], [26]. Bibliographical synthesis carried out for the studies conducted in cities of some African countries came to conclusion that wells of these cities are the most confronted with pollution of anthropic origin[26]**.**

Data processing by factor analysis[27] showed that factor one alone explains more than 50% of chemical composition source. However, the cumulative percentage is slowly tending towards 100%, which reflects the complexity of influences on water chemistry. We have also selected third factor which represents 8.32% of total inertia. All factors are shown in Figure 7 and the eigenvalues of each factor are summarized in Table 4, thus indicating the importance of certain factors in further interpretations. Factor analysis limited to, factor two (Table 5) show that factor one (F1) is correlated with all parameters, except nitrates, correlated by factor two (F2). According to these analyses, nitrates source is anthropogenic and is believed to be related to agricultural activities and wastewater. The distribution of variables in Plan I-II after varimax transformation allows us to attribute significance to the first factor (Figure 8). It groups together in its right part all the chemical elements constituting the mineralization of water. It should be noted, however, that elements of pollution (pH; E.C.) contribute as significantly to the pole of mineralization as K, TH and Na parameters, characteristic of sodipotassic and magnesian calcium chloride facies of aquifer system water.

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The HAC initially considers all observations as clusters containing only one observation[17]. The most "resembling" observations are grouped into homogeneous clusters, which will gather more or less quickly depending on their similarities[28], [29]. The interest of this classification is the grouping into homogeneous groups of water points studied in order to facilitate sampling campaigns for monitoring of these waters, by taking a representative point for the whole group or the subgroup considered. Analysis of figure 1 in relation to the distribution of water points shows that all the water points of a sub-group are not in a homogeneous zone but rather randomly distributed over the entire area of the study zone, which indicates the complexity and heterogeneity of the aquifer system of Atakpamé commune.

Acidic pH of water in the environment is believed to result from the presence of dissolved carbon dioxide (free CO_2) in pockets of rock formation[30], [31]. In addition, the pH decrease (acidification) would also result from low total mineralization (conductivities) and to inputs of NO_3^-, Fe_T (total iron), followed by HCO_3^- concentrations decrease. Rate of water points meeting WHO standards (6.5-8.5)[11] for drinking water is 46.87%. The studies conducted on center of Mono watershed o which Atakpamé commune belongs also gave the same results[18].

Piper diagram analysis shows that low dispersion of points, particularly at cation triangle indicates that few mineralization processes interact within aquifers and surface waters

The consumption of nitrogen-laden water can lead to a methemoglobinemia syndrome in young children (blue baby syndrome)[7] and increases the risk of certain cancers [32], [33]. Nitrate levels measured in water are very high, with an average of 49.66 mg. L^{-1}, which is almost equal to WHO standard (50mg/l) for water, for human consumption; that is a nitrate pollution rate of 32.5% compared to sampled points. Work carried out in Agoê-zongo (Lomé) using the same methods showed nitrate pollution of well and boreholes up to 9 times WHO standard, acid pH and electrical conductivity higher than recommended standards, which confirms weight of anthropogenic activities on the quality of water in our cities [4]. The sandy-clay nature of soils and the significant fracturing of area contribute to aggravation of nitrate pollution [30]. Nitrate pollution of groundwater studied would be due to massive use of nitrogenous fertilizers, the zone being highly agricultural and to black water. Numerous studies carried out throughout the country show nitrate pollution[34], [4].

One of the most promising aspects of geographic information systems (GIS) is their ability to contribute to decision support [35], [36]. Changes in land use and occupation, because of the impact they can generate on environment, should no longer be considered in the short term. Thus, man can act on the environment without the repercussions of his actions being immediately perceptible [37], [38]. The analysis of land use (figure 10) actually shows the weight of increasing population density and land use for anthropogenic activities through the pollution zones related to the exploited areas.

4. CONCLUSION

This study made it possible to present and analyze a few sources of drinking water supply in districts and villages of Atakpamé commune served with drinking water from TdE. As a whole, the study determined the most downgrading parameters of Atakpamé commune's water. The most vulnerable zones are targeted. The objectives as defined at the beginning of the work have been reached but the main work remaining is monitoring and sensitization.

Nitrates are the most downgrading parameter and are of the anthropogenic origin. The low pH is due to the acid hydrolysis of rocks. Globally, well water in Atakpamé commune has poor quality which implies the need to improve the rate of TdE service in the concerned localities. During the sampling following the questionnaires, it appears that some owners are aware of the phenomenon and ensure good maintenance of structures to preserve the quality of water. On other hand, the majority do not care much about it. However, simple technical solutions exist to effectively improve the quality of well water. They are: Protect runoff water by diking; Hermetically cover the shafts with a concrete slab and slope; Maintain the sump in a good state of cleanliness; Move wells away from the main sources of pollution (animals, waste, latrines, cesspools, etc...). These are inexpensive ways to protect the quality of drinking water. Raising public awareness for behavioral change could contribute to this.

In perspective, bacteriological analyses and the analyses of heavy metal and isotopic elements need to be performed to confirm these sources of pollution.

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