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Physico-Chemical Characterization of Surface Waters, Traditional Wells and Cisterns Waters Consumed in the Town Halls of Agbangnizoun and Za-kpota In South Bénin

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ABSTRACT

The majority of households in the town halls of Agbangnizoun and Za-Kpota do not have access to drinking water due to the non-existence of drinking water supply. Consequently, the communities of these two town halls use surface waters, traditional wells and cisterns to satisfy their daily needs without any prior treatment. This work was undertaken to assess the physico-chemical quality of these waters. Thus, over two successive years, twelve (12) rivers, eighteen (18) wells, twenty (20) cisterns and two (02) boreholes (witness samples) were sampled in the Districts of the two town halls. The physical parameters such as the pH, the temperature, the turbidity, the rate of dissolved solids (TDS) and the conductivity were measured in situ with a mobile multi-parameter device of the brand HANNA HI 9829 while the colour, the suspended matters (SM), the ammonium, nitrate, nitrite, phosphate and sulphate ions are measured in the laboratory by colourimetric method. The data collected were recorded in Excel and then treated with software R. The Student-Newman Keuls test with the significance level of 5% shows that surface waters are more polluted whereas well waters are highly mineralized. The waters consumed by the populations of Agbangnizoun and Za-kpota town halls do not respect drinking water standards.

Introduction

Among the nine (09) town halls in the Zou department, the town halls of Agbangnizoun and Za-kpota both have a low rate of drinking water coverage. In fact, 25.2% of households have access to drinking water in the town hall of Agbangnizoun and 21.5% of households have access to it in the town hall of Za-kpota (INSAE, 2016) for an average coverage of 53.4% in Zou department. The majority of households therefore use rainwater collected in cisterns, wells and surface waters to satisfy their daily needs, without any prior treatment. Surface waters and traditional wells are, for the most part, unfit for consumption because of their high levels of contamination from various origins and may contain pollutants that are toxic to human beings (WHO, 2003, Babadjidé, 2011). In these two town halls, agriculture has an important place with the use of pesticides and chemical fertilizers. The consumed waters are therefore confronted with the contamination from agricultural origins because the contamination of surface or ground waters by toxicants is closely linked to that of the soil. The problem of household waste management is particularly acute in the two town halls where 94.8% of Agbangnizoun households and 91.6% of Za-Kpota households throw garbage at random (INSAE, 2016). The current study aims at evaluating the physical quality and the level of contamination of inorganic elements (nitrogen, sulphate, phosphate) of surface waters, wells and cisterns consumed by the populations of the concerned areas.

1. Materials and Methods

1.1. Study framework

The study framework, concerns the Agbangnizoun and Za-kpota town halls located in South Benin (Figure 1), in the Zou department in a plateau area of 200 to 300 m altitude. There is a climate of transition between the subequatorial climate and the humid tropical climate of the Sudano-Guinean of North Benin with two rainy seasons and two dry seasons. The rainy seasons are from March to July for the high season, August to October for the short season while the two dry seasons are from December to March for the high season and from July to August for the short season. The average annual rainfall varies between 900 and 1200 mm of water.

Agbangnizoun town hall has 72.55 inhabitants, of which 34.78 are males and 37.77 are females in 16.76 households. It has ten (10) districts and fifty - one (51) villages. As for the town hall of Za-kpota, it has 132.82 inhabitants, of which 61.95 are males and 70.87 are females in 29.24 households. It is made up of 56 villages divided into eight (8) districts (INSAE, RGPH4, 2013).

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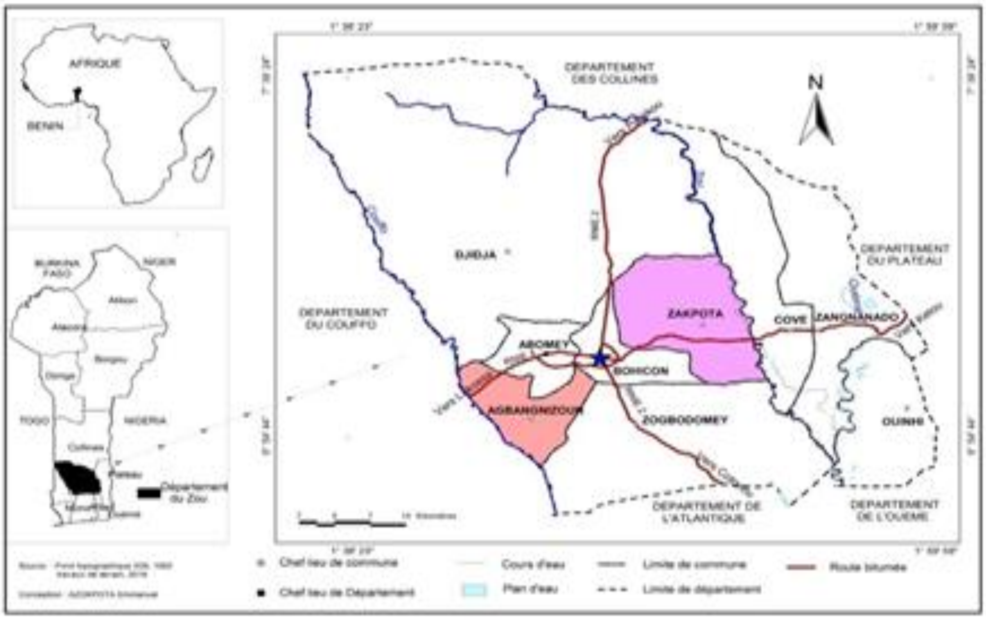

Figure 1. The map of Zou department showing the location of the study area

1.2. Water sampling

The choice of water sampling sites was made in taking into account the villages where surface, well and cistern waters (Figure 2) are used as drinking waters. This water was therefore taken from the districts where there was no public drinking water available. Overall, fifty-two (52) samples were taken from twelve (12) surface waters, eighteen (18) well waters, twenty (20) cistern waters and two (02) drilling waters which have served as a witness. Sampling sites are chosen at random from the villages, taking into account the criteria for the use of water by the populations for their different needs.

Regarding the samples, we have used plastic bottles. These bottles are washed with acidulated water and rinsed several times with distilled water. They are then sterilized in an autoclave. In these sites, the plastic bottles are rinsed three times with the water to be sampled and then filled with this water. Once filled, they are cleaned, wrapped in aluminum foil to prevent the penetration of light which could modify certain parameters. They are labeled and put in a cool place (at 4 °C) in coolers containing the cold accumulators then transported to the laboratory for analyses.

Photo 1 :Surface **Photo 2** : Traditional well **Photo 3** : Cistern

Figure 2. Different sources of drinking water supply in the study area.

1.3. Methods

Temperature, hydrogen potential (pH), electrical conductivity, turbidity, Total Dissolves Solids (TDS) were measured in the sites because of their variation which could occur during transport. These measurements were carried out using a mobile multi-parameter device of the HANNA HI 9829 brand. The suspended matters (SM) were determined by filtration (NFT 90-105-1 replaced by EN 872) with filter papers Whatman porosity 0.7 µm. The colour was measured by the photometric method using the HACH DR 3900 brand molecular absorption spectrophotometer calibrated to read directly in Platinum-Cobalt (PtCo). The inorganic pollution indicator parameters (nitrogen, phosphate, sulphate) were determined by colourimetry using the same spectrophotometer and the filtrated water samples.

1.4. Statistical treatment of analysis results

The software R was used for the statistical processing of the data. When the influence is significant from the analysis of variance, the separation of averages was done with the Student-Newman Keuls test. The relationship between different water parameters was assessed with Person's correlation test. The one-sample t-test was used to assess the water quality of each water source. The references used are the Beninese standards and those of the World Health Organization for drinking water. For all statistical analyses, the significance level used is 5%.

2. Results and discussion

2.1. Evolution of physical parameters

The results of the analyses of the physical parameters are presented in Table 1.

Table 1. Variation of physical parameters depending on the water sources

Parameters	*Water sources*			
	Cisterns	*Wells*	*Surface waters*	*Drilling waters (control sample)*
pH (Unity pH)	8.81 ± 0.17^{a}	7.56 ± 0.15^{c}	7.94 ± 0.18^{b}	7.01 ± 0.01^{c}
Température (°C)	26.93 ± 0.20^{c}	29.32 ± 0.18^{a}	27.20 ± 0.37^{c}	28.07 ± 0.40^{b}
Color (PtCo)	5.35 ± 1.08^{b}	3.61 ± 1.37^{b}	128.67 ± 10.18^{a}	3.00 ± 0.40^{b}
Turbidity (mg/L)	1.35 ± 0.13^{b}	3.43 ± 1.37^{b}	76.16 ± 31.68^{a}	0.68 ± 0.01^{c}
electric Conductivity (µS/Cm)	62.55 ± 2.72^{c}	125.67 ± 7.78^{a}	105.04 ± 3.90^{b}	92.71 ± 1.11^{b}
TDS (mg/L)	36.15 ± 2.85^{b}	69.40 ± 3.95^{a}	62.48 ± 2.19^{a}	45.13 ± 2.90^{b}
SM (mg/L)	2.58 ± 0.34^{b}	3.77 ± 0.87^{b}	96.82 ± 6.20^{a}	1 ± 0^{b}

Hydrogen potential (pH) variations

On the one hand, the results show that there is no significant difference between the pH values of the well waters (7.56 ± 0.15) and those of the drilling waters (7.01 ± 0.01) which has served as a witness. On the other hand, the pH values of the drilling water (witness) are significantly different from those of surface waters (7.94 ± 0.18) and tank (cistern) waters (8.81 to ± 0.17). This can be explained by the fact that the characteristics of the pH are linked to the geological nature of the aquifers and to the soils crossed (Boubakar, 2010). Rainwaters are naturally acidic but the basic nature of rainwater stored in the cisterns would be due to the long storage period since these waters are used during the lean period in the dry season. The acceptable pH interval varying from 6.5 to 8.5 for drinking water (WHO standards, 2006 and Beninese standards, 2001), the comparison of the values obtained in the different water sources, shows that well and surface waters have a basic pH within the defined range. In addition, the pH of the water in the cisterns (8.81) is higher than the standards and is more alkaline. This pH value obtained in cistern water is in the range of 7.6-8.83 and 7.46-10.9 values obtained respectively by Gnazou and *al.*, 2015 and Dovonou and *al.*, 2020 in cistern waters in Morocco and Benin. As for surface waters, the value obtained is in the range of values obtained by Maoudombaye and *al.*, 2015 in Tchad, Abboudi and *al.*, 2012 in Morocco and Lamizana and *al.*, 2008 in Boukina-Fasso. Concerning the well waters, the value obtained is in the range of 6.5-8.3 values obtained by Bouchemal and *al.*, 2015 in Briska, but different from those obtained by Maoudombaye and *al.*, 2015 in Tchad (5.47 ± 0.54), Chaïeb and *al.*, 2015 in Morocco (6.32-7.5) and Ngakomo and *al.*, 2020 in Cameroon (5.3-6.3).

Temperature variations

The temperature of well waters (29.32 °C ± 0.18) differs significantly from that of cistern waters (26.93 °C ± 0.20 °C) and surface waters (27.20 °C ± 0.37 °C). It has been higher in well waters than in tank and surface waters. Although the WHO does not set a guideline value, temperature particularly influences physicochemical and microbiological parameters. For example, temperature can have an impact on the presence of inorganic compounds and chemical pollutants, thus modifying the water taste. The values measured in the water from the sampled sources in the study area are high and determined by the average ambient temperature. The high temperatures could be explained by the influence of ambient heat on the sampled water and also by the geothermal gradient of the study area (Degbey and *al.*, 2010).

Changes in electrical conductivity and TDS

Analysis of variance results have showed that electrical conductivity has significantly varied ($p < 0.05$) depending on the water source. Indeed, the value of the electrical conductivity of well waters (125.67 ± 7.78) differs significantly from the values of surface waters (105.04 ± 3.90) and cistern water (62.55 ± 2.97). In contrast, no significant difference was recorded between the conductivity values of surface waters and those of drilling waters (witness). Electrical conductivity is significantly higher in well waters and lower in cistern waters. The TDS in the collected waters follows the same trend as the electrical conductivity. The results of the variance analysis of this parameter show that there is no significant difference between surface waters (62.48 ± 2.19) and well waters (69.40 ± 3.95) whereas the TDS values of these waters (surface water and well water) differ significantly from those of cistern water (36.15b ± 4.25) and borehole water (45.13 ± 2.90). However, no significant difference was observed between tank and borehole waters. The values of the electrical conductivity admitted by the WHO (2006) and Benin are respectively 2000 µS/Cm and 200 to 400 µS/Cm. And the electrical conductivity of the different sources of water measured is significantly low ($p < 0.0001$) compared to these standard values. Relatively to this parameter, the standards established for drinking water are therefore respected. The conductivity value obtained in well waters is in the range of values 93 µS/Cm - 540 µS/Cm and 11.60 µS/Cm-280 µS/Cm obtained respectively by Dovonou and *al.*, 2011 and Gbamele and *al.*, 2020 in Benin and Côte-d'Ivoire, but different from that obtained (16.33 µS/Cm – 47.17 µS/Cm) by Ngouala and *al.*, 2020 in Congo. As for the surface waters, the value obtained is lower than those obtained by Abboudi and *al.*, 2014, Lakhili and *al.*, 2015 and Ayad and *al.*, 2017 respectively in Morocco and Algeria. The mineralization of rainwater stored in the cisterns is lower than those obtained by Hebabaze and *al.*, 2015 in Morocco, Gnazou and *al.* 2015 in Morocco and Dovonou and *al.*, 2020 in Benin.

Evolution of turbidity values

The results of the analysis of variance have showed that the turbidity values of tank waters (1.35 ± 0.13) and well waters (3.43 ± 1.37) are not significantly different. On the other hand, surface waters showed values (76.16 ± 31, 68) significantly different from those of cistern and well waters. Compared to cistern and well waters, surface waters are therefore more turbid. The turbidity values compared to the standards (5 NTU) show that the tank waters have significantly low values. Likewise, there is no significant difference ($p = 0.2875$) between the turbidity of the well water and that recommended. Furthermore, surface water is significantly more turbid, that is to say 76.16 NTU against 5 NTU recommended by the WHO and Beninese standards. In relation to this parameter, surface water is therefore not suitable for human consumption. The results of our work confirm the high turbidity of surface water reported by Wanga and *al.*, 2015 in the Democratic Republic of Congo.

Evolution of suspended matters concentrations (SM)

As far as the suspended matters are concerned, the results obtained are similar to those for turbidity. The average value of suspended matters obtained in surface water is 96.82 mg/L and significantly higher than the values obtained in other water sources (cisterns and wells). As opposed to surface water, well water (3.77) and cistern water (2.58 mg/L) contain less suspended matters.

The suspended matters in the water from cisterns and wells are significantly ($p < 0.05$) lower compared to the WHO standards (<30 mg/L). On the other hand, those obtained in surface water are significantly ($p < 0.05$) higher than the WHO standards.

In relation to this parameter, surface water is therefore not suitable for human consumption. The abundant presence of SM in the analysed surface waters could be explained by the exposure of these waters to all kinds of pollution.

Evolution of water colour

The results of the analysis of variance showed that the colour of the water is a discriminatory factor among the different water sources. On average, cisterns and wells waters have a low colour value, respectively 5.35 PtCo and 3.61 PtCo, while surface water has a strong colouration (128.67 PtCo). The colour values of well and cistern waters are significantly low compared to the Benin standard value (15 PtCo) while surface water has a colour significantly exceeding this standard. Surface water is unsuitable for human consumption with regard to the values of this parameter. This strong colour intensity of surface water is thought to be due to the presence of increasing levels of suspended matters from human activities. The colour value of surface water is in the range 27.66-153 Pt Co obtained by Wanga and *al.*, 2014 in the Democratic Republic of the Congo.

2.2. Evolution of inorganic pollution indicators' parameters

The results of the analyses of the inorganic pollution indicators carried out are presented in Table 2.

Variations in ammonium ion concentrations

The average values of ammonium ions for well (0.06 ± 0.01) and cistern waters (0.063 ± 0.014) differ significantly from that of surface waters (0.31 ± 0.05) mg/L. No significant difference was noted between cistern and well waters. These values are significantly lower ($p < 0.05$) than the standards set by the WHO (0.5 mg/L). There is also a significantly lower difference between the water from cisterns and wells and the standards set by Benin (0.1 mg/L). On the other hand, surface water in ammonium ions has a significantly higher concentration ($p = 0.0077$) than in Benin (0.1 mg/L). The value of ammonium obtained in the wells is lower than that obtained by Maoudombaye and *al.*, 2015 in Tchad, Lagnika and *al.*, 2015 and Makoutode and *al.*, 2006 in Bénin.

Variations in nitrate ion concentrations

The average value of nitrate ions for well water (44.70 ± 4.81) mg/L differs significantly from those of cistern water (4.04 ± 0.86) and surface water (5.98 ± 1.70) mg/L. There is no a significant difference observed between tank water and surface one. Only well water presented the highest levels (44.70 mg/L). The value of 50 mg/L being indicated by the WHO and Benin for drinking water, only well water has a nitrate ion concentration approximatively equal to the WHO and Benin standards. The water sampled therefore does not show any drinking water problem with regard to nitrate ions. The presence of nitrates in well water could be due to the chlorination of nitrites which oxidizes them rapidly (Health and Welfare Canada, 1982). The nitrate value obtained in surface water is in the value range 4.11 - 19.73 mg/L obtained by Abboudi and *al.*, 2014 in Morocco. For well water, the value is in the value range 4.3-127 mg/L obtained by Lagnika and *al.*, 2014 in Benin. On the other hand, this value is below of that obtained by Maoudombaye and *al.*, 2015 in Tchad.

Variations in nitrite ion concentrations

The results of the analysis of variance performed on nitrite ions have showed that they vary significantly ($p < 0.05$) from one water source to another. In fact, the surface waters exhibited a significantly high nitrite level (0.15 mg/L). On the other hand, the lowest nitrite concentrations were observed in cistern water. The nitrite ion concentrations measured in the cisterns (0.022 mg/L) and wells waters (0.035 mg/L) are significantly lower ($p < 0.05$) than the standards set by WHO (0.1 mg/L) and Benin (3.2 mg/L). On the other hand, there is no significant difference ($p > 0.05$) between the nitrite ion concentration in surface water and the standard regulated by the WHO. The value of nitrite ions observed in the well water sampled is much lower than the average value of 0.86 ± 0.50 mg/L obtained by Maoudombaye and *al.*, 2015 testifying to pollution by nitrites of well water examined in Tchad.

With regard to surface water, the value obtained is within the range of values obtained by Abboudi and *al.*, 2014 in the surface water of Oued Guigou in Morocco where the nitrite concentrations are very low and do not exceed the WHO standard.

Variations in sulphate and orthophosphate ions concentrations

The analysis of variance has carried out for this parameter that the different concentrations obtained did not vary significantly, regardless the water source (Table 2). Nevertheless, the orthophosphate concentrations in the well water (1.48 mg/L) are the highest compared to the concentrations obtained in the standpipe water (0.18 mg/L) which served as a witness. From the comparison of Benin and WHO standards with the obtained concentrations, it should be concluded that orthophosphate is at significantly lower concentrations ($p < 0.0001$) than the standards in the different water sources.

The results obtained from the determination of sulphate and orthophosphate ions in the water samples reveal that all the water analysed (cistern, wells and surface water) have sulphate and phosphate concentrations which are well below the admissible standard of WHO (400 mg/L for sulphate and 5 mg/L for phosphate). The results of our work confirm those of Abboudi and *al.* (2014) who obtained sulphate ion concentration between 14.03 and 237.74 mg/L (below the standard) in the surface waters of Oued Guigou in Morocco. They are also consistent with those of Lagnika and *al.* (2014) who obtained sulphate values varying from 0.50 to 26 mg/L and phosphate values varying from 0.22 to 2.84 mg/L in well water in Pobè (Benin).

2.3. Spatial evolution of water pollution parameters' indicators

The study of water quality according to the town halls where waters where sampled, reveals significant differences in conductivity, TDS and the rate of suspended matters (figure3).

The analysis of the physical parameters' variance according to the two town halls

Figures 3A, B, C, D and E show the results of the analysis of the physical parameters' variance measured on the water samples according to the town halls sampled. Among the physical parameters of water, the conductivity of the water, the TDS and the rate of suspended matters vary significantly between the two concerned town halls during the present study. On average, the water samples collected in the Za-kpota town hall have a higher conductivity and TDS (169.44 µS/Cm and 100.35 mg/L respectively) (Figure 3A and B) while the sampled water in the Agbangnizoun town hall is more turbid (Turbidity = 19.37 NTU) and contains a greater amount of suspended matters (SM = 33.56 mg/L) (Figure 3C and D).

Table 2. Variation of inorganic pollution indicators according to water sources

Parameters	Water sources			
	Cisterns	Well	Surface water	Drilling water
Ammonium (mg/L)	0.063 ± 0.014^{b}	0.06 ± 0.01^{b}	0.31± 0.05^{a}	0
Nitrate (mg/L)	4.04 ± 0.86^{c}	44.70 ± 4.81^{a}	5.98 ± 1.70^{c}	8.69± 0.10^{a}
Nitrite (mg/L)	0.022 ± 0.01^{b}	0.035 ± 0.01^{b}	0.15± 0.04^{a}	0.016 ± 0.0004^{b}
Sulphate (mg/L)	14.39 ± 2.47^{a}	14.28 ± 0.72^{a}	19.44 ± 1.35^{a}	15.64 ± 2.45^{a}
Ortho-phosphate (mg/L)	0.39 ± 0.14^{a}	1.48 ± 0.97^{a}	0.73 ± 0.40^{a}	0.18 ± 0.004^{a}

NB. On each row, the average values with different letters are significantly different at the 5% threshold

Analysis of chemical parameters' variance according to the study town halls

Regarding the chemical parameters, it was also found a significant difference between the two town halls for some water chemical parameters. The samples collected in Agbangnizoun have a higher average nitrite concentration (0.06 mg/L) (Figure 4A) whereas, in the Za-kpota municipality, the water has a higher average nitrate concentration (14, 22 mg/L) and orthophosphates one (1.05 mg/L) (Figure 4B and C).

Analysis of the chemical parameters' variance water according to the localities

Figures 4A, B, C, D and E show the results of the analysis of the chemical parameters' variance measured on the water samples according to the localities (villages) sampled. These results reveal that conductivity, TDS, turbidity, rate of suspended matters and colour have significantly varied between the localities sampled during the said study. On average, water conductivity and TDS are higher in water samples collected at Assalin (311.02 µS/Cm) and Kpakpamè (299.85 µS/Cm). The turbidity and suspended matters rate in the water are higher in Couffonou (203.00 mg/L and 277.00 mg/L respectively). The average water colour value is higher in Adjaha and Togadji.

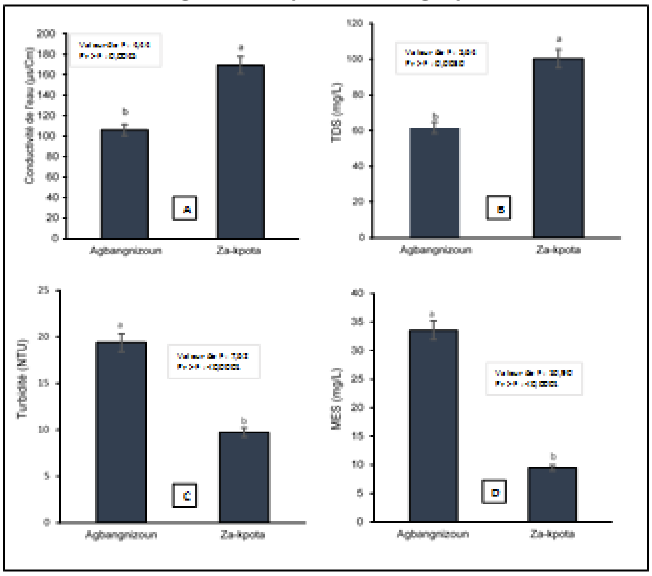

Figure 3. Changes of physical parameters in the Za-kpota and Agbangnizoun town halls

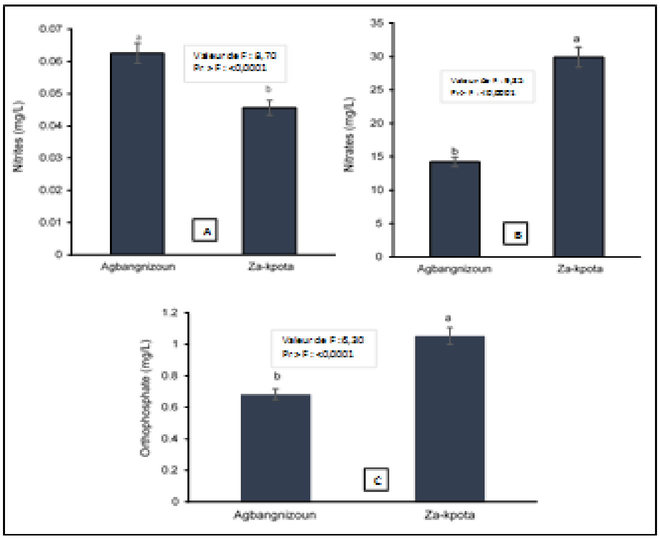

Figure 4 . Changes of chemical parameters in the Za-kpota and Agbangnizoun town halls

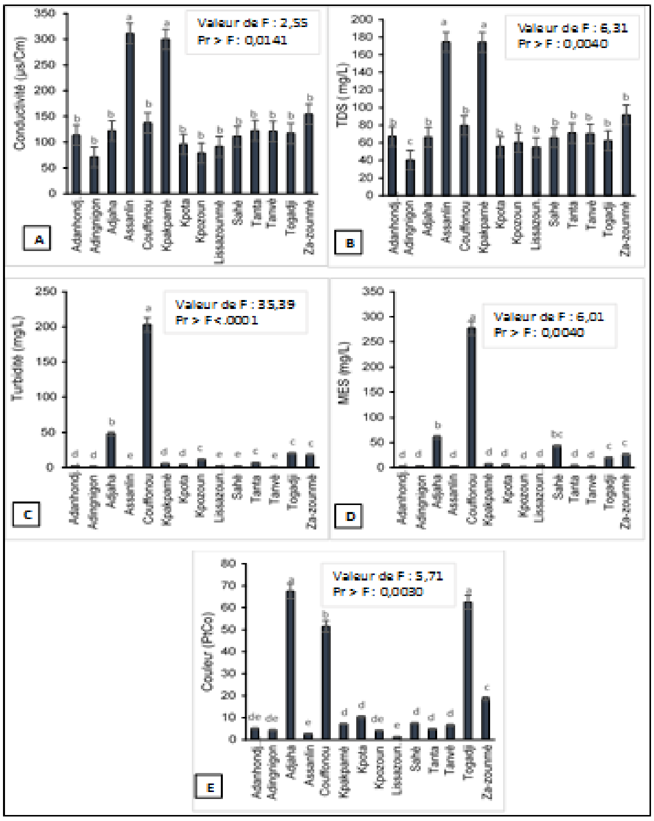

Figure 5 . Changes of physical parameters in sampled localities

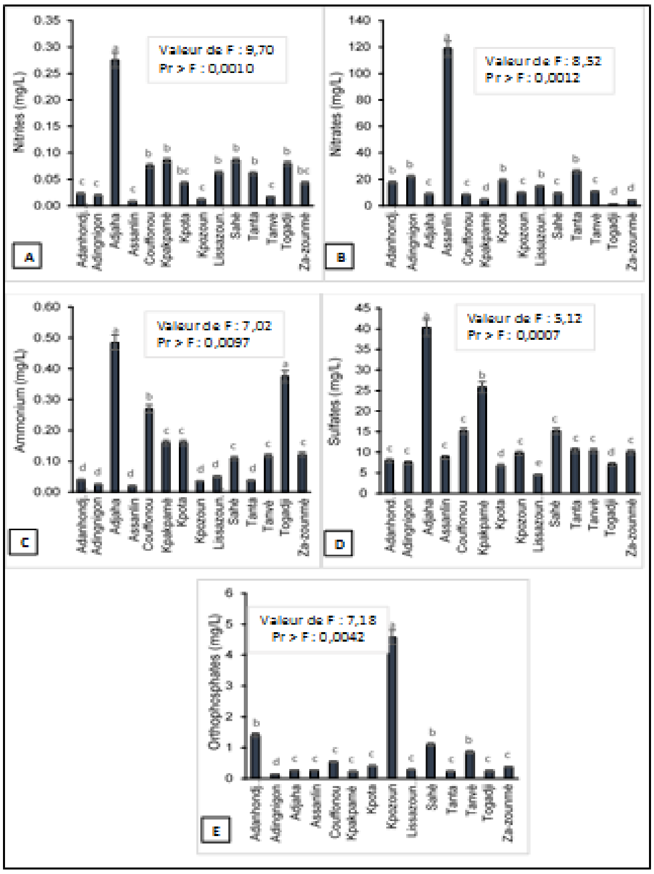

Figure 6 . Changes of chemical parameters in sampled localities

Analysis of variance of inorganic pollution indicators' parameters according to localities

Figures 6A, B, C, D and E show the results of the analysis of variance of the chemical parameters measured on the water samples. The concentrations of nitrite, nitrate, ammonium, sulphates and orthophosphates showed a significant difference between the localities. The average nitrite concentration is higher in Adjaha (0.28 mg/L) while the nitrate one is higher in Assalin (118.76 mg/L). Ammonium is more concentrated in the waters collected from Adjaha (0.49 mg/L) and Togadji (0.38 mg/L) and less concentrated in the waters from Adanhodjigon, Adingnigon, Assalin, Kpozoun and Tanta. The ammonium concentration is slightly higher in Couffonou (0.27 mg/L). The water collected in Adjaha is contaminated in sulphates (40.30 mg/L). In contrast, Lissazounmè's drinking water has a lower sulphate concentration. The orthophosphates are more concentrated in the water sampled in Kpozoun and less concentrated in Adingningon.

Conclusion

The study of the physico-chemical quality of surface waters, traditional wells and cisterns used as drinking water by human populations in the town halls of Agbangnizoun and Za-kpota in southern Benin, has showed that these waters are not suitable for consumption. Indeed, the values of physical parameters such as hydrogen potential (pH), temperature, colour, turbidity, suspended matters (SM) measured in water do not comply with accepted Beninese and WHO standards for drinking water. Likewise, indicators' parameters values of inorganic pollution such as ammonium and nitrites in surface waters are higher than the accepted standards.

These results reflect the evidence of the poor quality of this surface water and the influence of human activities and poor sanitation in the study area.

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