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Spatialization of chemical characteristics of underground water - well water - in the township of Parakou

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Abstract

Liquid water is essential for life as we know it. Liquid water is essential for important prebiotic reactions. But equally important for the emergence of life is the contact of carbon molecules in liquid water with hot rocks and minerals. Water is a source of life for humans when it is in good quality i.e. drinkable and a source of various diseases when it is biologically or chemically contaminated. In this article, the chemical characteristics of well water in the township of Parakou are spatialized. Thus, 24 wells water has been sampled and physico-chemical analysis as well as sociological survey of 144 households has been achieved. Multiple Correspondence Analysis (MCA), Fisher's exact test, kriging interpolation and map overlay model are processed. The MCA found that dental fluorosis and dysentery are relatively present in Dokparou and Bakpérou due to the consumption of well water. Typhoid fever and stomach aches are more reported in Woré, Camp Pionnier, Kobi Gourou and Arafat while in other localities households feel that they do not suffer any harm from consuming well water. Colic and typhoid fever reported by households are significantly related to the turbidity of the well water they consume (p-values equal to 0.001 and 0.0001 respectively). The superposition of the layers of ions showed that 23.70% of well water is of relatively poor quality, while 54.85% is relatively of good quality and 21.45% is of very good quality in the township of Parakou. This final map makes it possible to identify areas unsuitable for drilling wells and makes it possible to recommend boreholes for the drinking water supply of the households concerned

Key Words*:* well water, chemical characteristics, GIS, Parakou, Benin

Spatialisation des caractéristiques chimiques des eaux souterraines – eaux de puits – dans la commune de Parakou

Résumé

L'eau est source de vie pour l'humain quand elle est potable et source de diverses maladies quand elle est biologiquement ou chimiquement contaminée. L'objectif de cet article est de spatialiser les caractéristiques chimiques des eaux de puits dans la commune de Parakou. La méthodologie adoptée repose sur le prélèvement des eaux de 24 puits, l'analyse physico-chimique, et une enquête sociologique auprès de 144 ménages. L'Analyse de Correspondance Multiple (ACM), le test exact de Fisher, l'interpolation par krigeage et le modèle de superposition des cartes sont les méthodes de traitement des données collectées. L'ACM a permis de constater que la fluorose dentaire et la dysenterie sont relativement présentes à Dokparou et Bakpérou en raison de la consommation des eaux de puits. La fièvre typhoïde et les maux de ventre sont plus signalés à Woré, Camp Pionnier, Kobi Gourou et Arafat tandis que dans les autres localités les ménages estiment ne souffrir d'aucun mal en consommant l'eau de puits. Les coliques et la fièvre typhoïde signalées par les ménages sont significativement liées à la turbidité des eaux de puits qu'elles consomment (p-values égale respectivement à 0,001 et 0,0001). La superposition des couches des ions a montré que sur 23,70% de la commune de Parakou, les eaux de puits sont de qualité relativement mauvaise, sur 54,85% elles sont relativement de bonne qualité et sur 21,45 elles sont de très bonne qualité. Cette carte finale permet d'identifier les zones impropres à la réalisation des puits et permet de recommander les forages pour l'alimentation en eau potable des ménages concernés.

Mots clés : eau de puits, caractéristiques chimiques, SIG, Parakou, Bénin,

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INTRODUCTION

Water is one of the most essential needs for life. About 0.3% of the water resources in the world are usable. Water is a very important required substance in order to sustain vital activities of human such as nutrition, respiration, circulation, excretion and reproduction. In addition, water is also a life space as well as being one of the basic substances in the formation of life environment. Water is essential in socio-economic activities as an invaluable resource in both developed and developing countries [1, 2, 3, 4]. However, the negative effects of global population increase, climate change impacts, and lifestyle changes are exerting growing pressures upon our vital water resources leading to higher degree of water composition and its contamination by various elements such as: bacteria, ammonia, nitrates and the chemical oxygen. Thus, water, which is the source of life, can be a serious threat to human and animal life as well as to the environment when it is contaminated by various pollutants that make it not good or usable for consumption [5]. Thus, the enumeration of bacteria, ammonia, nitrates and the chemical oxygen demand underground water downstream of a cemetery, reveal high concentrations of each of these contaminants near a cemetery, and their concentrations decrease with distance from graves [6]. Indeed, previous works carried out on underground water quality reported that these pollutants take their sources from geological, biological and anthropogenic, in particular from the infiltration of nitrates from wastewater, discharges from mineral industries and use of nitrogen and phosphate fertilizer in agriculture [7, 8, 9, 10, 11]. They can also be derived from lithological nature of the surface layer [8]; geological nature of the substrate which influences the pH of the water [12, 13, 14]; as well as the activity of certain bacteria (chlorothiobacteria, rhodothiobacteria, etc.) [15] which cause the sulfate level to fluctuate. As for ammoniacal nitrogen, it comes from nitrogenous organic matter and gas exchange between water and the atmosphere [16]. Regarding the sources of chloride contamination of deep waters, they are linked to the clay lithology of the main aquifer [17]. Industrial activities such as cement industry, led to pollution, especially manganese (Mn), of nearby well water [18]. With regard to the leachate which comes from the percolation of water and liquids in a waste zone or uncontrolled dump, mineral pollution is characterized by high conductivity with a low oxygen content [19, 20]. The presence of mercury in waters of a given area is often due to the effect of past and current gold mining activities carried out in the area [21]. The seasons also influence the concentration of contaminants in the water [22]. The concentration above national and international standards of all these contaminants in drinking water causes enormous health problems affecting juvenile layer [23]. Thus, the main problem is to be able to spatialize the types of contaminant in a region, based on appropriate interpolation and superposition methods, using the Geographic Information System. The linear interpolation model through kriging is used in the spatialization of continuous phenomena. The aim of this study is to spatialize chemical characteristics of well water in the commune township of Parakou.

MATERIALS AND METHOD

Presentation of the study environment: The present study has been carried out in the township of Parakou in the department of Borgou in Benin (fig 1). It is located between 2 ° 23'48"and 2°44'44" east longitude, then between 9°29'27" and 9°14'16" north latitude and covers an area of 56,470.31 ha. It is one of the three municipalities with special status in Benin after Cotonou and Porto Novo. The population is estimated to about 255,478 inhabitants with 46,181 households of average size 5.5 [24]. The climate of the study area is of sudanese type with average rainfall estimated at 1,200 mm per year [25, 26] which implies that the area is heavily watered which facilitate the flow and infiltration of water. The study area is entirely included in the large mass of syntectonic granite on which the tropical ferruginous soils are predominantly based, where the pedological processes are substantially identical [27].

Data used: The data used are the concentrations of chemical contaminants in well water as well as sociological data.

Data gathering: To determine the concentration of chemical contaminants in well water, sterilized plastic bottles were used to contain well water collected in order to perform physico-chemical analyzes. These analyzes were carried out in the water analysis laboratory of the Departmental Directorate of Water and Mines of Borgou. The concentrations of fluoride (F-), nitrate (NO3-), chloride (Cl-) ions and pH are the parameters of particular interest in this study.

Based on software, a survey questionnaire has been implemented to gathersociological data such as: the perception of households on well water quality, associated use and the corollaries of the use of this water on health and material goods.

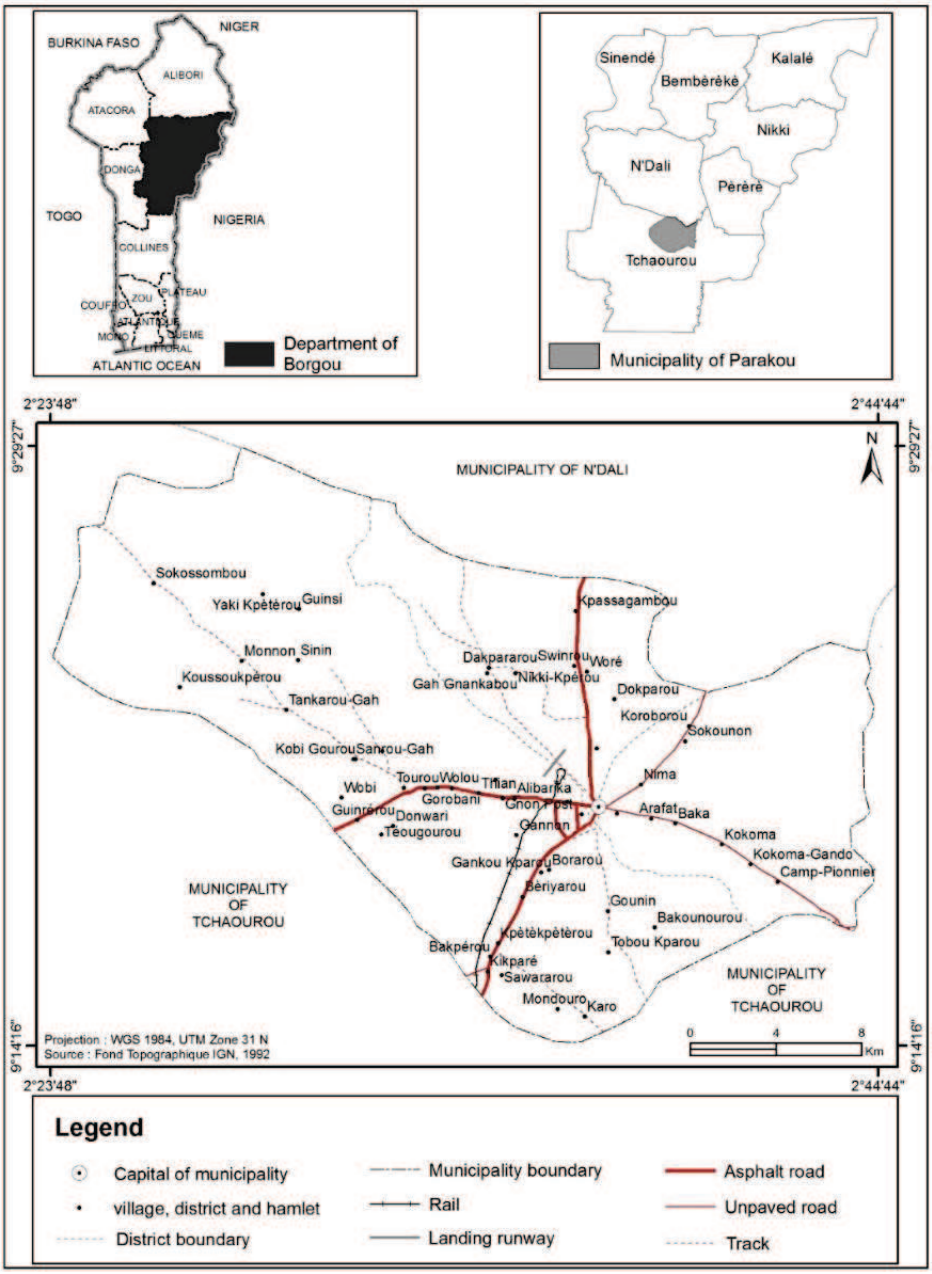

Figure 1 - Geographical location of the municipality of Parakou.

Data processing: The data collected was subject to statistical and cartographic processing. The factorial correspondence analysis was applied to determine the chemical contaminants and diseases associated with each neighborhood. The Chi-square test if the theoretical numbers are greater than 5, otherwise, Fisher's exact test is carried out to assess the link between the diseases reported by the populations surveyed and the state of the water they consume. The GIS software (ArcMap 10.3) was used for the spatialization of the results of the chemical analysis of the water. The kriging method [28] is a geostatistical technique which can be defined as a method of optimizing the estimation of a quantity which is distributed in space and measured on a network of points [29]. Kriging is used to perform spatial interpolation, that is to say, it makes it possible to predict the value taken by a natural phenomenon on a site, from point observations of this phenomenon. Spatial interpolation is a mathematical treatment that is sometimes useful when studying a natural phenomenon that continuously unfolds over a territory [30]. This method is used to spatialize the concentrations of chemical contaminants in well water at the level of Parakou township. The method of superimposing the layers of the different ions was used to bring out the most contaminated areas in terms of the number of ions whose concentrations are above the water potability standard set by the WHO.

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Sampling: The SurveyMonkey formula was used to determine the sample of households surveyed.

$$n = \frac{\left(z^2 \cdot p \dfrac{(1-p)}{e^2}\right)}{\left(1 + \dfrac{(z^2 \cdot p(1-p))}{(e^2 N)}\right)} \tag{1}$$

(SurveyMonkey : surveymonkey.com)

n = sample size; N = size of the population; e = margin of error (percentage in decimal form); z = dimension z; p = proportion of confidence level. The number of households in the commune of Parakou is 46,181. Taking the level of equal confidence of 85% and the margin of error of 6%, the size of the sample calculated is 144 distributed by locality in the table 1.

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Table 1 - Distribution of households by locality.

Arrondissements	**Numéro de maille**	**Localités**	**Effectifs par localités**	**Effectifs enquêté**
1	1, 2,	Sokossombou	6	12
		Yaki Kpèterou	6	
1	3, 4	Guinsi	12	12
1	5, 6	Koussoukpérou	6	12
		Monnon	6	
1	7, 8	Tankarou-Gah	3	12
		Gah Gnankabou	3	
		Dakpararou	6	
3	9, 10, 11	Swinrou	3	18
		Woré	3	
		Nikki-Kpérou	6	
		Dokparou	6	
1	12, 13	Kobi Gourou	6	12
		Tourou	6	
1, 2	14, 15	Albarika	6	12
		Arafat	6	
2	16, 17	Nima	6	12
		Baka	6	
1	18, 19	Téougourou	6	12
		Bériyarou	6	
1, 2	20, 21, 22	Gounin	6	18
		Koloma	6	
		Camp-Pionnier	6	
1	23, 24	Bakpérou	3	12
		Kikparé	3	
		Karo	3	
		Tobou Kparou	3	
			Total	144

Spatial sampling was done by a regular band of 5 km apart (Figure 2).

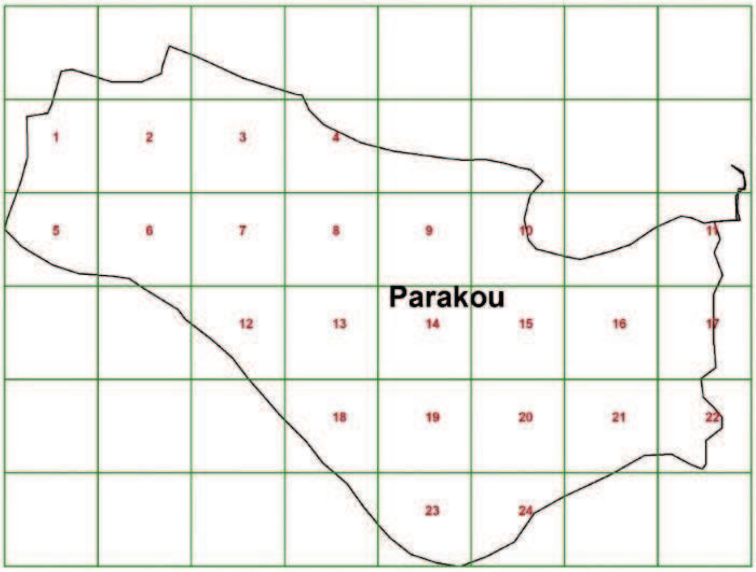

Figure 2 - Regular network of Parakou.

A well is selected from each of the meshes numbered from 1 to 24, for a total of 24 wells, and has been subjected to chemical analyzes.

RESULTS

Household perception of the quality of well water

Most households (97.48%) of respondents in Parakou township use well water in daily activities such as laundry, dishes, cooking as well as for bathing and 80.67% use it also for everyday consumption.

The taste of well water is perceived differently depending on the state of the water: whether it is acidic, basic, mild, neutral or brackish. Thus, nearly half of the population of Parakou township estimates the cost of their water from basic wells (fig. 3).

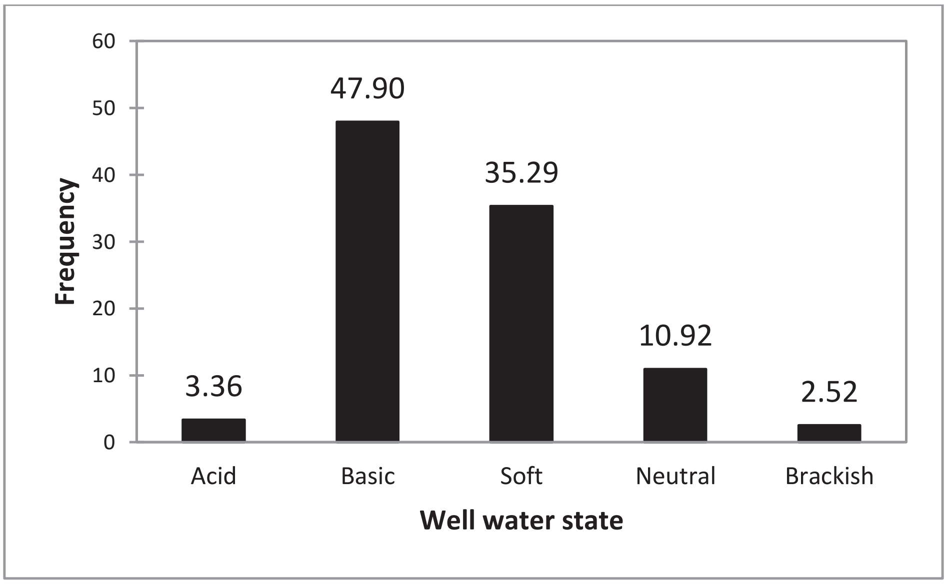

Figure 3 - Proportion of the assessment of the state of well water.

According to figure 3, 47.9% of the populations of Parakou township appreciate the taste of their well water as being basic and 35.29% find it sweet. The remaining appreciation are distributed between neutral, sour and brackish tastes. This differentiation of tastes is explained by the diversity of the lithological nature of the surface layers of the earth's crust crossed by infiltrated water as well as the nature of human activities carried out around respective wells.

The populations surveyed also reported some diseases from which they suffered due to the consumption of well water. The Multiple Correspondence Analysis (MCA) showed that various ailments are linked to the villages and city districts of Parakou township (Figure 4).

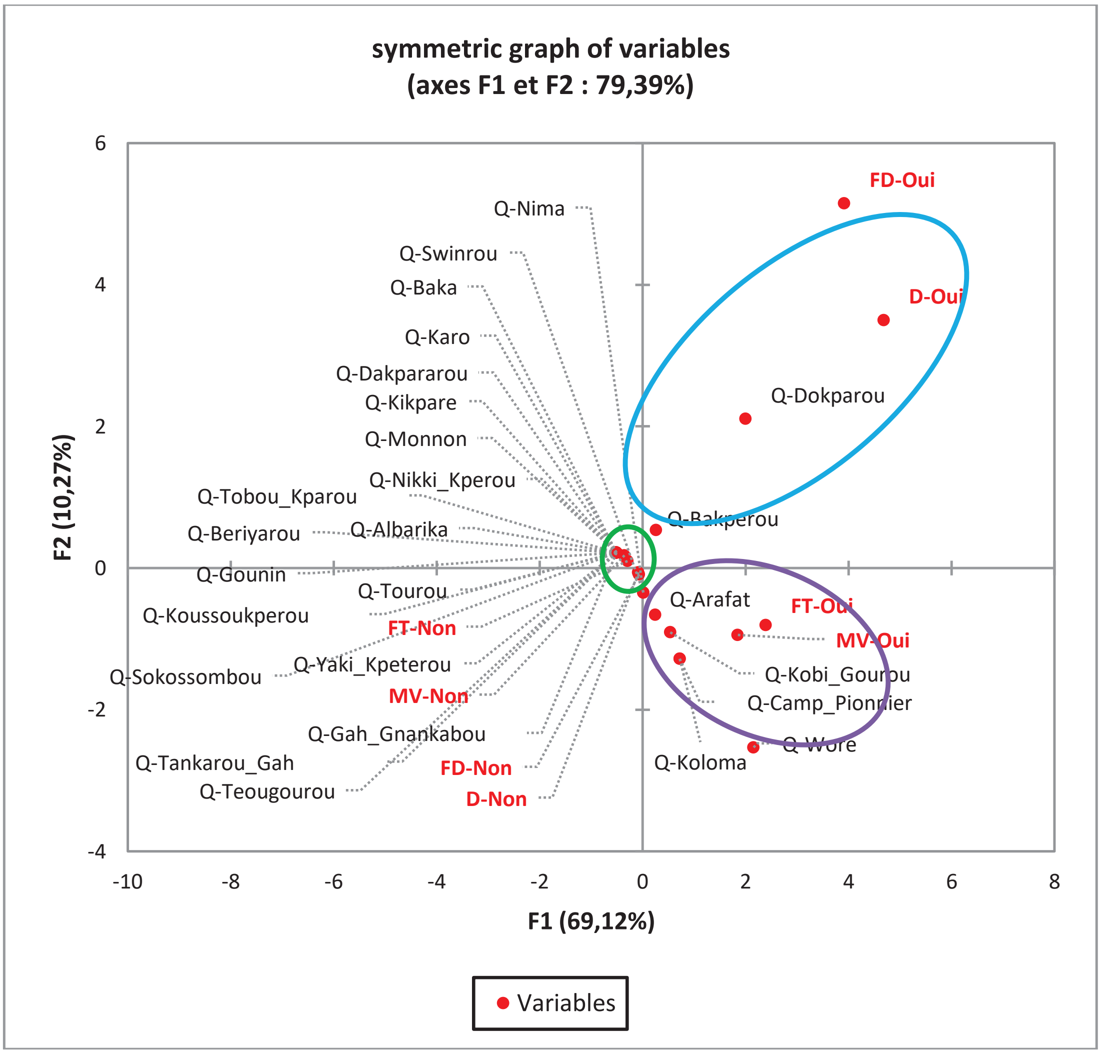

Figure 4 – ACM.

Figure 4 shows that dental fluorosis (FD) and dysentery (D) are relatively present in Dokparou and Bakpérou because of the consumption of well water. Typhoid fever (FT) and stomach aches (MV) are more reported in Woré, Camp Pionnier, Kobi Gourou and Arafat; while in other localities, people feel that they do not suffer any harm from consuming well water. The stomach aches and typhoid fever reported by the populations are significantly linked to the turbidity of the well water they consume (Fisher's exact test, p-values equal to 0.001 and 0.0001 respectively). As for dental fluorosis and dysentery, they are not significantly related to the turbidity of well water. However, not all of the diseases reported by the surveyed population are significantly related to: the acidity, basicity, neutrality and brackish state of the well water they consume.

Dissimilarity of well water

The well water collected from a sample of 24 wells was analyzed for physical and chemical properties. Among these properties we have: pH, temperature, conductivity, hardness, concentrations of nitrate, ammonium, fluorine, calcium, magnesium, chloride and bicarbonate ions. The dissimilarity analysis (Figure 5) was carried out these properties.

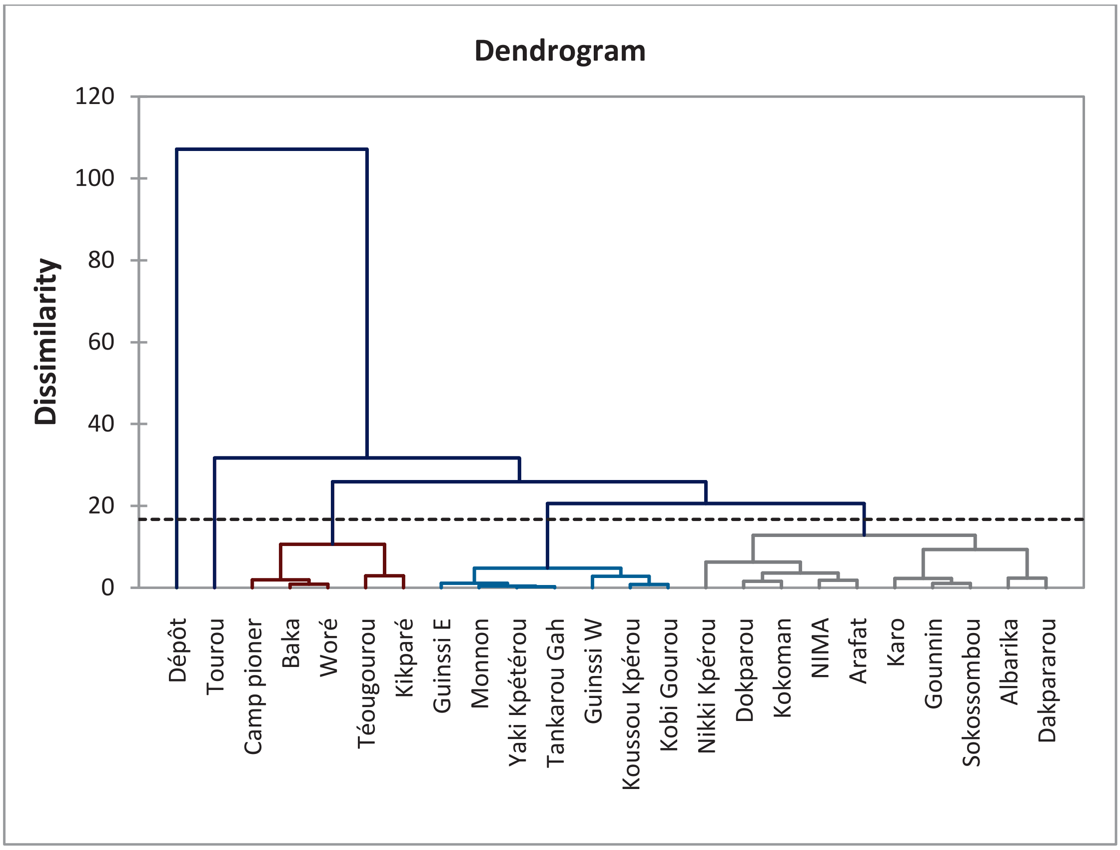

Figure 5 - Dissimilarity of the sampled waters.

Figure 5 shows five dissimilar classes from the 24 samples. The first class is composed of samples from Gounnin, Sokossombou, Karo, Nima, Dokparou, Kokoma, Arafat, Nikki Kpérou, Albarika and Dakpararou, while the second class is composed of samples from Depot, the third class is constituted of samples from Téougourou, Kikparé, Camp Pionnier, Kokoma, Baka and Woré, the fourth class samples comes from those of Tourou and the fifth class includes samples from Monnon, Guinssi E, Guinssi W, Yaki Kpétérou, Koussou Kpérou, Tankarou Gah and Kobi Gourou. It can be seen that almost all the localities of the third class are composed of localities reporting typhoid fever and stomach aches due to the consumption of well water. On the other hand, the second, fourth and fifth classes are composed of localities where populations do not seem to get sick from drinking well water. We noticed the opposite with the localities of Dokparou and Bakpérou which represent an eccentricity; but it is necessary to underline the case of the Depot district which represents a particularity due to the sulfuric acid contamination of the waters of the area. This acid comes from the sulfur storage of the Organization Commune Bénin-Niger (OCBN) which is located upstream and close to the neighborhood.

Spatialization of the chemical characteristics of well water

Results of physical and chemical analysis of sampled water show that only pH, nitrate, fluorine and chloride parameters are outside the WHO standard. These four parameters were the object of spatialization by kriging on the scale of the municipality of Parakou (Figure 6).

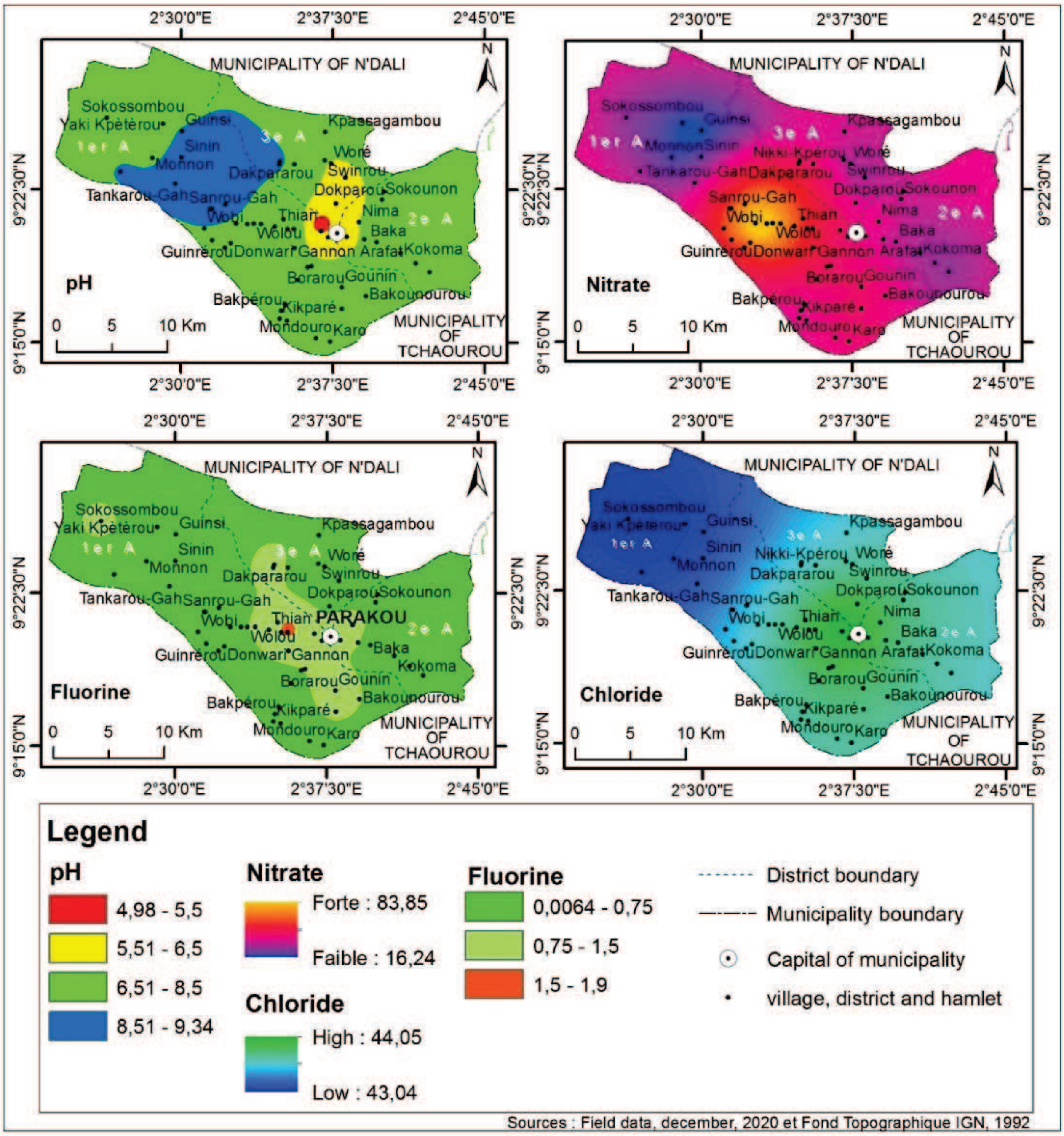

Figure 6 - Spatialization of the parameters considered at the Parakou scale.

The spatialization of the parameters considered presented by figure 6 indicates that at the level of the pH map the colors red and yellow (4.98 < pH < 6.5; acidic water) are the areas where the pH of the water from the wells is below the standard set by the World Health Organization (WHO). The color green (6.5 ≤ pH ≤ 8.5; relatively neutral water) occupies the space where the pH of well water is within the norm. The blue color (8.5 < pH < 9.34; basic water) is represented by the area occupied by wells whose water pH is above the WHO standard. The lowest values of the pH of well water are distributed approximately in the center of the municipality of Parakou, particularly in the Depot district where the pH = 3.32. This value is strictly low compared to all the values of the other samples. This is why this value is considered outlier by the kriging model and is generalized in the low range of between 4.98 and 5.5.

The spatialization map of nitrate ion concentrations (Figure 6) shows that the entire area of the municipality of Parakou contains wells with a nitrate ion concentration between 16.24 and 83.85 mg. L^{-1}. This value is strictly greater than $10 mg.L^{-1}$ which is the tolerance threshold for the nitrate ion concentration in water. The highest values are located in the Tourou area.

The fluorine ion concentration spatialization map (figure 6) indicates that the orange color ($1.5 < [F^-] \leq 1.9$) represents the zone where the fluorine ion concentration is greater than the standard set by the WHO, at the risk of dental fluorosis. The green and light green colors are the areas where the ion concentration of the well water is within the norm.

The spatialization map of chloride ion concentrations (Figure 6) illustrates that all the wells in the municipality of Parakou are within the standard set by the WHO with $[Cl^-] < 250 mg.L^{-1}$. However, the chloride ion parameter was taken into account because of the peculiarity of the sample from the Depot district, the chloride ion concentration of which is equal to 536.05 mg.L-1, strictly greater than $250 mg.L^{-1}$.

These four parameters considered were superimposed using a weighted superposition model in ArcGIS software following the graph shown in Figure 7.

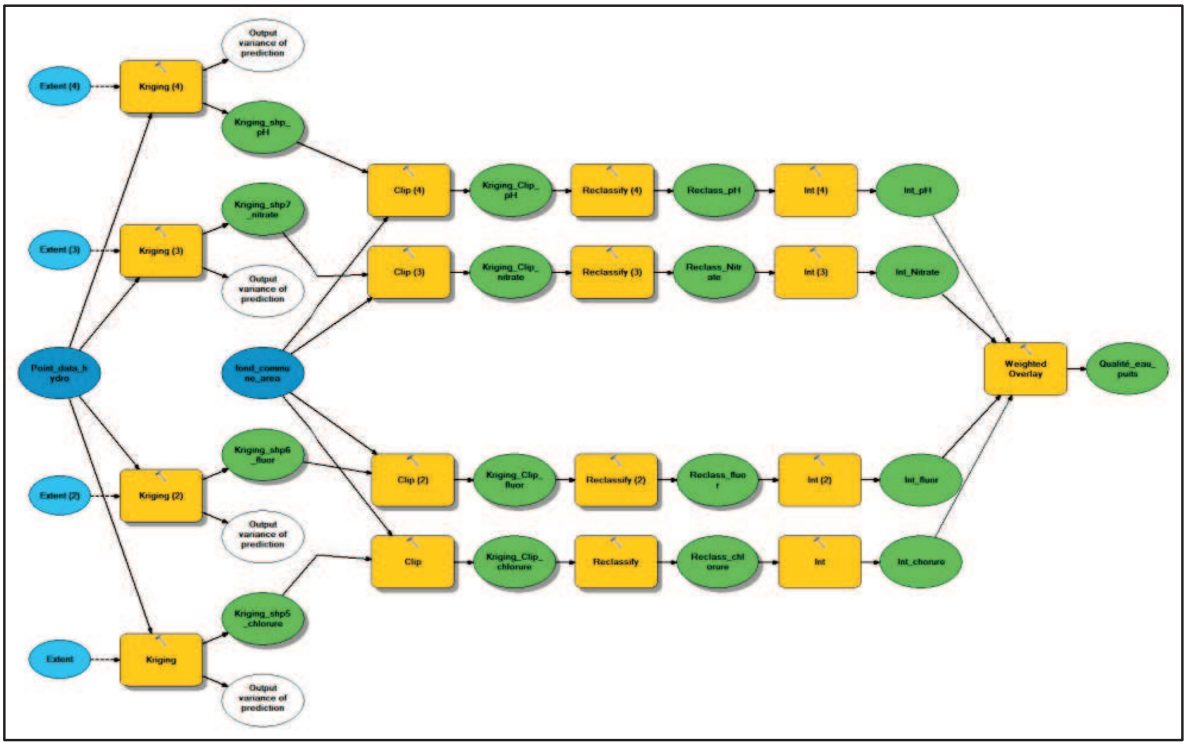

Figure 7 - Superposition model of the parameters considered.

After interpolation by kriging of the pH values and the concentrations of the ions considered, each of the maps generated was cut out, at the exact limit of Parakou township, then reclassified according to the WHO standard. These reclassified maps were superimposed to generate the final map of well water quality of Parakou township (figure 8).

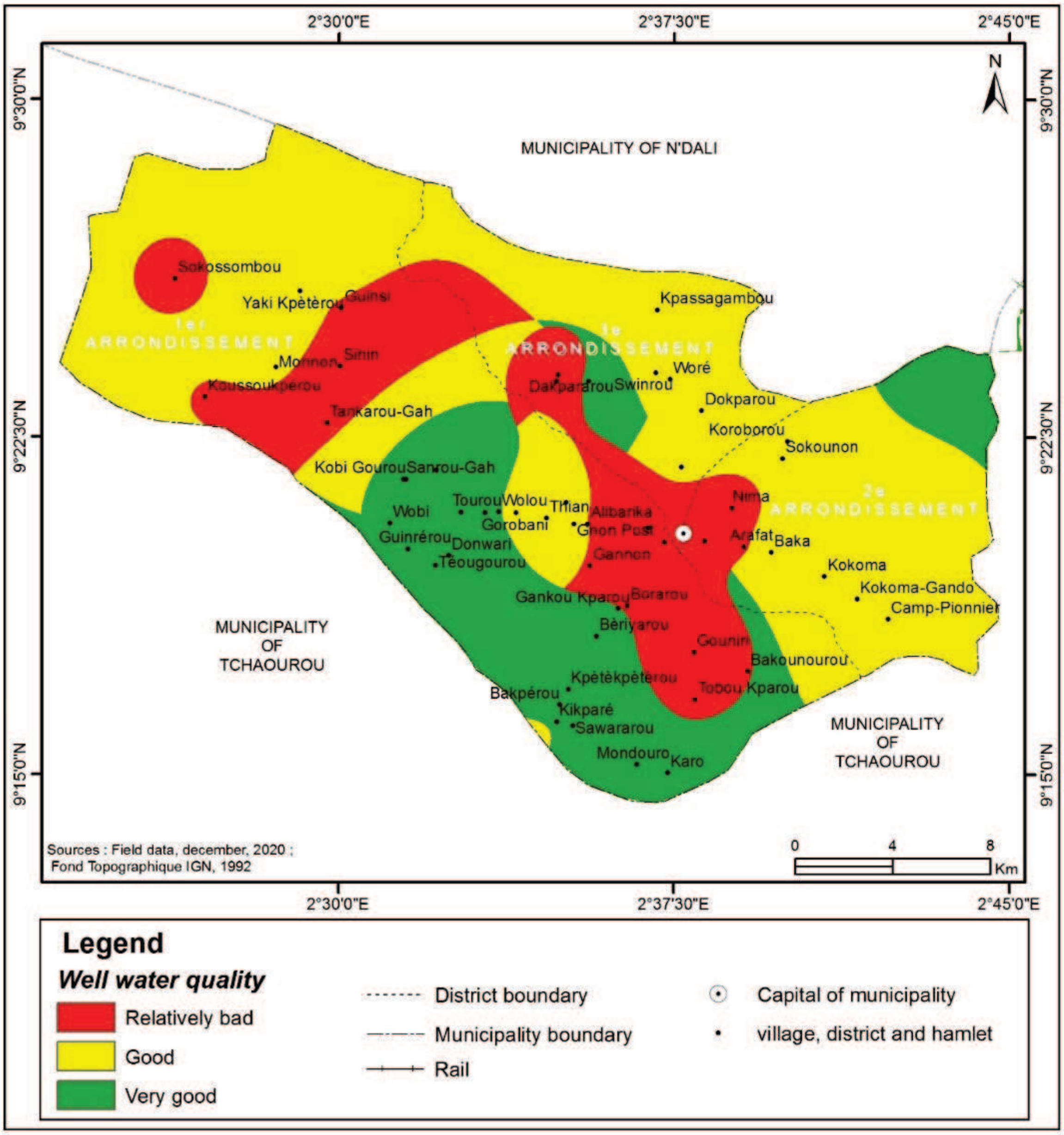

Figure 8 - Quality of well water in the municipality of Parakou.

According to figure 8, the color red (23.70% of the municipality) indicates areas where the quality of well water is relatively poor. The yellow color (54.85% of the municipality) illustrates the areas where the water from the wells is relatively of good quality. The green color (21.45% of the municipality) shows the areas where the well water is of very good quality.

Relatively poor quality well water is water whose pH and ion concentrations: nitrate, fluorine and chloride, are outside the WHO standard. Water of relatively good quality is water for which one or two of the parameters considered are out of the ordinary; while water of very good quality is water for which all the parameters considered are within the standard.

DISCUSSION

The perception of the populations of Parakou regarding the quality of well water is based on its acidity, basicity, smoothness, neutrality and brackish state. These assessments made by the population of the quality of the water are not based on the conclusions resulting from the work carried out using scientific measuring instruments, but rather based on the organoleptic characteristics, namely: the clarity of the water, its taste and smell [31]. These indicators allow them to assess water pollution and to link them to various diseases such as dental fluorosis, dysentery, typhoid fever and stomach aches. Thus, results from this study, showed that stomach aches and typhoid fever reported by the populations are significantly related (Fisher's exact test, p-values equal to 0.001 and 0.0001 respectively) to the turbidity of well water. These results corroborate those of [32], study which revealed that 66.7% of households in the commune of Abomey-Calavi in Benin qualified the well water as polluted, and 71.7% affirmed that they present health risks.

The results of the chemical analysis of well water collected of Parakou township showed that all these waters have a nitrate concentration strictly higher than the WHO standard, as well as in Abomey-Calavi township [33]. These results are half-verified in rural areas of Grand-Popo and Pobè townships [34, 35] where 50% of the samples have a nitrate content higher than the standards indicated by WHO. In contrast, in the region of Meknes in Morocco, physico-chemical analysis showed that the wells studied have concentrations below the standards recommended by WHO [36]. This difference between study areas of the two countries is explained by the difference in level of development and the differential application of hygiene and sanitation texts within the two types of populations.

To assess the extent of the chemical properties of well water above the WHO standard, throughout the municipality of Parakou, a spatialization of the values of these was made as [37] to Western Côte d'Ivoire. But, the difference is at the level of the spatialized chemical properties. The pH values, nitrate, fluorine and chloride concentrations of the 24 wells studied were spatialized by interpolation using the kriging method. This method is also used to spatialize the concentration of nitrate in the irrigated perimeter of Doukkala in Morocco [38]. Regarding the result obtained in terms of spatialization of values, one pH draws attention, one from Depot district where the well water is acidic ($pH < 4$). This acidity comes from the infiltration of rainwater and runoff at the OCBN sulfur storage which is located upstream and close to the neighborhood. This result is consistent with that of [39] which states that infiltration is the main source of mineralization and pollution of underground water in the Mzamza community. Similar results come from the work of [40] who conclude that inputs of agricultural chemicals, through surface runoff to the water table, are the sources of well water contamination causing related diseases.

Finally, the four interpolated values were superimposed to generate a map of the well water quality at the scale of Parakou township. The result obtained shows that 23.7% of the municipality has poor quality water. This percentage is three time higher than one from a study carried out in the irrigated area of Doukkala in Morocco, revealing a quality ranging from bad to very bad in the vast majority of the wells analyzed, i.e. 75.53% of cases [38].

CONCLUSION

Water quality is extremely important for the continuation of life. Water is life. Through the present study we were able to have the perception of households on the quality of well water and to categorize it according to the similarityof wells water of the different localities of Parakou township. This study spatialize the chemical characteristics of well water by categorizing the cartographic result according to the WHO potability standard. According to household perception, based on taste and sight, well water can be classified into acidic, basic, soft, neutral, and brackish water. Diseases caused by the consumption of well water are linked to certain localities including Bakpérou, Dokparou, Arafat, Kobi Gourou, Camp Pionnier, Kokoma and Woré. There is significant evidence that typhoid fever and stomach aches are related to the turbidity of the water consumed. The 24 wells were classified into five dissimilar classes. The Dépôt district is particularly visible with its acidic well water ($pH < 4$) due to the storage of sulfur near and upstream of the district. The pH, the concentrations of nitrate [NO3-], fluorine [F-] and chloride [Cl-] ions are out of the ordinary in well water in Parakou township depending on the locality. The superimposition of the layers of these water properties showed that 23.70% of the municipality has a relatively poor quality of well water; 54.85% represents areas where well water is of relatively good quality and 21.45% includes areas where well water is of very good quality. The results presented in this article are useful for well construction projects in order to identify suitable areas for the construction of good quality water wells or to know what treatment to bring to make potable water from poor quality wells or " opt for the construction of boreholes instead of wells. Therefore, every decision and every step to be taken on water is vital. It is extremely important. In our opinion, man is at the center of nature. However, we cannot talk about a situation such as the separation of man and nature.

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