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ORIGINAL ARTICLE

Hydrogeochemical Safe Drinking Water Assessment: The Case Of Kouara Tegui A Niamey Peripheral District (Niger)

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ABSTRACT
The issue of access to safe drinking water, in the peripherals district of Niamey forced residents to consume wells, boreholes and standpipes waters. This study aims at making a hydro geochemical analysis of Kouara Tegui (a Niamey city peripheral district) safe drinking waters. The methodological approach was centered on the determination of the physico-chemical water quality, based on a comparative analysis of the contents of physicochemical parameters with WHO standards. Thirteen physicochemical parameters were determined for each of the 15 water samples. The results were processed using techniques of multivaried statistical analysis. The Normalized Principal Components Analysis (NPCA) and that of Hierarchical Ascending Classification (HAC) were used to respectively highlight phenomena underlying the mineralization of the waters and the links between them. The results of the chemical analysis showed that the waters studied were acidic (5.2 <pH <6.4), the electrical conductivity of the waters varies between 77 µS/cm and 443 µS/cm, with an average of 193.13 µS/cm. The levels of the chemical parameters were below WHO standards. Analysis in Normalized Principal Component and Ascending Hierarchical Classification that the mineralization of Kouara Tegui area waters is controlled by three major factors: The mineralization residence time which results in the hydrolysis of minerals for groundwater, soils pluviolessivage for surface waters and the influence of the human activities in the production of polluting wastes.
Keywords: *Principal component analysis, Niamey, Ascending Hierarchical clustering, Groundwater, mineralization.*

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INTRODUCTION

The intensive use of natural resources and increasing human activities has caused serious problems in the quality of surface and ground water [1, 2]. Thus, in developing countries to get clean water for human consumption has become a serious problem due to lack of environmental protection. Niger, like other Sahelian countries is facing these water problems and remediation sometimes severe enough in some localities. It is true that the country is crossed on 550 km by an important River, (the River Niger) and in addition it contains, in its basement significant groundwater [3, 4]. However, the problem of urban and rural areas populations in water resources control and provision sometimes occur acutely. So at the Niamey urban community, the non-permanent water supply by the national distribution network has led people to resort to groundwater (wells and boreholes). However, the insufficiency of consumed water quality thus expose this segment of the population to the risk related to some hydric diseases (diarrhea, schistosomiasis, cholera, dysentery ...) [3, 4]. Indeed, the chemical composition of water from the natural environment is very variable. It depends on the geological nature of the soil where it comes from and also reactive substances that could occur during the flow [5]. However, this quality may be altered when external substances come into contact with the water table. This is the case of toxic or undesirable substances that make groundwater unsuitable for various uses and especially toxic as drinking water. The objective of this study is to establish the hydro geological context of Kouara Tégui district consumption water from a physicochemical analysis, to understand the mineralization acquisition of these waters. To achieve the objective of this study, wells, boreholes and standpipes water samples were taken and analyzed in the laboratory. The data collected were processed using a combination of statistical multi varied methods (Normalized Principal Components Analysis (NPCA) and Hierarchical Ascending Classification (HAC)).

PRESENTATION OF THE STUDY AREA

Niamey, the Niger Republic capital city since 1926 lies along the two banks of the Niger River on the left the plateaus and on the right bank a vast plain. The city covers an area of approximately 255 square kilometers and is located between 13^0 25' and $13^0$35' latitude north and 2^0 2' and 2^0 12' longitude east.
The study is centered on Kouara Tegui (Figure 1) a peripheral district in Niamey, located between 13°35'18.5'' of longitude North 2°06'57.1'' of latitude East. It is in Niamey Commune II, with a population of approximately 17,813 inhabitants and an area of about 4.5 km2 [6]. This area is occupied by seasonal migrants and disabled people (deaf, blind, etc...) and has been subdivided in recent years.

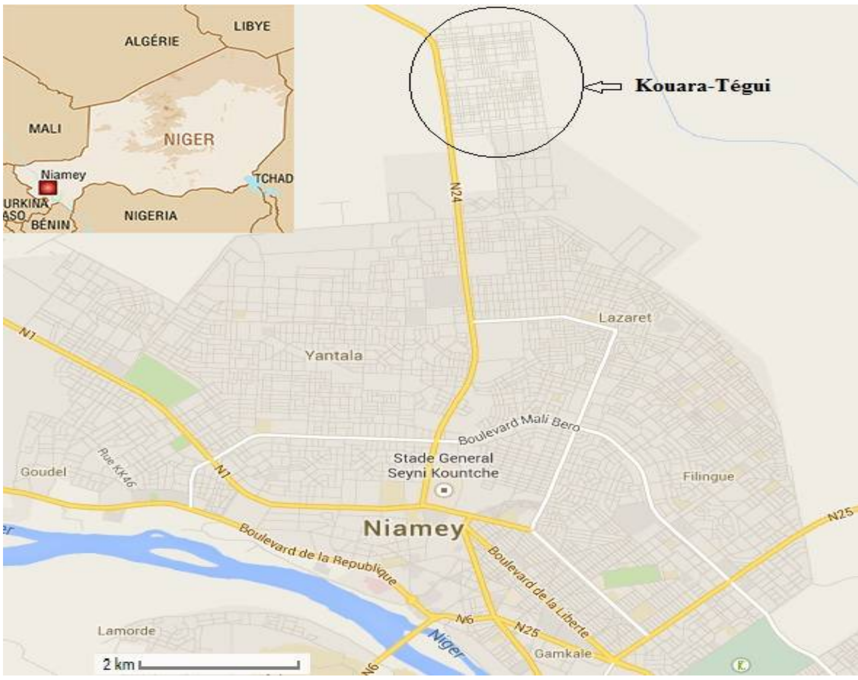

Figure 1: Location of study areas.

The groundwater resources of the city of Niamey are three in number:
- Discontinuous aquifers of existing base is under a thick layer of regolith, or in large sedimentary deposits of the Continental Terminal (CT). These layers are characterized widely by flow rates and varying hydrodynamic parameters;
- The aquifer of the Continental terminal is a continuous ground water which flows or reservations appear quite variable;
- The alluvial, are groundwater of weak extensions with varying hydro geological properties from one place to another [3].

MATERIALS AND METHODS

Test Methods

The waters of six (6) drillings, seven (7) water terminals; and two (2) Kouara Tegui wells were analyzed in the laboratory to evaluate their physicochemical characteristics and determine the quality of water consumed by these populations. Drilled or wells' waters come from the water table, and those from SEEN (A Niger Operating Water Company) standpipes come from Niger River after treatment routed through drinking water systems.
The collected water samples were placed in polyethylene bottles of 1.5 L capacity, previously washed with nitric acid and then with distilled water. On the ground before filling the bottles, they were washed three times with water to collect. Bottle filling was done to the brim and the screw cap to prevent gas exchange with the atmosphere. Water samples were then transported in a cooler at 4 ° C to the laboratory an hour after collection for analysis. Various Physico-chemical characteristics of the groundwater quality parameters were determined according to standard methods recommended by the French AFNOR standards.
The pH, electrical conductivity (EC), the temperature were measured on site using the PC 300 multiparameter Cyber Scan, and dissolved oxygen using a tight oxymeter Hand Scan DO 310 Physicochemical parameters of waters were determined using the methods: spectrometry for nitrate (NO_3^-), nitrite (NO_2^-), sulfate (SO_4^{2-}) and iron (Fe^{2+}), titration for calcium (Ca^{2+}), magnesium (Mg^{2+}) and chloride (Cl^-), and finally by flame photometry to determine the levels of sodium (Na^+) and potassium

(K^+). The WHO guidelines [7] of physicochemical parameters for drinking water quality values were used in the assessment of the physico-chemical quality of the studied waters.

Statistical Analysis

All data collected on water boreholes, wells and standpipes of Kouara Tegui district have been statistically analyzed. The approach of multi varied statistics has been made from a Normalized Principal Components Analysis (NPCA) and an Ascending Hierarchical Classification (HAC). Statistical analysis was performed on 15 samples and 13 variables (temperature (T ° C), electrical conductivity (EC), Dissolved Oxygen (O_2), pH, Na^+, Fe^{2+}, Cl^-, K^+, Ca^{2+}, Mg^+, SO_4^{2-}, NO_3^- et NO_2^- using the XLSTAT 2014 software. This analysis summarizes and classifies a large amount of data in order to extract the main factors that are the cause of the simultaneous evolution of variables and their interrelationship [8]. It helps to highlight the similarities between two or more chemical variables during their evolution. This analysis is very frequently used and gives very good results [9- 14].

RESULTS

Results of physicochemical analysis

The statistical variables and extreme values of the physico-chemical analyzes of the waters of Kouara Tegui district in Niamey were presented in Table 1 The water temperature varies between 29 ° C and 34 ° C, with an average of 31.27 ± 0.1 ° C. The pH of water varies respectively between 5.2 and 6.4 pH units, with an average of 6.02 pH units. The electrical conductivity of the water varies between 77 and 443 $\mu S.cm^{-1}$, with a mean value of 193.13 ± 23 $\mu S.cm^{-1}$. Waters average conductivity value comes mainly from those boreholes, F1 KT (443 $\mu S.cm^{-1}$), F4 KT (390 $\mu S.cm^{-1}$), and F3 KT (301 $\mu S.cm^{-1}$).

A comparison of the contents of physical and chemical elements of water of various drillings of the district, shows values defined (Table 1) within the ranges recommended by the World Health Organization.

Normalized Principal Components Analysis (NPCA)

The eigenvalues of the factors are presented in Table 2. The correlation matrix between the 13 parameters is shown in Table 3. In Kouara Tegui district, there are highly significant correlations between EC and Na, Ca, Mg; between Cl and NO_3, NO_2; between SO_4 and K; NO_3, NO_2 between; Na and Ca, Mg. Analysis of the NPCA variables in the F1-F2 factorial design is presented in Figure 2. This graph shows three clusters of variables.

The factor F1 (38.65%) is determined by two groups. In the first group are the K et O_2 parameters. In the second grouping are the parameters of the total mineralization EC, pH, Ca, Mg, Na, T (° C), and Fe. The EC reflects an overall water mineralization. Magnesium and Sodium are from alteration and the iron is dissolved by the oxidation-reduction mechanism. The elements that define this factor come from a long dissolution due to water-rock touch. The F1 factor is considered as an area of original mineralization at the same time natural (rock-water contacts) and bound redox mechanisms. The F2 factor is representative of NO_3, NO_2, SO_4 et Cl. Nitrates have a shallow origin related to agricultural, industrial and domestic activities, therefore witnessing an anthropogenic pollution. The F2 factor is considered as an axis which represents the mineralization that expresses soil pluviolessivage phenomenon.

Figure 3 shows the preponderance of the influence of these phenomena on the mineralization of the water. It appears from the analysis of this graph that the standpipes and boreholes waters are influenced by mineralization through the mechanisms of rocks alteration and minerals hydrolysis and through redox mechanisms. Waters from wells (P1, P2) and exceptionally drilled waters F5 KT undergo soils pluviolessivage phenomenon. This leads us to consider the relationship of similarity that may exist between these waters.

Hierarchical Ascending Classification Analysis (CHA)

Figure 4 shows the dendrogram resulting from the classification of surface waters of the area on the basis of their mineralization. This dendrogram shows three groups and sub-groups. The first group concerns water with less important mineralization. It takes into account the water of wells (P1 and P2) and drilled water (KT F6) which are affected by the phenomenon of soil pluviolessivage. The second group regards drilled water (F1 KT, KT F2, F3 KT, KT F4, and F5 KT) the most mineralized of waters studied. The preponderant phenomenon in acquiring ion is dissolved of the rock by minerals hydrolysis and by redox mechanisms. The third group consists of waters with intermediate mineralization and concern standpipes waters. Their mineralization is related to minerals hydrolysis.

Potability of standpipes waters

Standpipes waters are acidic. The average pH of standpipes waters equates 5.8 pH units, it is an aggressive and corrosive acid water. It can lead to degradation of cement-based materials, corrosion of water pipes and metal equipment. The presence of metallic trace elements (iron, magnesium) in the water contributes to the degradation of the organoleptic quality of the water (odor, taste, turbidity, color ...).

Table 1: Statistical variables and extreme values of Kouara Tegui waters.

Physico-chemical Parameters	**Units**	**WHO Norms 2011**	**Min**	**Max**	**Average**	**standard deviation**
PH		6.5-8.5	5.2	6.400	6.02	0.365
Temperature	°C	25-30	29.0	34.0	31.27	0.146
C.E	µS/cm	180-1000	77.0	443.0	193.13	22.986
Disolved Oxygen		0	2.600	6.0	5.0	1.073
Cl^-	mg/L	≤ 250	1.500	10.000	3.500	0. 211
SO_4^{2-}	mg/L	≤ 250	1.000	40.000	22.733	1.836
NO_3^-	mg/L	≤ 50	1.300	22.400	6.168	0.884
NO_2^-	mg/L	≤ 3	0.000	0.060	0.010	0.015
K^+	mg/L	≤ 12	1.250	5.000	3.117	1.299
Na^+	mg/L	≤ 200	4/000	25.000	12.00	1.905
Ca^{2+}	mg/L	NE	6.400	35.200	15.213	2.468
Mg^{2+}	mg/L	NE	2.000	16.300	5.191	1.737
Fe^{2+}	mg/L	≤ 0.3	0.020	0.120	0.051	0.027

Table 2: Eigen values and percentages expressed for the principal axes.

	F1	F2
Proper value	5.024	3.092
Variability (%)	38.648	23.786
% cumulated	38.648	62.435

Table 3 : Stamp of correlation

Variables	PH	C.E	Cl^-	SO_4^{2-}	NO_3^-	NO_2^-	K^+	Na^+	Ca^{2+}	Mg^{2+}	Fe^{2+}
PH	**1**										
C.E	0.469	**1**									
Cl^-	-0.323	-0.278	**1**								
SO_4^{2-}	-0.420	-0.123	-0.301	**1**							
NO_3^-	-0.172	0.052	**0.837**	-0.461	**1**						
NO_2^-	-0,132	-0.055	**0.810**	-0.329	**0.854**	**1**					
K^+	-0.538	-0.342	0.237	**0.735**	0.105	0.257	**1**				
Na^+	0.406	**0.913**	-0.044	-0.218	0.319	0.109	-0.293	**1**			
Ca^{2+}	0.474	**0.930**	-0.522	-0.031	-0.252	-0.354	-0.429	**0.774**	**1**		
Mg^{2+}	0.366	**0.603**	-0.225	-0.579	0.212	0.048	-0.587	**0.640**	0.547	**1**	
Fe^{2+}	0.208	0.357	0.069	-0.107	0.035	0.125	-0.195	0.150	0.291	-0.211	**1**

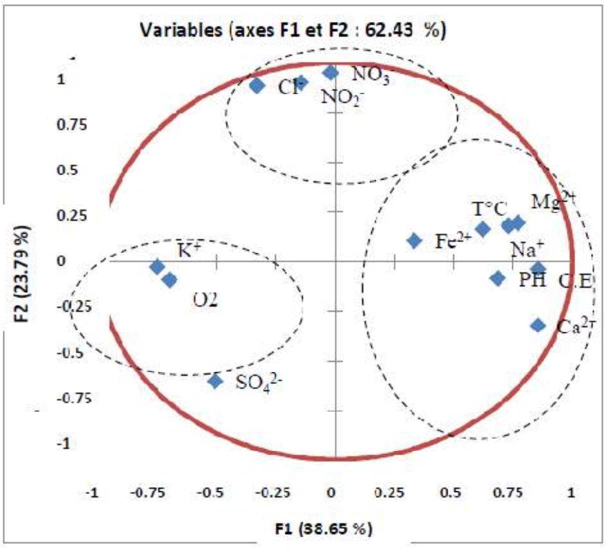

Figure 2: Analysis in the space of variables (factorial F1 - F2).

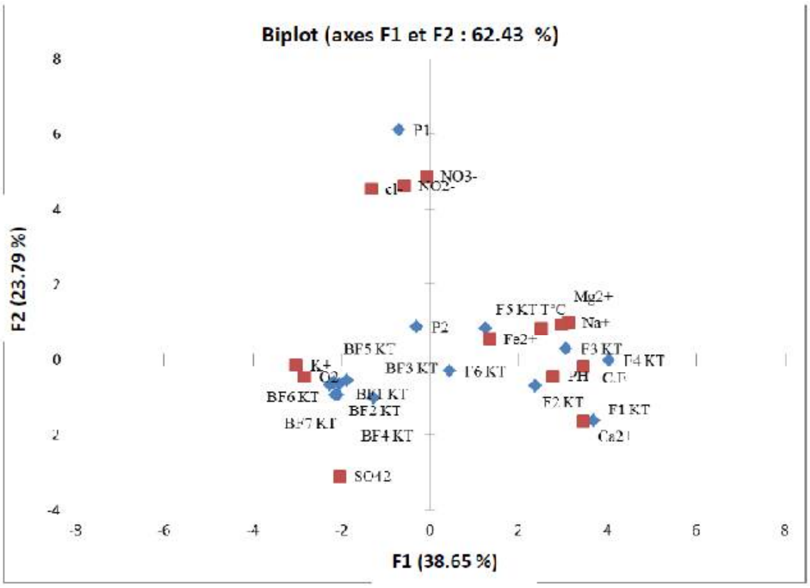

Figure 3: Analysis in the space of statistical units (F1 factorial design - F2).

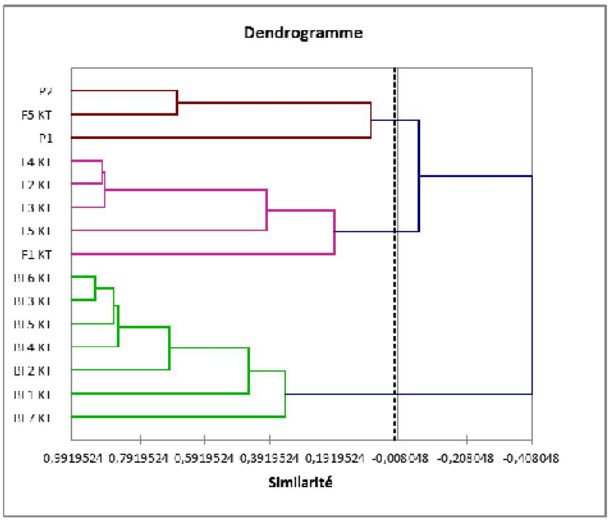

Figure 4: Dendrogram of the Kouara Tegui district waters.

DISCUSSIONS

Temperatures of the studied groundwater vary between 29 ° C and 34 ° C with an average of 31.2 ° C. The standard being fixed from 25 to 30°C. These waters have temperatures relatively higher than those recommended by WHO. The waters studied were relatively acidic with a pH ranging between 5.2 and 6.4 units with an average pH of 6.02. The acidity of water is mainly related to the production of CO_2 by the action of biological activities [15]. The CO_2 hydration reaction releases carbonic acid attacking rocks [16]. The waters values of electrical conductivity conform to WHO standards. The waters present elements of trace metals, with values exceeding WHO standard of potability. The acceptable maximum level of iron in a drinking water was set at 0.3 mg / L by WHO. This standard has been defined to respond more to aesthetic criteria and taste than health criteria. Indeed, ingestion of iron seems more necessary to man. This element is usually recommended for men with iron deficiency. However, high levels of iron confer an unpleasant metallic taste to water, appearance, and a reddish brown color that bring rural people to turn to other sources of supply whose bacteriological and parasitological quality may be questionable. In addition, the development of iron bacteria, increasing corrosion can be observed in drill holes, making them vulnerable to other sources of pollution that significantly degrade the quality of these waters [13]. The levels of sulfate can be considered eligible vis-à-vis the standards at 250 mg / L set by WHO. The presence of nitrites and nitrates indicates recent contamination resulting from sewage infiltration and a lack of oxygen environment [17- 18].

The results of various statistical multivariate analyses made it possible to highlight mineralization mechanisms. Minerals hydrolysis phenomenon in rocks is the primary mechanism for producing ions in the studied waters.

So in addition to the mineralization of the waters by hydrolysis, Principal Components Analysis showed that two other phenomena were involved in the mineralization of the waters in the study area. This is the soils pluviolessivage and the intervention of anthropic activities in the pollution of surface waters and shallow groundwater. The impact of anthropic activities on water quality is a major problem in the world and the subject of several studies [19-21]. According Luu et al. [22], the contributions of particles are linked to agricultural runoff.

The influence of the phenomena (water-rock contact, anthropisation and pluviolessivage) in mineralization revealed three groups of waters. The waters of the first group (well waters) are waters under high human pressure, twice polluted by poor sanitation of wastes in outlying areas that are dumps of the capital. The second group consists of boreholes waters whose mineralization is the most important, and finally boreholes waters of intermediate mineralization, constituting the third group.

CONCLUSION

The study of the hydrogeochemical characteristics of water resources in Kouara Tegui Niamey in Niger was made from the combination of hydro chemical methods and multivariate statistical analysis. The study of physico-chemical parameters showed high chemical variability of groundwater. This study also revealed that groundwater is physically and chemically throughout consistent WHO recommended except the pH standards indicating that the waters district Kouara Tegui water were acidic.

The Principal Component Analysis and Hierarchical Ascending Classification (CHA) indicate that mineralization of the waters studied is controlled by three phenomena. This is the residence time or hydrolysis mineralization of soil pluviolessivage for surface water (surface water and well water) and the influence of human activities in the production of polluting waste. The influence of these phenomena in the mechanism of acquisition of ions in water allowed us to distinguish three classes of waters. Water with high mineralization are those of drilling at intermediate water mineralization are those of fountains and water wells under high anthropogenic pressure.

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