Asian Journal of Environment & Ecology

Volume 22, Issue 2, Page 40-49, 2023; Article no.AJEE.104195
ISSN: 2456-690X

Evaluation of the Quality of Undeveloped Spring Waters Consumed Directly by the Local Population of Kasaï (Democratic Republic of Congo)

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Authors' contributions

This work was carried out in collaboration among all authors. Author CFN designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors CIN and EMB managed the analyses of the study. Authors CFN and DEM managed the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/AJEE/2023/v22i2479

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/104195

Original Research Article

Received: 05/06/2023
Accepted: 09/08/2023
Published: 14/08/2023

ABSTRACT

Objective: Contribute to the assessment of the quality of undeveloped spring water consumed by the local population of the province of Kasai in the Democratic Republic of Congo.
Design of the Study: This study consists of four parts, an introduction with literature review, a description of the study environment and sampling site, the materials and methods used and finally the presentation and discussion of the results obtained.
Location and Duration of the Study: This study was conducted in the province of Kasai, in the villages of Kamupafu, Kabilowa, Kayonga, Kankondo, Kankala, Lunyanya and Kumbikumbi in the town of Tshikapa. The study covered the period from September 29 to October 24, 2022.

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Methodology: The water samples taken (27) were carried out in the laboratory according to standard procedures and a series of physico-chemical and microbiological characterization analyzes were also carried out in the field and in the laboratory.
Results: Among other results obtained, it appears that the average pH was between 4.6±0.15 and 6.96±0.43; the EC between 12.91±0.51 $\mu S.cm^{-1}$ at the Dido/Milonga spring and 26.87±3.00 $\mu S.cm^{-1}$ at the Tshitenga spring. The turbidity, the soluble ion (NO_3^-, F^-) and arsenic (As) contents in the water reveal that with the exception of the turbidity in the Kamitutungulu spring (10 ± 1.04 NTU), the concentration of the other elements in the water from all the springs studied complies with WHO recommendations for drinking water quality. In addition, the average values (CFU 100 mL^{-1}) of total coliforms vary between 18 (KAMANKONDE/ROBERT) and 81 (KATOKA 3) for waters of all the springs.
Conclusion: All spring waters analyzed showed microbiological contamination by bacteria indicating faecal pollution (coliforms). It's therefore suggested that support be provided in terms of drinking water supply and hygiene by setting up village water supply structures.

Keywords: Evaluation; quality; water; undeveloped springs.

1. INTRODUCTION

The world is currently experiencing rapid urbanization that is leading to an increase in disadvantaged urban populations, which reinforces the exclusion of the poorest and most marginalized people, and widens inequalities in access to water, sanitation and Hygiene (WASH) [1]. The International Decade for Drinking Water and Sanitation (1981-1990) decreed by the United Nations brought renewed interest to the sector of drinking water supply and sanitation (AEPA) . Its mission was to promote access to drinking water for all. Its target group was low-income rural and urban communities. Four guiding principles have been proposed to enable equitable sharing of water [2]:

- protecting the environment and safeguarding health through the integrated management of water resources and both liquid and solid waste;
- institutional reforms aimed at promoting an integrated approach, a change in methods, attitudes, behaviors and the full participation of women at all levels;
- community management of services, supported by measures aimed at strengthening the capacity of local institutions to implement and sustainably manage drinking water supply and sanitation problems;
- sound financial management, thanks to better management of existing equipment and the generalization of appropriate technologies.

Also, in this perspective, the sixth Sustainable Development Goals aims to ensure universal access to drinking water and sanitation, but also to improve the quality of water and to contribute significantly to the reduction pollution, and among other things ensuring adequate use of water [3]. The National Water and Sanitation Action Committee at the national level is responsible for coordinating actions. The rural world in the province of Kasai, as mentioned before, is supplied with drinking water through many water points, mainly groundwater, whether or not developed, and sometimes rainwater collected from the roofs of houses; most water sources are not protected in any way. However, unlike in urban areas, water supply in rural areas is very restrictive and even very complex, since women and children are forced to travel many kilometers to fetch water. They leave early in the morning and return late with a weight of up to fifty kilos. Women therefore spend more time in search of drinking water, sacrificing other productive household activities.

1.1 Objective

The objective of this study is to assess the quality of undeveloped spring water consumed directly by the local population of Kasai province in DR Congo in order to meet sustainable access to drinking water in Kasai province.

2. STUDY SITES, MATERIALS AND METHODS

Kasai is since 2015 a province of the Democratic Republic of Congo following the breakup of the province of KasaÏ Occidental. With an area of 95,631 km² and a total population of 2,978,000 inhabitants, it is located in the center of the country on the Kasai River, between 5° 21′ 00" South and 21° 25′ 00" East [4,5]. It borders 6 Congolese provinces and one Angolan province to the south. It is therefore limited:

- In the north: by the provinces of Mai-Ndombe, Tshuapa and Sankuru ;
- In the South: by the province of Kwango and the Angolan province of Lunda North ;
- In the East: by the province of Kasai Central ;
- In the West: by the province of Kwilu.

Administratively, it is divided into one city and five territories, including the city of Tshikapa which is its capital and the territories of Dekese, Ilebo, Luebo, Mweka and Tshikapa (Kamonia) (Fig. 1).

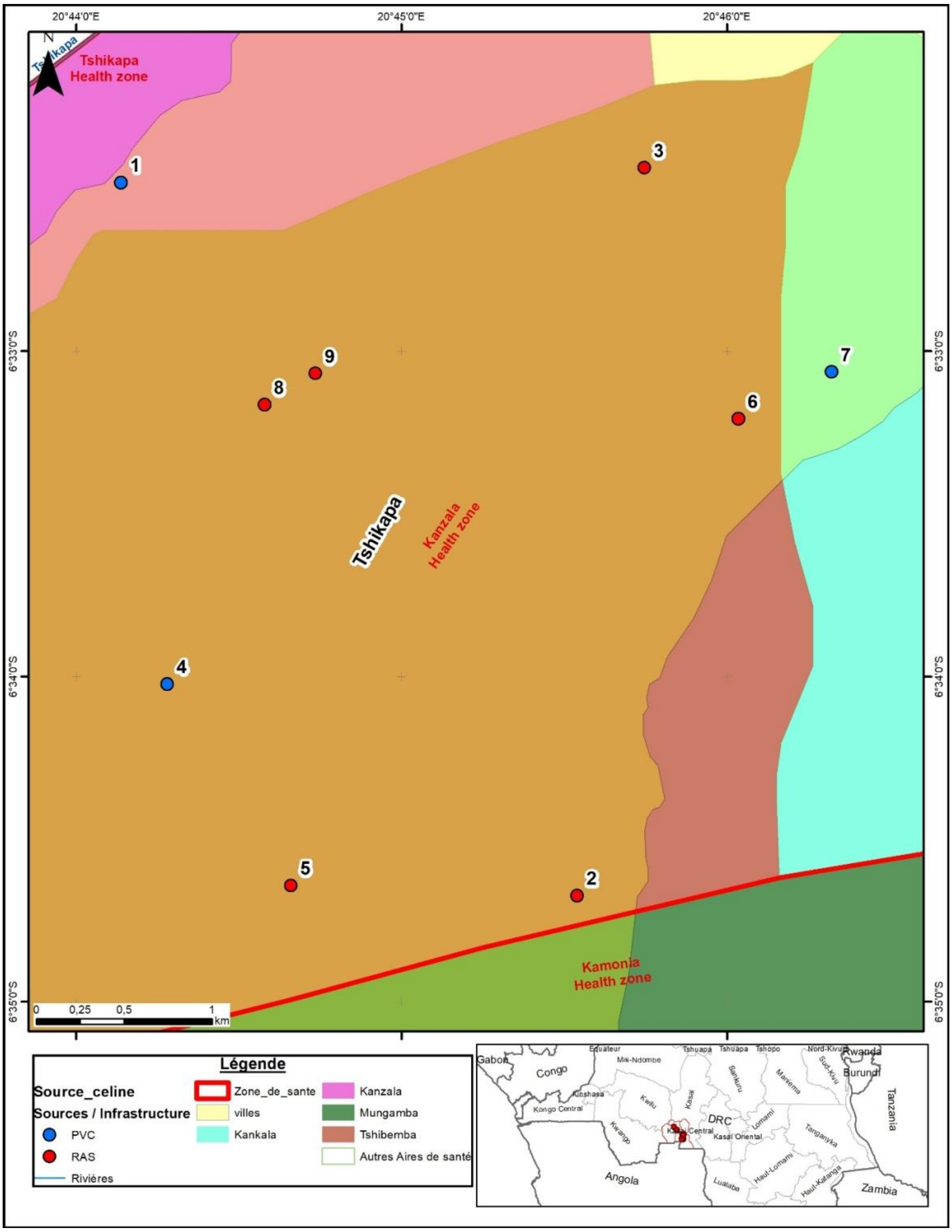

Fig. 1. Map of Kasaï province with overview of sampling sites in Tshikapa

Kasaï province is one of the country's provinces affected by water scarcity. This province is experiencing a shortage that restricts access to drinking water to the local population who often obtain water of poor quality and in insufficient quantity for needs with all the consequences on human health.

2.1 Methodology

2.1.1 Observation

Observations made at the sampling sites reveal questionable macroscopic characteristics (Fig. 2). Indeed, the indices on the coloring and the odors of the waters reinforced these observations and made it possible to formulate the first hypotheses on a possible contamination and the need to proceed by the characterization analyzes to evaluate the quality of these spring waters consumed by the population.

2.1.2 Water sampling procedure

According to the strategy implemented by Kapembo et al. [6], 27 spring water samples were taken manually in triplicate at 9 sites. Water is collected by directly dipping a polypropylene plastic container (500 ml) into it. Once collected, the samples were kept in a cooler at 4°C and transported to the laboratory for analysis within 24 hours according to [7]. The samples were labeled according to the name of the village where they were taken. The geographical coordinates of the sampling sites and the names of the villages and springs are reported in Table 1.

2.1.3 Physico-chemical characterization of water

In situ measurements of the parameters were made immediately in the sources using a multi-parameter 350i (WTW, German brand). For the measurement of these parameters (pH, temperature, conductivity, turbidity, TDS), the multi-parameter is calibrated from the boat and then launched at each sampling station. The values obtained are displayed on the screen where they are carefully recorded by the operator. For the measurement of transparency, the principle is to lower the disc into the water using a graduated rope until it disappears.

Fig. 2. Some sampling points in the 9 sites (photos taken by Nyembo in September 2022).

Table 1. GPS coordinates of water sources

Village	Source	Geographical coordinates		Distance
		Latitude	Longitude	
FERME DIDO	KAVUDI 2	S6°32'28,885''	E20°44'8,257''	1020 m
KIBILOWA 1	KAMANKONDE/ROBERT	S6°34'40,354''	E20°45'32,392''	900 m
KAYINGA	KAMITUTUNGULU	S6°32'26,167''	E20°45'44,805''	800 m
KANKALA 1	MWABEYA 1	S6°34'1,348''	E20°44'15,781''	730 m
KANKALA 2	BAFANA	S6°34'38,51''	E20°44'39,624''	830 m
LUNYANYA	TSHITENGA	S6°33'12,449''	E20°46'2,1''	680 m
KUMBIKUMBI	KATSHIBANGU	S6°33'3,812''	E20°46'19,3''	800m
FERME DIDO	FERME DIDO	S6°33'9,828''	E20°44'34,738''	630 m
FERME DIDO	DIDO/MILONGA	S6°33'7,499''	E20°44'34,836''	600 m

The concentration of dissolved ions (NO_3^-), arsenic and fluoride was measured using ion chromatography (Dionex ICS3000, Canada) according to the method described by [8,9]. In addition, the certified water material (CRM, Ontario-99, Water Research Institute, Canada) was used to verify instrumental accuracy using the technique described by [7]. Thus, the results obtained from the CRM were within the acceptance range indicated on the CRM certificate.

2.1.4 Microbiological characterization of water

Microbiological analyses were used to identify and enumerate total coliforms and faecal coliforms. These microorganisms were identified and enumerated using the membrane filtration method [10,6]. For each sample, triplicatas of 100 mL of water were passed through a 0.45 mm filter (Sartorius stedim, biotech, German brand), The membranes were then placed on selective media for 24 hours at 37 ° C in the thermo-stated oven. The following media were used:

- For the analysis of ENT bacteria: each water sample was inoculated in the Slanetz Bartley Agar medium (SBA) and incubated at 44 ° C for 48 h, then transferred to the Bile Aesculin Agar medium (BAA) at 44 ° C for 4 h, and in the Endo Agar medium, incubated at 35 ° C for 24 h for CT.

Results are expressed in colony forming units (CFU) per 100 mL of water sample (CFU/100 mL). The reproducibility of all experimental procedures was tested using triplicatas. Field and laboratory controls were performed as described in previous studies [9,11].

2.1.3 Statistical analyses

All water sample analyses were performed in three dilution replicates to quantify the FIB to establish the standard deviation of colony counts [12]. Statistical analysis of the data was conducted using SigmaStat 11.0 (Systat Software, Inc.). The data were subjected to a Spearman rank correlation test to investigate possible relationships using RStudio statistical software, version 1.3.1093, 2009-2020 RStudio, © PBC.

3. RESULTS AND DISCUSSION

3.1 Physico-Chemical Characteristics of Spring Water

The results of the physicochemical parameters of the water, in particular the temperature (T), the pH, the electrical conductivity (EC) and the level of dissolved solids (TDS) of the source waters are reported in Table 2. The values of T, EC, TDS and turbidity observed at all sampling sites are within the values recommended by the World Health Organization guidelines for drinking-water quality [13].

The water temperature was higher in the waters of four springs, namely: Katshibangu, Kamitutungulu, Bafana and Tshitenga, with maximum values respectively around 26.1±0.4; 26±0.3; 26.4±0.3 and 26.5±0.29^0 C. The pH was between 4.6±0.25 and 6.96±0.43. For the CE, the maximum value of 26.87±3.00 µS/cm was observed at the Tshitenga spring and the minimum value of 12.91±0.51 µS/cm was observed at the Dido/Milonga spring. With regard to the TDS, the values obtained were between 6.45 ± 0.42 and 16.3 ± 1.50 mg/l.

Statistical analysis of variance revealed a significant difference ($P \leq 0.05$) between all parameters analyzed in the nine sources. These values are similar to those of other studies conducted in environments with almost the same characteristics in tropical areas [11,7]. On the other hand, the values obtained by the present study are lower than the values observed by [14] in the waters of springs and wells in the municipalities of Bumbu (Kinshasa). These waters are weakly acidic and little ionized.

The concentration of turbidity, soluble ions (NO_3^-, F^-) and arsenic (As) in water samples are reported in Table 3. Except for turbidity in Kamitutungulu spring (10 ± 1.04 NTU), the concentration of other elements in water samples from all studied sources is in line with WHO guidelines for drinking-water quality [13]. Moreover, all the concentrations obtained varied significantly according to the sampling sites ($P \leq 0.05$).

Several recent studies have addressed the issue of nitrate levels in groundwater and its potential risks to human health [7,15]. Indeed, the low concentrations of NO_3^- observed in the spring waters studied are much lower than those found by [7] in the urban environment of Bumbu and Kimbanseke communes in the city of Kinshasa where the NO_3^- ion levels exceeded WHO recommendations. This difference could be explained by several aspects, including the absence of agricultural activities in the surroundings that could contaminate seepage water rich in chemical fertilizers, the low permeability of the unsaturated zone, the depth of the aquifer, etc. [14,16].

3.2 Microbiological Quality of Spring Water

The microbiological quality of the water samples taken from the springs is presented in Table 4. For these undeveloped springs, the average FIB values (faecal coliforms and total coliforms) were between (2 – 5) x 10^3 and (18 – 81) x 10^3 CFU / 100 mL, for faecal coliforms and total coliforms respectively. Faecal coliform and total coliform levels in water samples varied significantly between sampling sites and seasonal variations ($P < 0.05$). Bacteriological water pollution was significantly higher with respect to total coliforms. Indeed, in the waters of all springs, the average values (CFU / 100 mL) of total coliforms vary between 18 (KAMANKONDE/ROBERT) and 81 (KATOKA 3). As for pollution by faecal coliforms, some sources have been concerned by the presence of germs. But surprisingly, no faecal coliform contamination was observed in the water samples taken from 5 of the 9 springs (KAMANKONDE/ROBERT, BAFANA, TSHITENGA, FERME DIDO and DIDO/MILONGA).

Thus, these results suggest the presence of faecal contamination (total coliforms) in at least all the sources, indicating that the water from these sources cannot be used for domestic purposes in accordance with the WHO regulations for domestic water, which recommends 0 CFU / 100 mL [17]. These springs are undeveloped and unmanaged (considered public property), close to cattle ranches, etc. This constitutes a great challenge for users for public health since these waters are often consumed raw. Our observations corroborate those of [11] in their study carried out in a similar environment (Kikwit, DRC). Indeed, these authors stipulate that during the rainy season, for example, rainfall in tropical areas is of great intensity and carries contaminated soil from watersheds which, in turn, contaminates streams, rivers and springs. with faeces, especially during the rainy season.

The results of this study demonstrated that the microbiological analysis of water samples from 100% of the unmanaged/undeveloped sources (with the exception of 5 sources for faecal coliforms) is highly contaminated with faeces. Therefore, water from these sources is likely to contain pathogenic organisms that cause water-borne diseases such as gastrointestinal diseases, typhoid, cholera and other diarrheal diseases [18,19]. The deterioration of the microbiological quality of water from these sources can be explained by several causes, including open defecation and the short distance between toilets and water sources, percolation of contaminated surface soils during rainy events, infiltration of toilets located near sources, and direct contamination by users who are not aware of the management of drinking water sources.

3.3 Statistical Correlation

The data obtained were subjected to a Spearman correlation analysis which made it possible to identify the possible relationships between the parameters analyzed. The results of this analysis are presented in Table 5 shown. In general, no significant correlation was observed between physicochemical parameters and bacteriological parameters (faecal coliforms and total coliforms) of these source waters.

Table 2. Physico-chemical parameters (temperature T, pH, Electrical Conductivity (EC) and rate of dissolved solids (TDS)) of water samples from springs at 9 sites

SOURCE	T°C	Ph	CE (µS/cm)	TDS (mg/l)
Kavudi 2	25.4±0.22	6.25±0.12	18.30±0.56	9.01 ± 0.90
Kamankonde/Robert	25.1±1.15	4.6±0.15	17±1.12	8.36 ± 0.53
Kamitutungulu	26±0.3	5.63±0.36	32.5±2.14	16.3 ± 1.50
Mwabeya 1	25.6±1.2	4.68±0.25	20±1.50	9.58±0.53
Bafana	26.4±0.3	5.37±0.11	24.32±1.84	12.08±0.23
Tshitenga	26.5±0.29	5.7±0.55	26.87±3.00	12.89±0.40
Katshibangu	26.1±0.4	6.5±0.30	17.8±1.14	8.69±0.80
Ferme Dido	25.3±0.46	6.96±0.43	26.84±0.96	13.07±0.12
Dido/Milonga	25.4±0.6	6.20±0.30	12.91±0.51	6.45±0.42
Normes de l'OMS*	25	6.5-9	100-1500	<500

** Limit recommended by the World Health Organization guidelines for the quality of drinking water [13]*

Table 3. Physico-chemical parameters (Turbidity, Nitrates (NO_3^-), Fluorides and Arsenic of water samples from springs at 9 site

SOURCE	Turbidite (NTU)	Nitrate (mg/l)	Fluorure (mg/l)	Arsenic (µg/l)
Kavudi 2	0	16.28±0.10	0.36±0.01	0
Kamankonde/Robert	0	2.34±0.12	0.38±0.11	0.02
Kamitutungulu	10±1.04	2.26±0.19	0.36±0.02	0.003
Mwabeya 1	0	1.44±0.23	0.34±0.05	0
Bafana	0	7.20±0.05	0.30±0.03	0
Tshitenga	0	10.60±0.07	0	0
Katshibangu	1.0±0.57	1.35±0.39	0.40±0.04	0.02
Ferme Dido	0	5.41±0.06	0.30±0.02	0.07
Dido/Milonga	1.0±1.12	10.38±0.29	0.37±0.01	0
Normes de l'OMS*	<5 NTU	< 50 mg/l	< 1.5 mg/l	10 µg/L <

** Limit recommended by the World Health Organization guidelines for the quality of drinking water [13]*

Table 4. Microbiological analyzes of pring waters

SOURCE	COLIFORMES FECAUX (UFC ± SD x 10^3 100 mL^{-1})	COLIFORMES TOTAUX (UFC ± SD x 10^3 100 mL^{-1})
KAVUDI 2	5 ± 1.51	40 ± 0.91
KAMANKONDE/ROBERT	0	18 ± 3.37
KAMITUTUNGULU	3 ± 0.25	19 ± 1.02
KATOKA 3	2 ± 0.23	81 ± 1.30
BAFANA	0	15 ± 2.51
TSHITENGA	0	80 ± 11.8
KATSHIBANGU	3 ± 0.79	40 ± 1.36
FERME DIDO	0	65 ± 1.88
DIDO/MILONGA	0	69 ± 1.13
Normes de l'OMS*	0	0

** Limit recommended by the World Health Organization guidelines for the quality of drinking water [13].*

These results suggest that the physicochemical and bacteriological parameters can be considered as coming from different sources. However, a significant positive correlation was observed between Total Coliform and pH ($R= 0.47791938$, $P < 0.001$) and between Total Coliform and pH again ($R= 0.27867873$, $P < 0.001$). Indeed, these results indicate that faecal coliform and total coliform could not come from common sources and be transported in the sources by common transporters. These observations are different from those made in some previous studies [9,20] which showed that the two forms of pollution are often correlated.

Table 5. Spearman order correlation of selected parameters in source water

	T °C	pH	CE	TDS	Turbidité	Nitrates	Fluorures	Arsenic	Coliformes fécaux	Coliformes totaux
T °C	1									
pH	-0,26816633	1								
CE	0,30422013	-0,03085112	1							
TDS	0,26560701	-0,35863155	0,0275283	1						
Turbidité	-0,12777503	-0,10487778	-0,10125996	-0,10413278	1					
Nitrates	-0,16490797	0,19491822	0,20415065	-0,04938775	0,28371319	1				
Fluorures	-0,23274035	-0,05929906	0,03851781	0,00881812	0,04173698	-0,08790066	1			
Arsenic	-0,09630099	0,18711151	-0,03179052	0,0512063	-0,14143328	-0,03668091	0,33984747	1		
Coliformes fécaux	0,17392841	0,27867873	-0,05284439	-0,08115997	0,15021933	0,03528893	0,03241199	-0,10865438	1	
Coliformes totaux	0,0166182	0,47791938	0,0910007	-0,12243778	-0,32543253	0,06977259	-0,44331538	0,05600656	0,07571938	1

4. CONCLUSION

The main objective of the study carried out on the evaluation of the quality of undeveloped spring water and consumed directly by the local population of Kasai was to verify the physico-chemical and microbiological quality of 9 springs (Kavudi 2, Kamankonde, Kamitungulu , Mwabeya, Bafana, Tshitenga, Katshibangu, Ferme dido and Dido milonga). To carry out this research, a field trip was made to collect the samples. The multiparameter probe was used to sample the physico-chemical parameters in situ. The most threatening parameters remain pH, temperature and turbidity, the averages of which remain high. Indeed the key results are the values of the acidic hydrogen potential observed in all nine sources, from 4.6 to 6.96; the Kamitutungulu site turbidity is higher than normal so 10 NTU and the temperatures of 4 sites are slightly elevated 26.1 to 26.5°C. The microbiological analysis of water samples from 100% of unmanaged/undeveloped sources (with the exception of 5 sources for faecal coliforms) shows a strong contamination by faeces following the presence of coliform germs, some of which can cause waterborne diseases.

The results obtained make it possible to conclude that the waters of these nine springs consumed by the population of Kasai do not meet the standards of drinking water and present a health risk for the population. The absence of effective sanitation and maintenance structures for these springs would be one of the major causes. It goes without saying that measures must be taken to preserve the health of the population, such as those centered on the regular maintenance and protection of springs before their use in order to eliminate pathogenic germs, hygiene and sanitation in their environment, as well as the establishment of a committee responsible for maintaining these springs and monitoring the implementation of these measures. It is imperative to promote research on drinking water and sanitation across the country in order to reduce the likelihood of waterborne diseases.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/104195