Drinking water quality and risk for human health in Pelengana commune, Segou, Mali

Amadou Toure, Duan Wenbiao, Zakaria Keita, Abdramane Dembele and Elsamoal Elzak Abdalla Elzaki

ABSTRACT

Water is an indispensable commodity for the survival of all living beings and for their well-being. The objective of this work is to evaluate the level of pollution of different drinking water sources consumed and its link with health in Pelengana commune, Mali. Samples of water were taken from various sources, namely, hand pumps, boreholes, dug wells, and shallow wells for physical, chemical, heavy metals, and bacteriological analyses, using American Public Health Association (APHA) Standard Techniques. Results revealed that the nitrate-nitrogen (NO_3^-N) values of the water samples from the different water sources had concentrations exceeding the United States Environmental Protection Agency's (US-EPA) regulation of 10 mg/L, as well as World Health Organization Guideline for Drinking Water Quality (WHO GDWQ) (11 mg/L). The same applies to heavy metals such as Cd, Pb, and Fe, in which, concentrations exceed their allowable limits in certain locations. Moreover, apart from water samples from some different boreholes, total coliform, and *Escherichia coli* have been detected in all selected water sources, which indicates fecal contamination. In all, there is a pressing need to stop the consumption of drinking water from contaminated sources and to effect appropriate treatment.

Key words | bacteriological, drinking water, health risk, heavy metals, Mali, water quality

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INTRODUCTION

Water is a renewable resource permanently threatened by pollution, among others, of demographic, agricultural, and industrial origins. Access to safe water may be a requirement for health, a basic right, and a key element of effective health protection policies. Its use for food, bodily hygiene, or recreational purposes requires a high level of physical, chemical, and microbiological quality. Contamination of water resources has significant impacts on the environment and on human health (Melloul *et al.* 2002; Hassoune *et al.* 2010). However, groundwater accounts for the safest and a significant source supply of drinking water in the world (Palamuleni & Akoth 2015). Roughly 1.5 billion people all over the world are daily provided drinking water through the groundwater (Iyasele & Idiata 2012). Indeed, it was found that groundwater was the foremost reliable source for responding to water request in rural areas of low-income countries (Harvey 2004). Nevertheless, groundwater quality will be changed once external substances are available to contact with the geological formation (i.e., aquifer). Unwanted material renders groundwater inappropriate for numerous utilizations, particularly for drinking need.

Typically, drinking water having various chemicals and heavy metals, in particular arsenic, cadmium, lead, mercury, chromium, iron, etc., has noticeable negative repercussions

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on human health, either thanks to a lack or extreme consumption. It is valuable to note that the presence of arsenic in drinking water is a major global health issue. The influence of this chemical on human health has widely surpassed the remaining chemical contaminants assumed to be found in drinking water, yet it is globally hidden by the human health effect of microbial contamination (Sorlini *et al.* 2013). After arsenic (As) was detected in Bangladesh, a considerable number of countries have performed certain chemical analyses with regard to it. Unfortunately, in the majority of cases, there are few or no data accessible on As in drinking water (Sorlini *et al.* 2013). In addition, Pb, Cr, Cd, and Hg are also hazardous to human health because they are poisonous and may be carcinogenic. Unfortunately, few investigations have been performed to evaluate their content in drinking water in low-income countries. Of course, nitrates and nitrites are naturally present in water and the toxicology of nitrate to humans results principally in its reduction to nitrite (Ikemoto *et al.* 2002). The major biological effect of nitrite is its involvement in the oxidation of normal hemoglobin to methemoglobin, which is unable to transport oxygen to the tissues. The dominant human health risk associated with nitrate consumption is considered to be of methemoglobinemia by nitrate-derived nitrite (Saadia *et al.* 2007). Heavy metals are naturally present in groundwater at concentration levels that depend on rock and sediment type (Moyo 2013). Moreover, thoroughgoing utilization of natural resources and accumulated activities of anthropic origin can cause grave groundwater quality problems due to the removal or spread of chemical and microbic substances on the surface of the soil and into soils or by the direct intrusion of waste into the water table (Dahhou *et al.* 2016).

Governments, the WHO and several other development partners have tried to extend water distribution systems in order to ensure potable water supply in low-income countries. Some noteworthy statistics from the WHO/UNICEF Joint Monitoring Program 2017 (JMP) for Water and Sanitation reveal that in low-income nations, roughly 748 million people do not have access to sufficient safe drinking water. Additionally, 2.4 billion human beings lack access to improved sanitation conditions (WHO & UNICEF 2017). However, the low coverage of drinking water and the risk behaviors of populations are at the origin of serious diseases such as diarrhea, typhoid, paratyphoid fever, and amoebic dysentery (Melloul *et al.* 2002; Hassoune *et al.* 2010).

Being a developing country, Mali needs to address a vast array of problems regarding water availability, quality, usage, and death caused by waterborne diseases. In Mali, potable groundwater has given a greater boost to the availability in general and is being utilized through dug wells, hand pumps, and shallow wells. The National Health Directorate (DNS) has responsibility for regulating the standards of drinking water. The agency has published guidelines for drinking water quality. Unfortunately, most of the populace in rural areas of Mali do not adhere to these guidelines. The rising interest of the private sector in groundwater development has encouraged the Government of Mali to transfer operational responsibilities of public sector boreholes to the private sector. Over 70% of the populace of Pelengana commune is currently supplied with water by hand pumps, dug wells, shallow wells, and boreholes (CPS/MS DNSI/MEIC 2007). Despite the fact that bacterial contamination could be the number one concern in the commune of Pelengana, inorganic contaminants and health risks pose an additional risk to water from these sources. Overall, the great majority of households in the rural area of Pelengana commune use the traditional pit latrine. However, it absolutely was detected that the drinking water sources in certain localities are more or less a 30 m or less radius from pit latrines, refuse tips, and other social amenities, which accentuates the hazard of contamination of the water table which provides villages. At the moment, there is no form of treated water supply in this area. Moreover, there is no relevant information offered about the water quality as well as the dominant water-associated diseases within the commune of Pelengana. It is thus in this context that the physical, chemical, and bacteriological parameters of drinking water in Pelengana commune were evaluated, as well as human health risks linked with the consumption of contaminated water.

MATERIALS AND METHODS

Study area description

The present study has been carried out in the Pelengana commune in Segou region of Mali in West Africa (Figure 1).

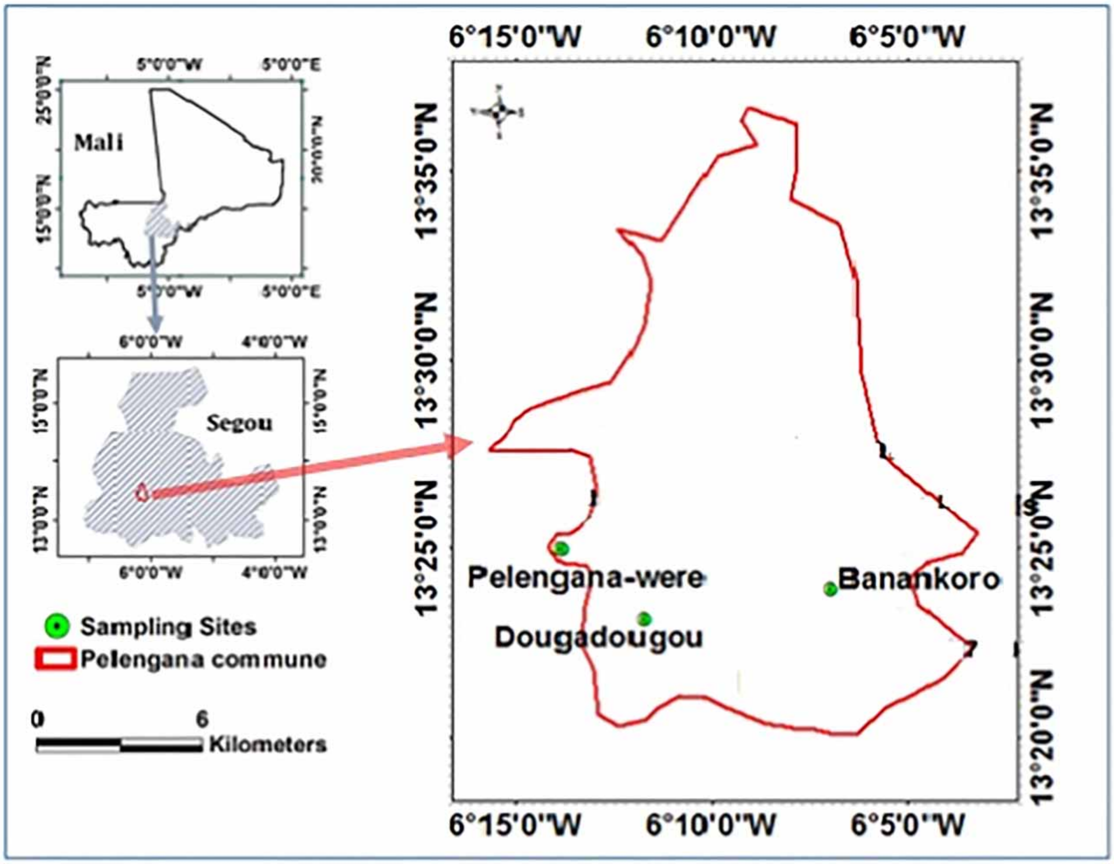

Figure 1 | Map of sampling sites in the rural commune of Pelengana.

Pelengana commune is found in the south of Mali, at a distance of approximately 235 km from the capital Bamako. It has a total population estimated at 118,814 inhabitants as of the populace and habitat census of 2009. The population density for the commune is estimated at 37.8 inhabitants per km^2, with an annual growth rate of 3.1% (INSTAT 2011). It is located between 13°26′ at latitude north and 6°12′ at longitude east. The Sudano-Sahelian type climate is marked by the alternation of two periods (i.e., two seasons): a rainy period from June to September and a longer dry season from October to May. Precipitation is quite low, with an annual mean of up to 625 mm/year, with the highest precipitation recorded in August. The average annual temperature is around 28 °C with a significant duration of sunshine which varies from 2,500 to 3,000 hours. Residents of the different villages of the area practice agro-pastoralism, relying mainly upon agriculture, including millet, groundnut, cotton, and vegetables. Hand pumps, dug wells, shallow wells, and boreholes are the most common sources of drinking water in the Pelengana commune.

Water sample collection

The water samples were collected from March to July 2018 from different water sources for physical, chemical, and bacteriological analyses. These include 4 hand pumps, 3 boreholes, 5 dug wells, and 12 shallow wells in the village of Pélengana-Wèrè; 5 hand pumps, 3 boreholes, 6 dug wells, and 17 shallow wells in Banankoro village; and 7 hand pumps, 3 boreholes, 9 dug wells, and 23 shallow wells in Dougadougou village. Samples were collected between 08.00 hrs and 10.00 hrs into a 1 L sterilized polyethylene flacon and, at each sampling point, two samples were collected in separate polyethylene flacons. All collection flacons were first washed with detergent, then rinsed with tap water and distilled water, and lastly rinsed three

times with the sampled water from the respective source stated above. Different sampling methods were used for various categories of water sources. Samples from the dug wells and shallow wells were collected with weighted buckets (50 cm below the water table). Boreholes and hand pump samples were taken after pumping for 5 min. Note that for chemical and bacteriological analyses, separate samples have been carefully collected and at each point a vial was filled with the site water sample while adding HNO_3 to 5% in order to prevent bacterial survival. The water samples were fastidiously tagged and kept in a cooler at temperatures ranging from 0 °C to 4 °C. Finally, they were delivered to the microbiology laboratory within 6 hours of their collection for further processing. In the laboratory, acidified water samples were used for heavy metal analysis, whereas water samples that did not contain acid were used for the remainder of the analysis.

Analytical procedures

It is necessary to examine the physico-chemical and bacteriological quality so as to determine the degree of water pollution regarding the different parameters, and also the hazards to human health related to consumption of water affected by contaminants within the investigated zone. All parameters were monitored in accordance with the American Public Health Association Standard Techniques (APHA 2012).

The hydrogen potential (pH), electrical conductivity (EC), and the salinity were measured in place employing a multimeter (Model HQ 40d, Hach, USA). First, the meter was calibrated employing both buffers at pH = 4.01 and pH = 7.0 and was then flushed extensively with deionized water. After five measurements the meter was checked. With respect to electrical conductivity, the meter was calibrated employing a 1,000 μS/cm NaCl standard solution and checked after five analyses. Total dissolved solids (TDS) was measured employing a multimeter (Sension-156, Hach, USA). Similarly, the meter was calibrated employing a 1,000 mg/L TDS standard solution and checked after five measurements. Salinity was determined using water checker U-10.

Chloride (Cl) concentration was ascertained in the laboratory using standard titrimetric technique (APHA 2012). To do this, a silver nitrate (BDH, UK) solution (0.0141 N) and potassium chromate (K_2CrO_4) were employed as titrant and indicator, respectively. Moreover, NaCl was employed to determine the resistance of silver nitrate. It should be noted that the pH of water was handled in such a way that it was between 7 to 10 pH units, and 1 mL of K_2CrO_4 indicator solution (BDH, UK) was added. The resulting solutions were then titrated with $AgNO_3$ Standard to a pinkish-yellow eventual result. The titrant was normalized and the reactant blank value determined (APHA 2012). The nitrate-nitrogen (NO_3^-N) and phosphate (PO_4^-P) concentrations were ascertained using ultraviolet spectrophotometer, HACH 2800, employing standard ethylene diamine tetra-acetic acid (EDTA) as directed by the American Public Health Association (APHA 2012).

The concentrations of Hg, Cd, Pb, Cr, Mn, Fe, As, and Cu were determined using flame an atomic absorption spectrophotometer (AAS) Shimadzu model AA 6300. For the analysis of mercury, 5 mL of concentrated H_2SO_4 and 2.5 mL of concentrated HNO_3 were added to 100 mL of water sample and thoroughly shaken to get a homogeneous mixture. 15 mL of 5% (w/w) of $KMnO_4$ and 8 mL of 5% (w/w) potassium persulfate were added to the mixture and heated at 95 °C for 2 hours. The mixture was then allowed to cool to room temperature and 6 mL of 12% (w/w) hydroxylamine hydrochloride were added to the resulting solution to reduce the excess permanganate. The digested solution was stored for analysis (APHA 2012). In the Hg determination, a carrier solution containing 3% (v/v) HCl and a reducing agent 1.1% (m/v) $SnCl_2$ in 3% (v/v) HCl was added to digest the sample to generate Hg vapor which was determined by cold vapor using a Shimadzu model AA 6300. For the determination of cadmium, 100 mL of acidified water sample was mixed with 5 mL each of conc. HNO_3 and conc. H_2SO_4. The mixture was heated until the mixture was reduced to about 20 mL on a hot plate. The digested samples were cooled to room temperature, filtered through a 0.45 μm Whatman filter paper and the final volume adjusted to 100 mL with double distilled water and stored for analysis (APHA 2012). For the determination of As, 5 mL of 0.5 MHCl and 5 mL of 0.5% $NaBH_4$ were added to the digested water samples to reduce all As to arsine gas, in the arsine gas generator. The arsine gas generator is coupled to the flame AAS (Shimadzu model AA 6300) for the determination of As in the samples.

With regard to bacteriological analyses, only the specific indicators of environmental and fecal contamination (total

coliforms and *Escherichia coli*) were searched for. They were enumerated in 50 mL aliquots of the water sample. In addition, aliquots of each water sample were filtered using 0.45 μm paper filters. So as to detect total coliforms and *E. coli*, the filter papers were placed onto m-FC and m-ENDO agar followed by incubation at 45 °C and 37 °C, respectively, for 24 h. Blue and metallic sheen colonies on membrane-fecal coliforms (m-FC) and Endo's medium (m-ENDO) agar plates were filtered and utilized for the microbiological identification assay. The biochemical test was performed and each plate was confirmed and given a positive or negative score.

Health survey

In order to determine the harmful effects of infected water on public health, a questionnaire survey was carried out among the inhabitants of the Pelengana commune. Three environmental science postgraduate students from the University of Bamako were trained as field workers to conduct this survey. Three rural villages in the Pelengana commune were selected for this study, namely, the villages of Pélengana-Wèrè, Banankoro, and Dougadougou. The survey was conducted with 480 randomly selected households per village which totaled 1,440 households (i.e., 2,991 residents including females and males) for the overall study. Questions in the survey included information regarding age, educational status, household income, household size, occupational exposure, waterborne diseases, and other health-related problems. Questionnaires have been fastidiously completed from the respondents of the different villages. The original questionnaire was formulated in French and the interview was conducted in Bambara (common language of Mali). This questionnaire survey was conducted throughout the study zone and entire questions posed to users of each water source. In addition, interviews were performed with health workers from different health centers of the commune in order to collect information about the waterborne diseases in the study zone.

Statistical analyses

The results obtained were analyzed by SPSS version 21.0 statistical software package. From a level $p < 0.05$, the test was retained as being significant, calculated using analysis of variance (ANOVA).

RESULTS

Physical parameters

Results of the physical analysis of the different parameters, such as pH, EC, TDS, and salinity in the water samples of the study area are summarized and presented in Table 1. However, results show that there was no significant

Table 1 | Average loads of certain physical parameters of drinking water collected from different sources in the commune of Pelengana

Target villages	Water sources	pH	EC (μs/cm)	TDS (mg/L)	Salinity (%)
Pélengana-Wèrè	Hand pump ($n = 4$)	6.62 ± 0.34	76.25 ± 07.04	16.02 ± 0.02	0.02 ± 0.00
	Borehole ($n = 3$)	6.54 ± 0.28	72.85 ± 01.05	14.60 ± 0.01	0.01 ± 0.00
	Dug well ($n = 5$)	6.91 ± 0.36	84.26 ± 1.10	17.15 ± 0.15	0.015 ± 0.01
	Shallow well ($n = 12$)	7.14 ± 0.42	86.18 ± 1.40	21.10 ± 0.25	0.03 ± 0.01
Banankoro	Hand pump ($n = 5$)	7.26 ± 0.23	106.23 ± 11.07	22.85 ± 0.04	0.04 ± 0.01
	Borehole ($n = 3$)	7.04 ± 0.17	104.81 ± 10.18	20.04 ± 0.05	0.04 ± 0.00
	Dug well ($n = 6$)	6.95 ± 0.25	99.76 ± 8.10	19.12 ± 0.27	0.03 ± 0.01
	Shallow well ($n = 17$)	7.07 ± 0.37	127.20 ± 2.15	22.16 ± 0.18	0.04 ± 0.00
Dougadougou	Hand pump ($n = 7$)	6.73 ± 0.08	88.14 ± 2.11	16.14 ± 0.01	0.02 ± 0.01
	Borehole ($n = 3$)	6.84 ± 0.15	71.80 ± 3.05	16.00 ± 0.20	0.02 ± 0.00
	Dug well ($n = 9$)	6.66 ± 0.09	84.84 ± 1.54	18.44 ± 0.52	0.018 ± 0.01
	Shallow well ($n = 23$)	6.88 ± 0.18	91.55 ± 2.28	20.05 ± 0.13	0.016 ± 0.01
Range		6.42–7.31	69.20–132.50	12.50–27.15	0.01–0.05

TDS, total dissolved solids; ± standard deviation.

difference ($p > 0.05$) in the average values of these parameters. The water samples at the sampling sites had a pH range of 6.42–7.31 with an average values' range of 6.54–7.26. The optimum acceptable pH range for drinking water varies from 6.5 to 8.5, although there is no health-based guideline. All the water sources recorded pH within the acceptable limit recommended by the World Health Organization (WHO GDWQ 2017) and the United States Environmental Protection Agency (US-EPA 2017) for drinking water quality (Table 2). The minimum and maximum pH values were found, respectively, in the sample collected from boreholes in the village of Pélengana-Wèrè, and in the sample of hand pumps from Banankoro village. Similarly, the EC values of the samples ranged from 69.20 to 132.50 μs/cm and were within the acceptable limits. The highest (132.50 μs/cm) concentration was obtained in the shallow well samples collected from Banankoro village, whereas the lowest (69.20 μs/cm) value was found in the borehole samples collected from Dougadougou village. The TDS of the samples had a range of 12.50–27.15 mg/L, with hand pumps from Banankoro village having the highest concentration. In this study, TDS values did not vary significantly ($p > 0.05$) in drinking water samples. No health-based guideline value is proposed for TDS, although WHO GDWQ does note that to avoid acceptability problems in drinking water, the threshold of TDS value is approximately 600 mg/L. However, all these values are below the WHO (600 mg/L) and the US-EPA (500 mg/L) guidelines for drinking water. The salinity levels ranged from 0.01% (borehole from Pélengana-Wèrè village) to 0.05% (shallow well from Banankoro village) and there has been no great difference observed between the values detected in various water samples.

Table 2 | Drinking water quality guidelines provided by WHO GDWQ (2017) and US-EPA (2017)

Parameter	Unit	WHO GDWQ (2017)	US-EPA (2017)
Non-metal contaminants			
pH	–	6.5–8.5	6.50–8.50
EC	μs/cm	NA	NA
TDS	mg/L	600	500
Salinity	%	NA	NA
Cl	mg/L	250	250
NO_3^-N	mg/L	11	10
PO_4^-P	mg/L	NA	NA
Metal contaminants			
As	mg/L	0.01	0.01
Hg	mg/L	0.006	0.002
Cu	mg/L	2.00	1.3
Cd	mg/L	0.003	0.005
Pb	mg/L	0.01	0.00
Mn	mg/L	0.40	0.05
Cr	mg/L	0.05	0.1
Fe	mg/L	NA	0.3
Bacterial contaminants			
TC	cfu/100 mL	0	5.0%
E. coli	cfu/100 mL	0	0

NA, not available; WHO GDWQ, World Health Organization Guidelines for Drinking-water Quality; US-EPA, United States Environmental Protection Agency.

Chemical parameters

The average concentrations of main chemical parameters determined in the different water samples collected from various water sources of the study area are shown in Table 3. The chloride concentrations in all water samples ranged between 23.55 and 126.50 mg/L. It is concluded from Figure 2(a) that there was no significant variation between Cl values obtained in different drinking water samples. Of water intended for human consumption, WHO GDWQ notes that water with chloride concentrations greater than 250 mg/L may cause consumer acceptability issues (appearance, taste). However, all the water sources recorded Cl within the acceptable limit stipulated by WHO GDWQ and US-EPA. Similarly, NO_3^-N levels ranged from 11.05 to 23.40 mg/L and were all above the permissible limits set by the WHO GDWQ and US-EPA (11 and 10 mg/L, respectively) (Figure 2(b)). Dougadougou water sources were significantly ($p < 0.05$) contaminated with NO_3^-N as compared to Banankoro and Pélengana-Wèrè. The concentrations of phosphate ranged from 0.13 to 0.48 mg/L, with the highest value of 0.48 mg/L being obtained in the shallow well water sample from Dougadougou while the lowest concentration (0.13 mg/L) was obtained from dug well water sample in Pélengana-Wèrè.

Heavy metals

The average concentrations of the heavy metals determined in the different water samples collected from various water

Table 3 | Average values of some chemical parameters of drinking water collected from different sources in the commune of Pelengana

Target villages	Water sources	Cl (mg/L)	NO_3^-N (mg/L)	PO_4^-P(mg/L)
Pélengana-Wèrè	Hand pump ($n = 4$)	47.60 ± 1.24	11.99 ± 1.04	0.22 ± 0.04
	Borehole ($n = 3$)	39.62 ± 2.18	11.17 ± 1.32	0.17 ± 0.01
	Dug well ($n = 5$)	52.11 ± 2.33	11.12 ± 1.05	0.15 ± 0.05
	Shallow well ($n = 12$)	63.25 ± 2.42	15.01 ± 1.08	0.30 ± 0.02
Banankoro	Hand pump ($n = 5$)	58.50 ± 2.13	11.33 ± 0.53	0.27 ± 0.04
	Borehole ($n = 3$)	51.74 ± 2.17	12.11 ± 1.01	0.14 ± 0.05
	Dug well ($n = 6$)	49.95 ± 2.05	11.66 ± 0.56	0.22 ± 0.07
	Shallow well ($n = 17$)	68.07 ± 3.47	17.30 ± 0.35	0.36 ± 0.04
Dougadougou	Hand pump ($n = 7$)	56.33 ± 2.08	12.14 ± 1.11	0.31 ± 0.01
	Borehole ($n = 3$)	54.04 ± 2.15	12.30 ± 1.05	0.23 ± 0.05
	Dug well ($n = 9$)	47.56 ± 2.19	14.24 ± 0.54	0.22 ± 0.02
	Shallow well ($n = 23$)	77.58 ± 2.15	19.45 ± 1.25	0.39 ± 0.03

PO_4^-P, phosphate-phosphorus; NO_3^-N, nitrate-nitrogen; ± standard deviation.

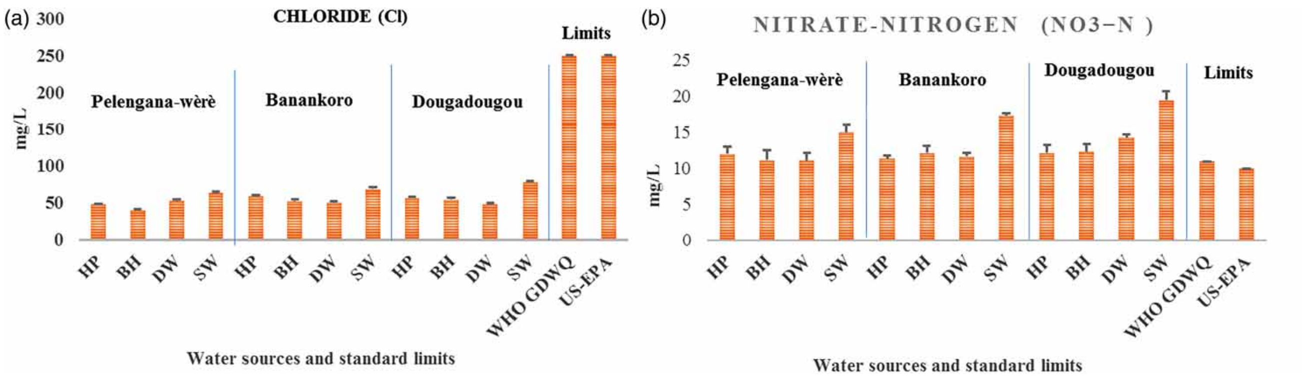

Figure 2 | Variation of (a) Cl and (b) NO_3^-N in drinking water samples compared to standards.

sources of the study area are shown in Table 4. The arsenic recorded ranged from 0.0001 to 0.0031 mg/L. Although higher As values have been experienced in drinking water sampled from water sources of Pélengana-Wèrè, these values are within the WHO GDWQ and US-EPA (0.01 mg/L) guidelines for drinking water, as given in Table 2. Hg concentrations varied between 0.00019 and 0.0053 mg/L and were recorded in borehole samples collected from Dougadougou village and shallow well samples from Pélengana-Wèrè village, respectively (Table 4). There was no great significant variation ($p > 0.05$) in Hg contents detected in various sources of drinking water. The study revealed that the Hg concentrations of all the drinking water samples were below the permissible concentration recommended by WHO GDWQ (Table 2). Similarly, the copper contents in drinking water samples of the study area ranged from 0.001 to 0.32 mg/L (Table 4) and did not exceed the acceptable limit set by WHO GDWQ (2 mg/L) and US-EPA (1.3 mg/L) (Table 2). The WHO GDWQ and US-EPA drinking water guidelines for Cd are 0.003 and 0.005 mg/L, respectively (Table 2). The study showed that all the drinking water samples had Cd levels that did not exceed US-EPA acceptable limits, while the values of some samples from some water sources exceeded the acceptable limit set by the WHO GDWQ. The minimum and maximum values ranged from 0.0001 mg/L (borehole from Dougadougou village) to 0.005 mg/L (hand pump from Banankoro village). However, there was insignificant change ($p > 0.05$) in Cd levels found in various sources of drinking water. The Pb values ranged from 0.002 mg/L to 0.21 mg/L, and with the exception of

Table 4 | Average values of some heavy metals in drinking water samples collected from different sources of Pelengana commune

Water sources	As (mg/L)	Hg (mg/L)	Cu (mg/L)	Cd (mg/L)	Pb (mg/L)	Mn (mg/L)	Fe (mg/L)	Cr (mg/L)
Pélengana-Wèrè								
Hand pump ($n=4$)	0.0018 ± 0.0012	0.0033 ± 0.0024	0.21 ± 0.02	0.003 ± 0.001	0.06 ± 0.02	0.033 ± 0.003	0.26 ± 0.02	0.005 ± 0.0002
Borehole ($n=3$)	0.0004 ± 0.0002	0.00045 ± 0.00037	0.04 ± 0.01	0.001 ± 0.0001	0.012 ± 0.01	0.016 ± 0.001	0.037 ± 0.01	0.036 ± 0.021
Dug well ($n=5$)	0.0008 ± 0.0002	0.00039 ± 0.00021	0.15 ± 0.11	0.004 ± 0.004	0.11 ± 0.02	0.012 ± 0.002	0.14 ± 0.12	0.008 ± 0.005
Shallow well ($n=12$)	0.0022 ± 0.0014	0.0046 ± 0.00027	0.28 ± 0.25	0.003 ± 0.002	0.14 ± 0.02	0.031 ± 0.0026	0.41 ± 0.02	0.031 ± 0.025
Banankoro								
Hand pump ($n=5$)	0.0012 ± 0.001	0.0027 ± 0.00032	0.34 ± 0.07	0.004 ± 0.002	0.009 ± 0.002	0.029 ± 0.0024	0.20 ± 0.03	0.012 ± 0.008
Borehole ($n=3$)	0.0005 ± 0.00018	0.00032 ± 0.0003	0.003 ± 0.003	0.0007 ± 0.0004	0.004 ± 0.001	0.0044 ± 0.0025	0.042 ± 0.018	0.0007 ± 0.0001
Dug well ($n=6$)	0.00021 ± 0.0002	0.00025 ± 0.00022	0.005 ± 0.002	0.001 ± 0.001	0.007 ± 0.002	0.025 ± 0.0013	0.030 ± 0.02	0.007 ± 0.002
Shallow well ($n=17$)	0.0017 ± 0.0011	0.0035 ± 0.0023	0.18 ± 0.08	0.003 ± 0.005	0.008 ± 0.02	0.028 ± 0.002	0.39 ± 0.12	0.027 ± 0.021
Dougadougou								
Hand pump ($n=7$)	0.0010 ± 0.002	0.0017 ± 0.0008	0.005 ± 0.001	0.002 ± 0.004	0.13 ± 0.02	0.016 ± 0.0041	0.16 ± 0.11	0.008 ± 0.0022
Borehole ($n=3$)	0.00027 ± 0.00015	0.00020 ± 0.0001	0.001 ± 0.001	0.0003 ± 0.000	0.06 ± 0.03	0.0037 ± 0.0022	0.061 ± 0.02	0.0005 ± 0.00044
Dug well ($n=9$)	0.00021 ± 0.00017	0.00023 ± 0.00021	0.003 ± 0.001	0.0002 ± 0.0001	0.007 ± 0.001	0.0046 ± 0.0017	0.024 ± 0.021	0.006 ± 0.003
Shallow well ($n=23$)	0.0011 ± 0.0004	0.0026 ± 0.00014	0.020 ± 0.015	0.002 ± 0.01	0.07 ± 0.04	0.033 ± 0.0088	0.45 ± 0.22	0.025 ± 0.0023
Range	0.0001–0.0031	0.00019–0.0053	0.001–0.32	0.0001–0.005	0.002–0.21	0.0032–0.037	0.019–0.47	0.0003–0.041

drinking water samples from Banankoro village which presented Pb concentrations below the recommended limits by WHO GDWQ (0.01 mg/L), most water sources of Pélengana-Wèrè and Dougadougou were above the permissible limits. The maximum value was detected in water samples collected in shallow wells from Dougadougou village, while the minimum was found in borehole water samples from Banankoro (Table 4). There was a significant variation ($p < 0.05$) in Pb concentrations detected in various sources of drinking water. The concentrations of Mn in water samples of the Pelengana commune ranged from 0.0032 to 0.037 mg/L (Table 4). Although there is no health-based guideline proposed for Mn, all these values are within the allowable concentration set by the WHO GDWQ (0.40 mg/L) and US-EPA regulation (0.05 mg/L) for drinking water. No health-based guideline value is suggested for iron, although the US-EPA's regulation does note that taste is affected above a concentration of 0.3 mg/L. Fe concentrations were within US-EPA's regulation limits of 0.3 mg/L established for drinking water, except those recorded in shallow well water samples which were above the permissible limit (Table 4). Moreover, Cr concentrations varied between 0.0003 and 0.041 mg/L. The highest values were recorded in drinking water samples collected from Pélengana-Wèrè village, while the lowest values were observed in Dougadougou village (Table 4). However, the study revealed that the Cr concentrations of all the drinking water samples were below the permissible concentration recommended by WHO GDWQ and US-EPA regulation (Table 2).

Bacterial contamination

The results presented in Table 5 are the average values of total coliforms (TC) and *E. coli* found in drinking water samples collected from different sources in the commune of Pelengana. Microbiological results on total coliform and *E. coli* bacteria denoted ranges of 0–15 cfu/100 mL and 0–12 cfu/100 mL, respectively. With the exception of water samples from boreholes, all the water samples from shallow wells, hand pumps, and dug wells contained total coliforms, and *E. coli* bacteria in excess of the permissible limit of 0 per 100 mL set by the WHO GDWQ (Table 2). However, analysis of variance denoted no great significant ($p > 0.05$) variation among the drinking samples from different localities in the study area.

Health survey results

A summary of the principal health issues mentioned during the survey in the study area was done and is presented in Table 6. Investigations were carried out in 1,440 households, i.e., 2,991 individuals including 1,357 females and 1,634 males. Results showed that the number who were illiterate was very high and ranged from 69.84 to 71.20%. As shown in Table 6, diarrhea, typhoid fever, gastroenteritis, and amoebic dysentery have been mentioned by 55–61%, 38–52%, 43–54%, and 31–39% of respondents, respectively. In addition, diseases such as hepatitis A, B, and C were reported by respondents, ranging from 16% to 29%, 13–20%, and 3–6%, respectively. Outside of these reported

Table 5 | Number of total coliforms and *E. coli* in drinking water samples collected from different sources of Pelengana commune

Target villages	Water sources	Total coliforms (cfu/100 mL)	*E. coli* (cfu/100 mL)
Pélengana-Wèrè	Hand pump ($n = 4$)	4.60 ± 1.04	3.30 ± 1.01
	Borehole ($n = 3$)	0.00	0.00
	Dug well ($n = 5$)	3.11 ± 1.13	2.33 ± 1.05
	Shallow well ($n = 12$)	12.35 ± 4.02	9.41 ± 2.88
Banankoro	Hand pump ($n = 5$)	2.50 ± 0.13	2.23 ± 0.20
	Borehole ($n = 3$)	0.00	0.00
	Dug well ($n = 6$)	2.65 ± 0.05	3.06 ± 1.10
	Shallow well ($n = 17$)	14.07 ± 1.57	11.10 ± 2.05
Dougadougou	Hand pump ($n = 7$)	1.53 ± 0.08	1.14 ± 0.11
	Borehole ($n = 3$)	0.00	0.00
	Dug well ($n = 9$)	2.56 ± 0.19	1.44 ± 0.04
	Shallow well ($n = 23$)	11.58 ± 2.15	10.45 ± 2.28

Table 6 | Number of households surveyed, educational status, and various diseases mentioned during the survey

Parameters	Pélengana-Wèrè	Banankoro	Dougadougou
Number of households surveyed	480	480	480
Number of individuals included in surveys	1,000	998	993
Gender			
Male	604	511	519
Female	396	487	474
Educational status (%)			
Literate	28.80	30.16	29.91
Illiterate	71.20	69.84	70.09
Diseases reported (%)			
Diarrhea	61	58	55
Amoebic dysentery	34	39	31
Typhoid fever	52	49	38
Gastroenteritis	50	54	43
Vomiting	26	19	15
Kidney issues	29	26	30
Abdominal pain	21	19	23
Hepatitis A	20	16	29
Hepatitis B	13	15	20
Hepatitis C	3	6	4
Appetite lack	47	44	49
General fatigue	42	41	50
Ulcer	23	27	34
Lung disease	4	2	1
Nausea	9	5	3
Skin lesion	5	11	8
Cancer	1	2	1

illnesses, other health issues have also been mentioned with different percentages; these include vomiting, kidney problems, abdominal pain, lack of appetite, general fatigue, ulcer, lung disease, nausea, skin lesion, and cancer.

DISCUSSION

It is important to ensure a safe and sufficient water supply for each community in order to preserve their health and reduce disease. Chemicals, heavy metals, and microbiological contaminants in drinking water have been shown to pose many risks to human health (Mora *et al.* 2009; Nguyen *et al.* 2009). In rural Mali, especially in the commune of Pelengana, the population lives in a precarious situation and does not have the means to obtain mineral water, i.e., drinking water packaged in bags or bottles. They are forced to depend on water from boreholes, hand pumps, shallow and dug wells, and many of these sources do not meet the international standard for the depth that groundwater must achieve. For this purpose, the water from these sources is considered not fit for consumption, as it is used without treatment. Nevertheless, people are convinced that groundwater is the safest and least contaminated source of drinking water. As a result, they do not consider pre-treatment of groundwater prior to consumption.

Earlier studies have shown that many parameters can affect drinking water quality and lead to the risk of disease (Saadia *et al.* 2007). The results presented in this work have shown that pH, conductivity, TDS, and salinity may be considered allowable and have no impact on the quality of drinking water. The measure of the pH content is a significant index of acidity or alkalinity. The hydrogen ion concentration of water has no direct negative results on humans, rather, indirect results due to the fact that it can carry out modifications in some parameters of water quality, including the initial chemical form of metals and survival of infectious agents. Also, it can cause gastrointestinal irritation in sensitive persons (Mkwate *et al.* 2016); however, occasional pH changes may not have any direct impact on consumers. In addition, issues linked with high levels of TDS are more of an esthetic issue than a health problem (Jidauna *et al.* 2017).

In principle, chloride, nitrate, and phosphate play a significant part in the quality of groundwater and have an effect on human health (Khan *et al.* 2012). In Pelengana commune, drinking water in the target villages was largely contaminated with phosphate. This may be explained by the excessive use of fertilizers on agricultural land practiced around these water sources. Also, the significant release of domestic wastewater highly charged with phosphate constituents around drinking water sources could be a contributory factor. Increased levels of phosphate compromise the palatability of water and also reduces its esthetic value. In addition, ingestion of high phosphate levels in

drinking water may increase the risk of kidney and cardiovascular disease in consumers (Ritz et al. 2012). In the study area, 26 to 30% of respondents confirmed having kidney disease during the survey. The NO_3^-N values of the water samples from the different water sources had concentrations exceeding the US-EPA's regulation of 10 mg/L, as well as the WHO GDWQ (11 mg/L). In our study area, the increase in nitrate contents observed is particularly related to human activities and intensive agricultural practices. The deficient septic systems, as well as the decomposition of plant and animal matter, can also be a source of nitrates in the water from these sources. Infant methemoglobinemia is the only health effect that has been associated unequivocally with excessive exposure to nitrates through drinking water (Chindo et al. 2013). Consumption of those waters should be prohibited to pregnant women and infants to prevent methemoglobinemia. However, adult individuals can withstand high levels of nitrate with little or no documented adverse health effects and can drink water with nitrate concentrations significantly above 10 mg/L without any acute toxic effects (Khan et al. 2012). It is worth noting that no case of methemoglobinemia was noticed during the investigation.

In the commune of Pelengana, various heavy metals have been identified in drinking water and, unfortunately, some of them have been above their permissible recommended concentrations. Cadmium contents exceeding the acceptable limit set by the WHO GDWQ were noticed in some drinking water sources from the study area. This cadmium contamination may be explained not only by the significant release of domestic wastewater which contained high amounts of phosphate constituents but also by overapplication of phosphate fertilizers onto the agricultural land. Short-term exposure (few days or weeks) to cadmium in drinking water at high concentrations may cause nausea, renal deficiency, vomiting, and diarrhea (Khan et al. 2012). Long-term exposure (several years or decades) to cadmium in drinking water can cause kidney damage, pneumopathies, nephropathies (Dahunsi et al. 2014). Most of the Pelengana-Wèrè and Dougadougou water sources had a higher level of Pb contamination, which may be caused by leaching from plumbing systems and transportation (Chanel et al. 1999). Lead is a toxic substance that accumulates in the body and affects multiple organ systems. It is particularly harmful for young children (Gerlach et al. 2002). Lead diffuses into the body to reach the brain, liver, kidneys, and bones. It is stored in the teeth and bones, where it accumulates over time (WHO 2006). The universally known symptoms of lead exposure are headaches, extreme fatigue, nausea, abdominal cramps, and joint pain (Dahunsi et al. 2012; Owamah 2013). Other health effects such as metallic taste in the mouth, poor appetite, vomiting and constipation, or bloody diarrhea may also be anticipated (Khan et al. 2012). Similarly, in the study area, some drinking water sources as well have Fe concentrations exceeding the allowable limit set by US-EPA's regulation for drinking water, which may be due to the water–rock interaction. High concentration of Fe in drinking water could cause water to have an unpleasant metallic taste. In addition, it may contribute to the development of Fe bacteria and render water disagreeable for consumption (Rahaman & Hafezur 2018). Ingestion of a large amount of Fe may bring about hemochromatosis. The known symptoms of exposure are the following: general fatigue, abnormal skin staining, diabetes, liver cirrhosis, heart failure, helplessness, and infertility (Huang 2003).

Most drinking water samples from different water sources of Pelengana commune contained total coliforms and *E. coli*. This indicates that the water sources in our study area have been contaminated with fecal matter and therefore may contain pathogens. This is consistent with results found by Boutin & Dias (1987) for the Marrakesh groundwater in Morocco, by Bordalo & Savva (2007) during research for safe drinking water in Guinea Bissau and, finally, by Egwari & Aboaba (2002) in Lagos, Nigeria on the environmental impact of the bacteriological quality of domestic water supply. Local sources of contamination can be multiple: manure spreading, grazing, septic tanks, latrines, and other sources, such as wildlife. Based on the biochemical profiles, various bacterial isolates were identified, namely *E. coli*, *Salmonella* sp., *Klebsiella* sp., *Bacillus* sp., *Citrobacter* sp., *Enterobacter* sp., *Staphylococcus aureus*, *Pseudomonas* sp., and *Micrococcus* sp. Identification of bacterial isolates in the drinking water sources destined for human consumption was undesirable, as they may bring about serious human health issues. The presence of *E. coli* is of medical importance because its presence is an indication of the presence of other enteric pathogens. *E. coli* is known to cause many enteric diseases such as travelers' diarrhea and other forms of diarrhea

(Sorlini *et al.* 2013). Other important pathogens identified above are known to cause gastrointestinal disorders such as diarrhea (Sorlini *et al.* 2013). An important aspect (i.e. one of the limitations) of this study is that health data have been self-reported. It should be noted that self-reported health data are largely influenced by human emotions and perceptions. However, results from the questionnaire survey (Table 6) appear to have a good correlation with the health effects of the analyzed factors that exceeded standard limits. It was mentioned during this study that the inhabitants in the study area who consume these waters containing a large number of bacteria often endure cases of diseases such as diarrhea, amoebic dysentery, typhoid fever, gastroenteritis, vomiting, kidney issues, abdominal pain, hepatitis, poor appetite, general fatigue, ulcer, lung disease, nausea, and skin lesion. In addition, data from different health centers of Pelengana commune have identified waterborne diseases as the main diseases that affect the community living in different target villages of our study. It should be noted that the majority of the population in the study area is illiterate and has no knowledge of water quality or the types of diseases that may be causing problems. However, it is suggested that villagers in the target area of our study be educated about drinking water contamination and the diseases it can cause in consumers. Farmers should also be informed about the responsibility of agrochemicals for contamination of drinking water sources in the study area. Further research work is needed about the treatment of contaminated water to protect the inhabitants from chronic health problems. In fact, the origin of microbiological, chemical, and heavy metals contamination needs to be investigated by also considering the hydro-geological characteristics of the sampling sites. Only by identifying the sources of contamination will it be possible to select and implement the most correct and appropriate solution to these water quality issues.

CONCLUSION

From the above results, it may be considered that the health of the population of the Pelengana commune in Mali is vulnerable to the effects of drinking water. The same applies to heavy metals such as Cd, Pb, and Fe. It was also discovered that drinking water sources were contaminated with coliform bacteria. Shallow water samples were found to be relatively most polluted, while the safest were the borehole water samples. Additionally, it was mentioned during the questionnaire survey that the inhabits in the study area who consume these waters suffer diseases like diarrhea, amoebic dysentery, typhoid fever, gastroenteritis, vomiting, kidney issues, abdominal pain, hepatitis, poor appetite, general fatigue, ulcer, lung disease, nausea, skin lesion, and cancer. These results confirm the impact of intensification of agriculture, discharges of domestic wastewater, and inadequate disposal of solid waste. However, it is suggested that the villagers need to be educated on the importance of maintaining clean and hygienic environments around the vicinity of the drinking water sources to ensure the safety of water from such sources.

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