Check for updates

Research Paper

An investigation of some water quality properties from different sources in Pelengana commune, Segou, Mali

Amadou Toure, Duan Wenbiao and Zakaria Keita

ABSTRACT

An assessment of consumer quality perception, as well as some physical and chemical characteristics of water samples sourced from wells, boreholes, and rivers in the locality of Pelengana commune, in Mali, was carried out. The World Health Organization (WHO) Guideline (or other) Values (GVs) for drinking water quality was used as a benchmark. One-way analysis of variance (ANOVA) alongside Duncan's multiple comparison tests for significant differences, and Principal Component Analysis (PCA) were used in analyzing differences and correlations regarding the parameters investigated. Results revealed that the majority of the households (61.2%) regarded wells and river water as unsafe for drinking. The physical and chemical quality of water was affected by climatic season. Also, with the exception of iron (average values), the parameters studied met the WHO GVs. Based on the analyzed parameters, the quality of these different water sources is chemically acceptable.

Key words | borehole water, Mali, Pelengana commune, physicochemical quality, river water, well water

Amadou Toure
Duan Wenbiao (corresponding author)
School of Forestry,
Northeast Forestry University,
No.26 Hexing Road Xiangfang District, Harbin 150040,
China
E-mail: *dwbiao88@126.com*

Zakaria Keita
Department of Study and Research in Public Health of the Faculty of Medicine and Odontostomatology of Bamako,
Bamako,
Mali

INTRODUCTION

Groundwater from captive and superficial aquifers are water resources that are exploited by man for various uses (Prasad & Narayana 2004). The chemical composition of natural water is variable. This could be due to the geological nature of the soil from which it originates and also the reactive substances that it may have encountered during flow (Matini *et al.* 2009). Thus, the quantitative and qualitative composition of groundwater in suspended and dissolved materials, of mineral or organic nature, determines its quality (Jain *et al.* 2005). However, this quality can be altered when external substances come into contact with the aquifer. Undesirable or even toxic substances make groundwater unsuitable and toxic for various uses, especially for human consumption. The intensive use of natural resources and increased human activities have caused serious issues with respect to groundwater quality (Mor *et al.* 2006). In developing countries, obtaining safe water for human consumption is challenging due to a lack of environmental protection. The bacteriological and physicochemical quality of water for public consumption requires constant assessment. Nowadays, in rural areas, especially in underdeveloped countries, waterborne diseases constitute the most health issues (Arnold & Colford 2007). Thus, access to safe drinking water is of essential need.

The supply of drinking water of sufficient quality and quantity remains a crucial public health challenge in most

---

This is an Open Access article distributed under the terms of the Creative Commons Attribution Licence (CC BY 4.0), which permits copying, adaptation and redistribution, provided the original work is properly cited (http://creativecommons.org/licenses/by/4.0/).

doi: 10.2166/washdev.2018.172

Downloaded from http://iwaponline.com/washdev/article-pdf/8/3/449/484182/washdev0080449.pdf
by guest

African countries (Healy Profitós *et al.* 2014). Some noteworthy statistics from the WHO/UNICEF Joint Monitoring Program 2017 (JMP) for Water and Sanitation reveal that about 2.1 billion human beings lack good quality water, 4.5 billion do not have access to adequate sanitation and roughly 1.5 million deaths every year are attributed to diarrheal disease (WHO & UNICEF 2017a, 2017b). Additionally, it is estimated that 58% of the latter figure (842,000 deaths per year), is due to unsafe water supply, insufficient hygiene, and sanitation, and includes 361,000 deaths of children below five years, especially in developing countries (WHO 2014). Water for human consumption must not contain organisms and chemical substances in concentrations sufficiently high to affect health (Brian 2007).

Over the past decade, a rebellion linked with terrorism in the northern part of Mali has resulted in the migration of thousands of people into the peripheral areas of Pelengana commune in Segou region. Currently, the rural settlements in that area are overpopulated, thus leading to poor living conditions such as inadequate water, poor hygiene, and sanitation. Moreover, under such conditions, waterborne diseases (diarrhea, typhoid and paratyphoid fever, amoebic dysentery, etc.) are the principal class of diseases that may stricken the majority of such a population (Pelengana commune) living in such precarious conditions (Baig *et al.* 2012). During this study, it was noted that approximately 66.8% of that population source water from unimproved sources (unprotected dug wells, traditional wells, and rivers) and 33.2% from improved sources (such as boreholes and protected dug wells). Also, these waters are more often than not consumed without physical, chemical and biological treatment. Although microbiological contamination is a leading preoccupation of the Pelengana commune, inorganic contaminants of health and aesthetic concern may be present in such waters. Residents of the area practice agro-pastoralism. In order to increase agricultural yield, chemical fertilizers are often utilized which are rich in nitrate, ammonium, phosphate, and zinc, and are more often used above the accepted amounts. If nitrate is not absorbed by plant roots, it leaches into the soil or can be run off into water reservoirs during wetting or rainfall (Tamme *et al.* 2009). Consuming contaminated groundwater or crops with a high concentration of nitrate has negative effects on human health (Ikemoto *et al.* 2002). In surface and groundwater, zinc enters the environment from various sources but predominantly from the erosion of soil particles containing zinc (Noulas *et al.* 2018). Also, water sources are susceptible to contamination by fluoride due to minerals in the aquifer rocks, anthropogenic activities and fecal pollution originating from animals and the poor protection of these sources (Chidambaram *et al.* 2013; Manikandan *et al.* 2014).

This work investigates some physical and chemical qualities of water from three sources, namely river, well and borehole, situated at three sites within the commune of Pelengana. These sites are Pelengenewere, Pelengana Primary School, and Koukoun. The present work is justified by the fact that there is lack of scientific information with respect to water quality from the region concerned.

MATERIALS AND METHODS

Study area and sampling sites

Our research was conducted in the rural commune of Pelengana in Segou region (Figure 1). The region is located in the center of Mali between 12° 30′ and 15° 30′ N latitude and 4 and 7° W longitude, with a total area of 62,504 km² and a population of 2,338,349 based on the 2009 census (INSTAT 2011). Segou region has a sudano-sahelian climate with two seasons; a dry season that lasts eight months (October–May), and a rainy season that lasts four months (June–September). Rainfall in this region ranges from 200 to 800 mm per year and the average annual temperature is 28 °C (PROMISAM 2011). Farming, animal husbandry, and angling are the predominant activities of the population in the area of Segou.

A preliminary field investigation was carried out to evaluate the common source of drinking water for most households. Also, interviews were conducted to estimate perceptions of water taste issues, odor, color, turbidity, and health problems. Forty randomly selected people per site (480 people) were used for the interview. Water samples were collected each month from July 2016 to April 2017 from three different water sources: (1) a well from Pelenganawere (unprotected dug well with used wood acting as a curb, no perimeter of protection, animals nearby, farms all around), (2) a borehole (hand pump from Pelengana

Downloaded from http://iwaponline.com/washdev/article-pdf/8/3/449/484182/washdev0080449.pdf
by guest

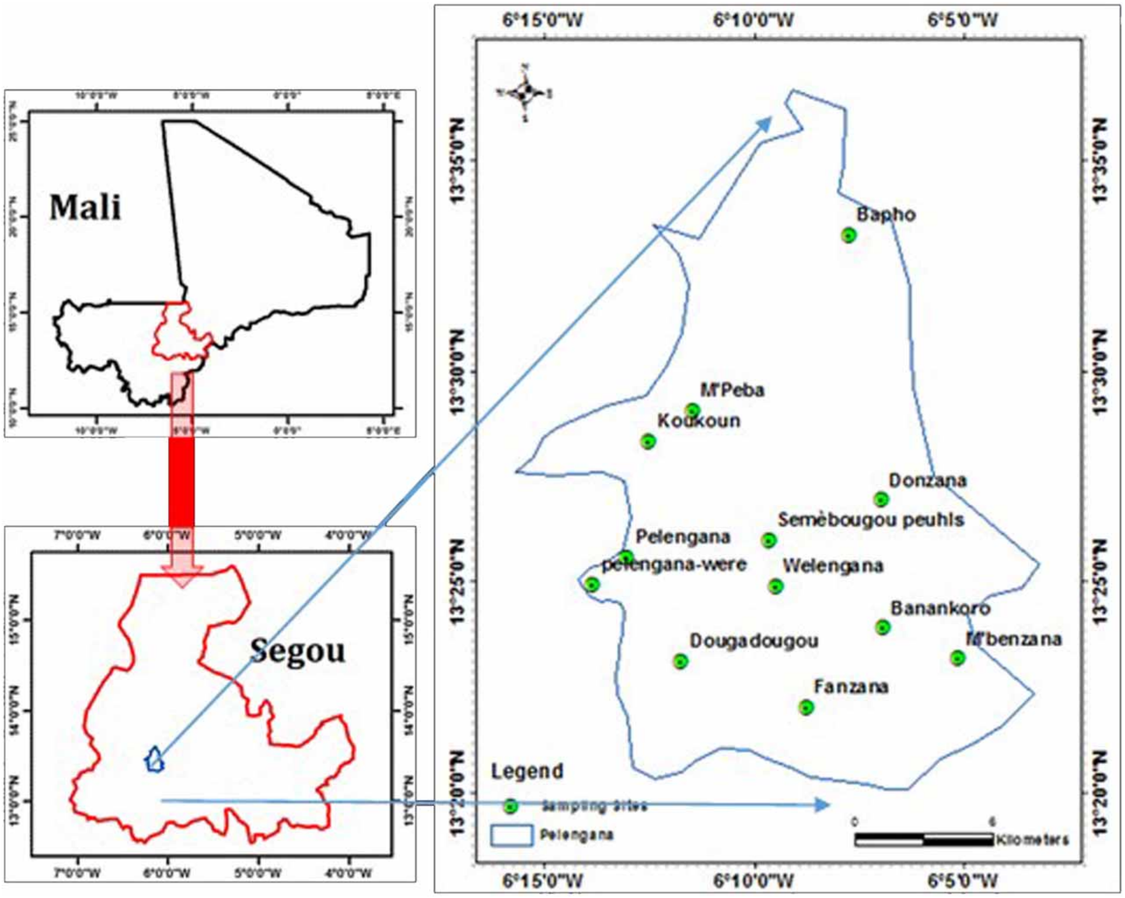

Figure 1 | Map of sampling sites in the rural commune of Pelengana.

Primary School where water is sold to the population; practices of agriculture around), and (3) a river (the only river crossing Koukoun village) in Pelengana commune. These sites were selected for sampling in such a way that they represented a large cross-section of users who could be at risk of waterborne diseases, assuming the water is of poor quality due to the vicinity of pollution sources. The sources were chosen following a preliminary field investigation that assessed the proximity of wells and boreholes to pollution sources, nature of the environment, and depth of the water table. It is worth noting that testing of water from each collection site was carried out each month. In addition, ten repetitions were performed in order to ensure even representation, thus, a total of 30 water samples were collected for analyses. Water samples were collected in 1 L polyethylene bottles. These bottles were previously washed with detergent, rinsed with tap water and then with distilled water, and finally rinsed three times with water from the sampling source. The water samples were labeled and kept between 0 and 4 °C in a cooler. They were then sent for laboratory tests with sample sheets containing all the required information. It is worth noting that some field tests were also conducted.

Methods

In order to ascertain the level of drinking water contamination with respect to the various parameters and the risks to human health associated with the ingestion of contaminated water in the study area, it is therefore necessary to consider the physical, chemical and bacteriological quality, as well as heavy metals contamination. However, in this work, only 10 parameters (physical and chemical) under the recommendation of the communal hygiene office of Pelengana commune were studied. These parameters are:

Downloaded from http://iwaponline.com/washdev/article-pdf/8/3/449/484182/washdev0080449.pdf
by guest

temperature, electrical conductivity (EC), pH, nitrate (NO_3^-), nitrite (NO_2^-), phosphate (PO_4^-P), fluoride (F^-), ammonium (NH_4^+), iron (Fe) and zinc (Zn^{2+}). The physical parameters, such as temperature, pH, and EC, were measured *in situ* using a digital thermometer, pH meter WTW, and a conductivity meter WTW, respectively, while the chemical analyses were achieved according to the manual of Rodier *et al.* (2009). The nitrate and nitrite concentrations were measured employing the sodium salicylate and N-1 naphthylethylenediamine method, respectively. Ammonium was measured using the indophenol blue method. Phosphate (PO_4^-P) was measured using the phosphomolybdate method. Fluoride was measured by the potentiometric method using an Ionometer WTW (pH/ION 340i and probe F800). Finally, zinc and iron were measured using a Photometer WTW, model Photoflex Turb Set by the Photometric method.

Statistical analysis

The statistical analysis was been carried out using SPSS software version 21.0. The average values of physicochemical parameters for the dry and the rainy seasons were compared by applying Student's test and one-way analysis of variance (ANOVA) and Duncan's multiple comparison tests was used to establish the difference between the average values of parameters that were measured at various water sources, using a 5% significance level ($p < 0.05$). In addition, principal component analysis (PCA) was performed using XLSTAT software 2015.4.01. The correlation coefficient between different water quality parameters was calculated by the Pearson correlation test. The quality of drinking water and the state of water pollution have been compared with the guideline (or other) values included in the WHO Guidelines for Drinking-water Quality in order to calculate the number of samples that did not comply with the guideline values.

RESULTS AND DISCUSSION

The drinking water sources and perception on water quality

In this study, it was noted that 66.8% of the population surveyed sourced water from unimproved sources (unprotected dug wells, traditional wells, and rivers) and 33.2% from improved sources (such as boreholes and protected dug wells).

Regarding the perception of the water quality and other water source attributes, approximately 39% of respondents assessed their drinking water as safe for consumption, whereas the remaining respondents (61.2%) had concerns with safety, particularly from wells and river water. It was also discovered that in more than 28% of households in the commune mentioned previously, at least one household member had suffered some water-borne disease during the last three years. Respondents were asked to rate water quality based on four sensory characteristics of drinking water. The majority of respondents (74.6%) reported dissatisfaction with the odor and clarity of water from traditional and modern wells, while approximately 53% were satisfied with the taste of the water. These findings are similar to Mkwate *et al.* (2016) who conducted research in the Balaka district of Malawi, where the population was dissatisfied with the odor and clarity of shallow well water. There was a very high sense of satisfaction in terms of the quality of borehole water among all households in the commune of Pelengana, specifically on reliability, odor, color, taste, turbidity, and safety against contamination. In terms of river water, many respondents judged odor (48.3%), taste (31.1%), color (9.3%), and turbidity (11.2%). It is important to note that the respondents had poor knowledge about the sensory attributes of water because they most often misconstrued visual and organoleptic characteristics decisively in the quality of water consumed.

Physico-chemical parameters

The results of physico-chemical analysis (average ± standard deviation, minimum, maximum values) are presented in Tables 1 and 2. The number of samples analyzed (N), the guideline values (GVs) for drinking water are also indicated. In some cases, no WHO GV, but other values (GVs) have been used for clarity. Table 3 compares the average values of the water quality parameters for the different seasons (dry and rainy) at the different water sources.

The optimum acceptable pH range for drinking water varies from 6.5 to 8.5, although there is no health-based guideline. Three borehole water samples (30%), one river

Downloaded from http://iwaponline.com/washdev/article-pdf/8/3/449/484182/washdev0080449.pdf
by guest

Table 1 | Variations of the main physical parameters in the samples

Parameter	Sample location	N	Average ± St. Dev	Min	Max	WHO GV	Other value	% not within GV
pH	Borehole water	10	6.58 ± 0.30^a	6.11	7.10	–	6.5–8.5	30
	River water	10	7.17 ± 0.41^b	6.45	7.90			10
	Well water	10	6.03 ± 0.64^c	5.17	6.88			70
Temperature (°C)	Borehole water	10	31.43 ± 2.95^a	27.9	37.0	–	–	–
	River water	10	28.24 ± 0.36^b	27.6	33.8			–
	Well water	10	29.90 ± 2.12^{ab}	25.3	36.5			–
EC (µs/cm)	Borehole water	10	288.36 ± 158.50^a	90.7	550.5	–	–	–
	River water	10	274.63 ± 132.58^a	100.0	500.4			–
	Well water	10	617.28 ± 125.52^b	392.0	778.0			–

For each parameter, means with the different letters (superscripts) are significantly different ($p < 0.05$), using Duncan's multiple range test. N, number of samples analyzed; WHO GV, World Health Organization (WHO) Guideline Values (GVs).

Table 2 | Variations of the main chemical parameters in the samples

Parameter	Sample location	N	Average ± St. Dev	Min	Max	WHO GV	Other values	% not within GV
NO_3^- (mg/L)	Borehole water	10	41.94 ± 10.75^a	30.36	62.48	50	–	20
	River water	10	46.64 ± 9.75^a	36.26	65.23			30
	Well water	10	32.01 ± 6.75^b	21.20	42.48			0
NO_2^- (mg/L)	Borehole water	10	0.97 ± 0.62^a	0.12	2.10	3	–	0
	River water	10	1.66 ± 0.55^b	0.84	2.54			0
	Well water	10	0.53 ± 0.30^a	0.14	1.05			0
F^- (mg/L)	Borehole water	10	0.16 ± 0.16^a	0.01	0.52	1.5	–	0
	River water	10	0.49 ± 0.26^b	0.11	0.84			0
	Well water	10	0.21 ± 0.12^a	0.11	0.52			0
NH_4^+ (mg/L)	Borehole water	10	0.26 ± 0.22^a	0.14	0.61	–	1.5	0
	River water	10	0.97 ± 0.19^b	0.69	1.25			0
	Well water	10	0.25 ± 0.33^a	0.09	1.09			0
PO_4^-P (mg/L)	Borehole water	10	0.43 ± 0.23^a	0.06	1.08	–	–	
	River water	10	0.31 ± 0.04^b	0.15	1.12			
	Well water	10	0.46 ± 0.40^a	0.07	1.89			
Fe (mg/L)	Borehole water	10	3.23 ± 3.4^a	0.01	10.12	–	0.3	60
	River water	10	1.28 ± 0.67^b	0.1	5.1			30
	Well water	10	3.18 ± 0.9^a	0.32	10.17			100
Zn^{2+} (mg/L)	Borehole water	10	1.09 ± 0.07^a	0.27	2.15	3	–	0
	River water	10	1.04 ± 0.01^a	0.16	3.11			20
	Well water	10	1.28 ± 0.12^b	0.32	3.15			30

For each parameter, means with the different letters (superscripts) are significantly different ($p < 0.05$), using Duncan's multiple range test. N, number of samples analyzed; WHO GVs, World Health Organization (WHO) guideline values (GVs).

water sample (10%) and seven well water samples (70%) fell outside the recommended pH range, being acidic in nature. The minimum and maximum pH values (5.17 and 7.90) were observed respectively in the well water and river water with significantly lower average values observed in the dry season. A significant difference ($p < 0.05$) was noted among the well, borehole and river which had average pH values of 6.03, 6.58, 7.17, respectively (Table 1). The well water value was below the WHO range (6.5–8.5). The pH of the well water may be attributed to the discharge of acidic products into this source by agricultural and domestic activities. This is supported by the fact that studies have shown that 98% of all groundwater worldwide is related to the geological nature of the aquifer formations and the lands

Downloaded from http://iwaponline.com/washdev/article-pdf/8/3/449/484182/washdev0080449.pdf
by guest

Table 3 | Average values of water parameters compared with two seasons at the three water sources

	Variables (Average ± standard deviation)					
	Borehole water		**River water**		**Well water**	
Parameter	**Dry season**	**Rainy season**	**Dry season**	**Rainy season**	**Dry season**	**Rainy season**
T (°C)	$28.23^b \pm 0.84$	$36.08^a \pm 1.03$	$27.8^b \pm 0.68$	$32.20^a \pm 0.97$	$25.89^b \pm 0.43$	$35.50^a \pm 0.75$
pH	$6.16^b \pm 0.28$	$6.69^a \pm 0.14$	$6.50^b \pm 0.25$	$7.65^a \pm 0.11$	$5.24^b \pm 0.13$	$6.81^a \pm 0.08$
EC (μS/cm)	$100.04^b \pm 47.56$	$345.81^a \pm 63.77$	$166.47^b \pm 41.69$	$419.80^a \pm 33.02$	$396.21^a \pm 58.67$	$630.68^a \pm 33.20$
NH_4^+ (mg/L)	$0.17^b \pm 0.08$	$0.54^a \pm 0.14$	$0.65^b \pm 0.18$	$1.09^a \pm 0.67$	$0.06^b \pm 0.02$	$0.78^a \pm 0.10$
NO_2^- (mg/L)	$0.19^b \pm 0.06$	$1.52^a \pm 0.08$	$0.88^b \pm 0.07$	$2.21^a \pm 0.05$	$0.16^b \pm 0.03$	$0.99^a \pm 0.03$
NO_3^- (mg/L)	$30.39^b \pm 0.38$	$58.24^a \pm 0.28$	$38.60^b \pm 0.15$	$63.80^a \pm 0.22$	$22.73^b \pm 0.14$	$39.94^a \pm 0.13$
Iron (mg/L)	$0.03^b \pm 0.1$	$10.03^a \pm 6.4$	$0.23^b \pm 0.6$	$4.33^a \pm 3.1$	$0.43^b \pm 0.3$	$10.02^a \pm 7.2$
PO_4^-P (mg/L)	$0.07^b \pm 0.03$	$1.02^a \pm 0.83$	$0.17^b \pm 0.03$	$1.09^a \pm 0.23$	$0.08^b \pm 0.04$	$1.84^a \pm 1.02$
F^- (mg/L)	$0.003^b \pm 0.07$	$0.37^a \pm 0.85$	$0.09^b \pm 0.08$	$0.56^a \pm 0.05$	$0.04^b \pm 0.09$	$0.32^a \pm 0.07$
Zn^{2+} (mg/L))	$0.28^b \pm 0.18$	$2.09^b \pm 0.68$	$0.20^b \pm 0.13$	$3.08^b \pm 1.64$	$0.35^b \pm 1.67$	$3.21^b \pm 1.18$

For each parameter, means with the different letters (superscripts) are significantly different ($p < 0.05$), using Duncan's multiple range test.

traversed (Sorlini *et al.* 2013). The pH values for both borehole and river water are within the recommended ranges of WHO drinking water quality guidelines. These results are similar with values reported from borehole waters in Malawi (Sajidu *et al.* 2008; Grimason *et al.* 2013) as well as those in other countries in Africa (Bordalo & Savva-Bordalo 2007).

The temperature of the three water sources varied according to the sampling period (rainy or dry). The highest temperature was observed from May to October, corresponding to the rainy season (Table 3). The ideal water temperature is between 6 and 12 °C (Degbey *et al.* 2011). The temperature of the borehole water (31.43 °C) differed significantly ($p < 0.05$) from that of the river (28.24 °C). On the other hand, there was no significant difference ($p > 0.05$) between the borehole and well water (29.90 °C) and also between the river and well water (Table 1). The minimum and maximum values (25.3 and 37.0 °C) were observed respectively in the well water and borehole water. The high temperatures could be explained by the influence of the ambient heat in the collected water and also by the geothermal gradient of the zone. However, high temperature values would not be harmful to human health, but pose a problem of acceptability because cool water is generally more palatable than warm water (Degbey *et al.* 2011).

EC measures the capacity of a solution to conduct electric current. It also makes it possible to estimate the amount of salts dissolved in water. The average value of the EC of well water (617.28 μs/cm) differed significantly ($p < 0.05$) from borehole water (288.36 μs/cm) and river water (274.63 μs/cm) (Table 1). The minimum and maximum EC values (90.7 and 778.0 μS/cm) were observed, respectively, in the borehole and well water. Significantly higher average values were observed in the rainy season (Table 3). Large differences were observed between the conductivity values of well water and those of borehole and river waters. High conductivity indicates high water mineralization (Rodier *et al.* 1996). In a geomorphological context, the depth of the levels captured and geological nature of soil formations are factors that influence variations in conductivity (Boubacar 2010). A study by Sajidu *et al.* (2008) also reported wide EC value ranges for borehole water in the villages of Southern Malawi, namely, Chikhwawa (1,450–2,800 μS/cm), Nsanje (2,150–6,600 μS/cm), Mangochi (295–6,800 μS/cm), Zomba (129–805 μS/cm) and Machinga (55–1,175 μS/cm). In addition, Ngaram (2011) reported a range of 13.90–52.65 μS/cm for the Chari River waters in Chad.

Concerning nitrate, two borehole water samples (20%) and three river water samples (30%) had concentrations exceeding the WHO GV of 50 mg/L. The average value for

Downloaded from http://iwaponline.com/washdev/article-pdf/8/3/449/484182/washdev0080449.pdf
by guest

well water (32.01 mg/L) was significantly lower ($p < 0.05$) than the borehole (41.94 mg/L) and rivers (46.64 mg/L) (Table 2). The minimum and maximum nitrates values (21.20 and 65.23 mg/L) were observed, respectively, in the well water and in the river water. In addition, the highest average value for nitrate (63.80 mg/L) was noticed in the river water which was taken during the rainy season (Table 3). In our study, the increase in nitrate levels observed is particularly related to human activities and intensive farming practices. This is consistent with the findings of Hanis *et al.* (2009), who noted that significant contamination of well waters by nitrates was due to intensive agriculture.

Nitrites are mostly absent from surface waters, but their presence is possible in groundwater, mainly because nitrogen will tend to exist as ammonia or more oxidized (nitrate) forms. WHO GV retains 3 mg/L as a limit value for drinking water quality (GDWQ 2017). The average value for river water differed significantly ($p < 0.05$) from borehole and well water (Table 2). However, they are all below the WHO GV for drinking water, but these sources may not be safe for domestic and livestock use. Lagnika *et al.* (2014) reported averages of 0.072 and 5.01 mg/L, respectively.

Fluoride is widely found in underlying rocks and soil and may be released into groundwater through geochemical processes. High fluoride content in groundwater causes severe damage to the teeth and bones of humans (dental fluorosis and skeletal fluorosis) (Udhayakumar *et al.* 2016). The concentration of fluoride was found to be between 0.01 and 0.84 mg/L respectively in the borehole and river waters. High average values of fluoride were noticed in the rainy season compared to that of the dry season (Table 3). There was a significant difference ($p < 0.05$) between the mean value of river waters and those of wells and boreholes (Table 2). However, all these values are below the WHO GV (1.5 mg/L) for drinking water. These results revealed a similar pattern with previous studies in the commune of Pobé (Benin) where the mean well water value was 0.142 mg/L (Lagnika *et al.* 2014). Concentrations below 0.5 mg/L and above 1 mg/L are undesirable. Approximately 1 mg/L of fluoride concentration is desirable in drinking waters for public health (GDWQ 2017).

The average load of contamination of NH_4^+ in the different sources were 0.25 mg/L (well water), 0.26 mg/L (borehole water) and 0.97 mg/L (river water). It appears that there are significantly more concentrations of NH_4^+ ($p < 0.05$) in the river water samples than in the well and boreholes waters (Table 2). No health-based guideline value is proposed for NH_4^+, although GDWQ does note that at alkaline pH, the odor threshold is approximately 1.5 mg/L. A high average value for NH_4^+ was noticed in the rainy season in river water compared to that of the borehole and well water (Table 3). The high values could be explained by anthropogenic activities and fecal pollution originating from animals (spreading of wastewater, livestock breeding, use of animal waste as fertilizer for agricultural land adjacent to water points) and the poor protection of these sources.

Phosphates come not only from domestic sewage (human urine and detergents) but also from agricultural activities via soil erosion (Nora *et al.* 2015). The phosphate values of the water samples from the different water sources ranged from 0.06 to 1.89 mg/L. The well and borehole water samples significantly had high phosphate concentrations ($p < 0.05$) than those of river water (Table 2). The highest average value for phosphate (1.84 mg/L) during this study was from well water which was obtained in the rainy season, whereas the lowest value (0.07 mg/L) was observed in borehole water which was taken during the dry season (Table 3). This confirms the hypothesis of the infiltration of phosphates resulting essentially from the soil amendment by chemical fertilizer under rainfall conditions.

The waters of Pelengana commune are rich in iron, particularly in the Pelenganawere village. The maximum value was noted in the well water (10.17 mg/L) in Pelenganawere, while the minimum was observed in the borehole water (0.01 mg/L) in Pelengana Primary School. The average value for river water (1.28 mg/L) was significantly different ($p < 0.05$) from borehole (3.23 mg/L) and well (3.18 mg/L) waters (Table 2). No health-based guideline value is suggested for iron, although GDWQ does note that taste is affected above a concentration of 0.3 mg/L. Six borehole water samples (60%), three river water samples (30%) and 10 well water samples (100%) were above 0.3 mg/L. These percentages and the high loads observed in the three sources certify that the taste and also the color of water from that area are indeed of poor quality. However, the

Downloaded from http://iwaponline.com/washdev/article-pdf/8/3/449/484182/washdev0080449.pdf
by guest

highest average values for iron during the study were obtained in the rainy season (Table 3). This may be due to soil leaching phenomenon as well as the result of the water–rock interaction.

Zinc is of benefit for human health, but if ingested in large amounts it can cause emesis (Roohani *et al.* 2013). However, zinc is one of the least toxic metals and deficiency problems are more frequent and more serious than those of toxicity (Ricardo 2013). Of water intended for human consumption, WHO GDWQ notes that water with zinc concentrations greater than 3 mg/L may cause consumer acceptability issues (appearance, taste). Two river water samples (20%) and three well water samples (30%) were all above the WHO GV. There is a significant difference ($p < 0.05$) between the average value of well waters and those of river and boreholes (Table 2). The average zinc concentrations were all below the WHO GV. However, the highest average values were obtained in the rainy season compared to the dry season (Table 3). The zinc content in water from the different sources investigated may mainly be due not only to excessive applications of fertilizers rich in zinc, but also water–rock interaction. This observation concurred with the results presented by Sardar *et al.* (2015) in Charsadda district, Pakistan. They reported a high presence of zinc in some drinking water sources.

PCA profiles of correlation between different parameters

The correlation between physico-chemical parameters was developed using the PCA. A total of 10 variables were used, namely pH, EC, temperature, NO_3^-, NO_2^-, NH_4^+, PO_4^-P, F^-, Fe and Zn^{2+}. Figure 2(a) projects the correlation circle of the aforementioned water quality parameters. Figure 2(b) shows the results of the PCA performed on the different of water sampling sites (individuals) from Pelengana commune, compared to the first (F1) and the second (F2) principal components (axes). F1 and F2 principal components respectively accounted for 39.96 and 16.27% of the total inertia, corresponding to a total of 56.23%. Table 4 represents the value of the correlation between variables and factors (axes) as shown by PCA.

According to the PCA, parameters such as temperature, F^-, and pH were not significant and did not greatly influence the statistical analysis. In decreasing order, Fe and Zn^{2+} were strongly and positively correlated to F1 while pH and F^- were negatively correlated. With respect to the axis F2, in decreasing order, temperature, EC, NO_3^-, NO_2^-, NH_4^+, and F^- were positively correlated while PO_4^-P, and Fe were negatively correlated. This axis expresses an acidity and chemical pollution of environmental or anthropogenic origins. Statistical analysis using Pearson at $p < 0.05$ showed that EC and NO_3^-, EC and NO_2^-, EC and NH_4^+, temperature and EC, NH_4^+ and NO_3^-,

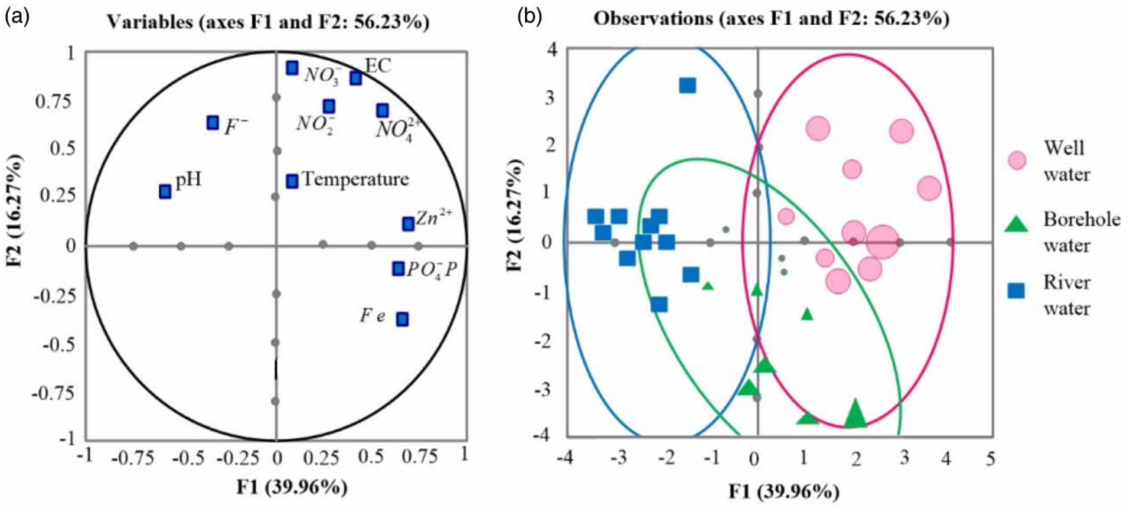

Figure 2 | Distribution of the physical-chemical parameters with respect to the first and the second principal components in the sampled boreholes, rivers, wells waters; (a) correlation circle; (b) results of the principal component analysis.

Downloaded from http://iwaponline.com/washdev/article-pdf/8/3/449/484182/washdev0080449.pdf
by guest

Table 4 | Correlation between variables and axes as shown by PCA

	F1	F2
Temperature	0.332	0.640
PH	−0.811	0.118
EC	0.457	0.860
NO_3^-	0.086	0.667
NO_2^-	0.199	0.783
NH_4^+	0.557	0.641
Fe	0.741	−0.263
PO_4^-P	0.660	−0.091
F^-	−0.490	0.713
Zn^{2+}	0.656	0.064

NH_4^+ and NO_2^-, NO_3^- and NO_2^-, PO_4^-P and Fe, PO_4^-P and Zn^{2+}, PO_4^-P and NH_4^+, Fe and Zn^{2+} were significantly correlated. Based on the PCA, three groups could be observed. Group 1 contains parameters (EC, temperature, NH_4^+, NO_3^-, NO_2^-, and Zn^{2+}) positively correlated to axis F1 and F2. Group 2 contains parameters (PO_4^-P, Fe) positively correlated to axis F1 and negatively correlated to axis F2, and group 3 contains variables (pH, F^-) negatively correlated to axis F1 and positively correlated to axis F2. These results reveal that the mineral composition of the water is almost identical throughout the sampling locations. However, the extent of this mineralization differed according to seasonal variability.

CONCLUSIONS

The physical and chemical quality parameters of water from different water sources (well, borehole and river) in Pelengana commune were studied. This work therefore affords baseline water quality data in the region concerned. In addition, it helped to identify the main concerns regarding the quality of drinking water, in order to suggest appropriate solutions to reduce the observed contaminations and to motivate the local public authorities to plan future interventions in this sector.

It was revealed that the physical and chemical quality of water was affected by climatic season. Generally, the average values of all the parameters measured were higher in the rainy season than in the dry season. The parameters investigated, with the exception of iron, had average values that met the guideline (or other) values included in the WHO Guidelines for Drinking-water quality. It is worth mentioning that the different water sources considered in this work are prone to contamination due both to the water–rock interaction and the prevalence of agricultural practices in that region.

Although the average values of the parameters measured did comply with the WHO GV, the different water sources considered constitute potential sources of contamination. It is also worth noting that this work is not an exhaustive or complete analysis of drinking water quality. For this reason, it is recommended that groundwater for human consumption is treated in the same manner as surface water sources before distribution to users. Detailed and continuous monitoring and assessment of other chemical species in the area is highly recommended. Furthermore, population involvement through protection of drinking water sources from contamination could contribute to improving the water situation throughout the region, thus ensuring a healthy environment, for instance, rules governing activities within the area, particularly pit latrine siting, best management practices for farming, general hygiene and adequate storage practices at the household level.

REFERENCES

Arnold, B. F. & Colford Jr, J. M. 2007 Treating water with chlorine at point-of-use to improve water quality and reduce child diarrhea in developing countries: a systematic review and meta-analysis. *Am. J. Trop. Med. Hyg.* **76** (2), 354–364.

Baig, R., Xu, S. A. & Khan, X. 2012 Microbial water quality risks to public health: potable water assessment for a flood-affected town in northern Pakistan. *Rural Remote Health* **12**, 2196.

Bordalo, A. A. & Savva-Bordalo, J. 2007 The quest for safe drinking water: an example from Guinea-Bissau (West Africa). *Water Res.* **41**, 2978–2986.

Boubacar, H. A. 2010 *Superficial and Deep Aquifers and Urban Pollution in Africa: Case of the Urban Community of Niamey (NIGER)*. Thesis of the Univ. Abdou Moumouni from Niamey (Niger) (in French). Thèse de l'Univ. Abdou Moumouni de Niamey (Niger), 198 pp.

Brian, O. 2007 Environmental Quality Centre Environmental Engineering and Earth Sciences. Wilkes University, Wilkes-Barre, PA.

Chidambaram, S., Bala Krishna Prasad, M., Manivannan, R., Karmegam, U., Singaraja, C., Anandhan, P., Prasanna, M. V. & Manikandan, S. 2013 Environmental hydrogeochemistry and genesis of fluoride in groundwaters of Dindigul District, Tamilnadu (India). *Environ. Earth Sci.* **68**, 333–342.

Degbey, C., Makoutode, M., Agueh, V., De Dramaix, M. & Brouwer, C. 2011 Factors associated with the quality of the

Downloaded from http://iwaponline.com/washdev/article-pdf/8/3/449/484182/washdev0080449.pdf
by guest

well water and prevalence of water-borne diseases in the commune of Abomey-Calavi (Benin). *Sante* **21** (1), 47–55.

GDWQ 2017 *Guidelines for Drinking-Water Quality*, 4th edn. Incorporating the first addendum. World Health Organization, Geneva.

Grimason, A. M., Morse, T. D., Beattie, T. K., Masangwi, S. J., Jabu, G. C., Taulo, S. C. & Lungu, K. K. 2013 Classification and quality of groundwater supplies in the Lower Shire Valley, Malawi E Part 1: Physico-chemical quality of borehole water supplies in Chikhwawa, Malawi. *Water SA* **39** (4), 0378–4738.

Hanis, S., Daniel, B., Khattabi, J. E., Bastin-Lacherez, S. & Isam, S. 2009 Impact of fertilizer application and urban wastes on the quality of groundwater in the Cambrai Chalk aquifer, Northern France. *Environ. Geol.* **57** (7), 1579–1592.

Healy Profitós, J. M., Mouhaman, A., Lee, S., Garabed, R., Moritz, M., Piperata, B. A., Tien, J. K., Bisesi, M. S. & Lee, J. 2014 Muddying the waters: a new area of concern for drinking water contamination in Cameroon. *Int. J. Environ. Res. Public Health* **11**, 12454–12472.

Ikemoto, Y., Teraguchi, M. & Kaneene, Y. 2002 Plasma level of nitrate in congenital heart disease: comparison with healthy children. *Pediatr. Cardiol.* **23**, 132–136.

INSTAT 2011 *4th General Census of Population and the habitat of Mali (RGPH-2009): Analysis of the Final Results: Theme 2: State and Structure of the Population*. National Institute of Statistics, Bamako, Mali (in French).

Jain, P., Sharma, J. D. & Sohu Sharma, D. P. 2005 Chemical analysis of drinking water of villages of Sanganer Tehsil, Jaipur District. *Int. J. Environ. Sci. Tech.* **2** (4), 373–379.

Lagnika, M., Moudachirou, I., Jean-Pierre, C., Valentin, D. & Nestor, G. 2014 Physical-chemical characteristics of well water in the Municipality of Pobé (Benin, West Africa). *J. Appl. Biosci.* **79**, 6887–6897 (in French).

Manikandan, S., Chidambaram, S., Ramanathan, A. L., Prasanna, M. V., Karmegam, U., Singaraja, C., Paramaguru, P. & Jainab, I. 2014 A study on the high fluoride concentration in the magnesium-rich waters of hard rock aquifer in Krishnagiri district, Tamilnadu, India. *Arab. J. Geosci.* **7**, 273–285.

Matini, L., Moutou, J. M. & Kongo-Mantono, M. S. 2009 Hydro-chemical evaluation of groundwater in urban areas south-west of Brazzaville, Congo. *Afr. Sci.* **5** (1), 82–98.

Mkwate, R. C., Chidya, R. C. G. & Wanda, E. M. M. 2016 Assessment of drinking water quality and rural household water treatment in Balaka District, Malawi. *Phys. Chem. Earth* **100**, 353–362.

Mor, S., Ravindra, K., Dahiya, R. P. & Chandra, A. 2006 Leachate characterization and assessment of groundwater pollution near municipal solid waste landfill site. *Environ. Monit. Assess.* **118**, 435–456.

Ngaram, N. 2011 *Contribution to the Analytical Study of Heavy Metals Type Pollutants in the Chari River Waters During its Crossing of the City of N'djamena*. PhD Thesis of Claude Bernard University, Lyon, 164 pp. (in French).

Nora, K., Slimane, K. & Houria, B. 2015 Evaluation of the physico-chemical and bacteriological quality of surface waters in Guelma Basin, Algeria. *Int. J. Environ. Monit. Anal.* **3** (5), 238–244.

Noulas, C., Tziouvalekas, M. & Karyotis, T. 2018 Zinc in soils, water and food crops. *J. Trace Elem. Med. Biol.* https://doi.org/10.1016/j.jtemb.2018.02.009.

Prasad, B. G. & Narayana, T. S. 2004 Subsurface water quality of different sampling stations with some selected parameters at Machilipatnam Town. *Nat. Env. Poll. Tech.* **3** (1), 47–50.

PROMISAM 2011 *Provisional Report of the Study on the Rapid Recognition of Cereal Marketing Axes and Channels in Mali*. USAID, Mali (in French).

Ricardo, N. A. 2013 *Evaluation of the Current Contamination of Heavy Metals and Certain Persistent Organic Compounds in Sport Fish of the St. Lawrence River in Quebec City*. Master Thesis, University Training Center for Environment and Sustainable Development, Quebec, Canada (in French).

Rodier, J., Bazin, C., Boutin, J.-P., Chambon, P., Champsaur, H. & Rodi, L. 1996 *Analysis of Water, Natural Waters, Wastewater, Seawater*, 8th edn. Dunod, Paris, France, 1383 p. (in French).

Rodier, J., Legube, B. & Merlet, N. 2009 *Analysis of Water, Natural Waters, Wastewater, Seawater*, 9th edn. Dunod, Paris, France, 1600 pp. (in French).

Roohani, N., Hurrell, R., Kelishadi, R. & Schulin, R. 2013 Zinc and its importance for human health: an integrative review. *J. Res. Med. Sci.* **18** (2), 144–157.

Sajidu, S. M., Masamba, W. R. L., Thole, B. & Mwatseteza, J. F. 2008 Groundwater fluoride levels in villages of southern Malawi and removal studies using bauxite. *Int. J. Phys. Sci.* **3** (1), 1–11.

Sardar, K., Maria, S., Noor, J., Shafiqur, R., Tahir, S. & Islamud, D. 2015 Drinking water quality and human health risk in Charsadda district, Pakistan. *J. Cleaner Prod.* **60**, 93–101.

Sorlini, S., Palazzini, D., Sieliechi, J. M. & Ngassoum, M. B. 2013 Assessment of physical-chemical drinking water quality in the Logone Valley (Chad-Cameroon). *Sustainability* **5**, 3060–3076.

Tamme, T., Reinik, M. & Roasto, M. 2009 Nitrates and nitrites in vegetables: occurrence and health risks. In: *Bioactive Foods Promoting Health: Fruits and Vegetables* (R. R. Watson & V. R. Preedy, eds). Academic Press, Salt Lake City, UT, USA, pp. 307–321.

Udhayakumar, R., Manivannan, P., Raghu, K. & Vaideki, S. 2016 Assessment of physico-chemical characteristics of water in Tamilnadu. *Ecotoxicol. Environ. Saf.* **134**, 474–477.

WHO & UNICEF 2017a *Progress on Drinking Water, Sanitation and Hygiene*. 2017 Update. World Health Organization, Geneva.

WHO & UNICEF 2017b *WHO/UNICEF Joint Monitoring Programme (JMP) for Water Supply and Sanitation*. [Online] Available from: www.who.int/water_sanitation_health/publications/jmp-2017/en/.

World Health Organization WHO 2014 *Water Sanitation Hygiene: Diseases and Risks*. Available from: www.who.int/water_sanitation_health/diseases-risks/en/.

First received 9 November 2017; accepted in revised form 27 April 2018. Available online 31 May 2018

Downloaded from http://iwaponline.com/washdev/article-pdf/8/3/449/484182/washdev0080449.pdf
by guest