Research Journal of

Environmental Sciences

ISSN 1819-3412

Academic
Journals Inc.

www.academicjournals.com

OPEN ACCESS Research Journal of Environmental Sciences

ISSN 1819-3412
DOI: 10.3923/rjes.2021.9.19

Research Article
Sanitation Practices and Groundwater Quality in a Precarious Neighbourhood of a Coastal City in Central Africa

[1]Onana Fils Mamert, [2]Tamsa Arfao Antoine, [1]Jiofack Charles Joèl, [1]Ngaldeu Noupoue Alexandra Geordie, [3]TAMATCHO KWEYANG Blandine Pulchérie and [2]Zebaze Togouet Serge Hubet

[1]Department of Aquatic Ecosystems Management, Institute of Fisheries and Aquatic Sciences, University of Douala, Douala, P.O. Box. 2701, Cameroun
[2]Department of Animal Biology and Physiology, Faculty of Science, University of Yaoundé I, Yaoundé, P.O. Box. 812, Cameroun
[3]Department of Microbiology, Faculty of Science, University of Yaoundé I, Yaoundé, P.O. Box. 812, Cameroon

Abstract
Background and Objective: In the precarious neighbourhoods of developing countries built on the outskirts of urban centres, about 70% of the population is not connected to the drinking water network and consumes groundwater whose quality is not controlled. This situation is responsible for health disasters that lead to the death of several million people. In this study, sanitation practices, physicochemical and bacteriological quality of groundwater and the potential impact of equipping wells with electric pump were assessed in a precarious neighbourhood in sub-Saharan Africa. **Materials and Methods:** Questionnaires were administered to 100 households to determine their sanitation practices. The water samples from 12 wells were analyzed for physicochemical and bacteriological evaluations. **Results:** The solid and liquid wastes are evacuated in nature, watercourses and roads by the local population. The main sanitary facilities are traditional pit latrines and their distance to wells violated the limits of the guidelines. pH, Salinity and turbidity exceed the World Health Organization (WHO) standards within 58.33, 75 and 41.67% of the wells respectively, thus affecting the organoleptic quality of the groundwater. Faecal and total coliforms, faecal streptococci, *Salmonella* and *Vibrio* exceeded WHO guidelines in 91.67% of the wells. The presence of an electric pump does not significantly improve groundwater quality. **Conclusion:** To reduce the prevalence of waterborne diseases in precarious neighbourhoods in developing countries, it is necessary to extend the drinking water distribution network in these neighbourhoods and encourage the population to treat groundwater before consumption.

Key words: Groundwater quality, precarious neighborhood, sanitation practices, waterborne diseases, World Health Organization limits, faecal pollution, diarrhoea

Citation: Mamert, O.F. , T.A. Antoine, J.C. Joèl, N.N.A. Geordie, T.K.B. Pulchérie and Z.T.S. Hubet, 2021. Sanitation practices and groundwater quality in a precarious neighbourhood of a coastal city in Central Africa. Res. J. Environ. Sci., 15: 9-19.

Corresponding Author: Onana Fils Mamert, Department of Aquatic Ecosystems Management, Institute of Fisheries and Aquatic Sciences, University of Douala, Douala, P.O. Box. 2701, Cameroun

Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Access to good drinking water, adequate sanitation and hygiene are essential for the health and well-being of individuals. For this reason, in 2010, the United Nations General Assembly recognized access to quality water and sanitation as a human right. However, in most developing countries, these basic needs are still a luxury for many people who lack adequate drinking water and sanitation services. This situation is responsible for diarrhoea and faecal-danger diseases that lead to the death of more than 1.5 million children[1].

Like many cities in sub-Saharan Africa, Douala has experienced a rapid population growth manifested by the proliferation of precarious neighbourhoods where poor people are generally pushed back from the countryside and moved to the city[2]. These precarious neighbourhoods, generally built on the outskirts of urban centres, in areas prohibited from construction (swamps, mangroves) by the administrative authorities, therefore not taken into account during urban planning programs and characterized by an almost lack of sanitation infrastructure[2]. Thus, in Douala, less than 50% of the population is connected to the drinking water distribution network of Cameroon Water Utilities Corporation (CAMWATER), the company in charge of the public distribution of drinking water[3]. In this situation, the other half of the population not served by the CAMWATER drinking water system uses groundwater for its drinking water supply. However, all the pressures exerted by the city on groundwater through, in particular, poor sanitation practices and management of municipal and industrial waste[4], contribute to the degradation of the quality of groundwater through the infiltration of pollutants and consequently the recrudescence of waterborne diseases, such as typhoid, cholera and dysentery.

In Douala, studies related to groundwater quality have expanded considerably in the last decade. However, almost all of this work has been devoted to the hydro-geochemical aspects (physicochemistry) of these underground hydro-systems. Also, Ngo Boum[5] contributed to the knowledge of the hydro-geological determinants of the complexity of the aquifer system of the Douala sedimentary basin. Takem *et al.*[6] studied the acidification of Douala shallow groundwater from data collected between 2008 and 2013. Ketchemen Tandia *et al.*[7] identified the factors responsible for the presence of nitrates in the groundwater of the city of Douala. More recently, Fantong *et al.*[8] studied variations in the hydro geochemical characteristics of water in shallow wells and boreholes in the coastal city of Douala, while Emvoutou *et al.*[9] studied the factors controlling groundwater chemistry in the Douala coastal aquifer. To date and our knowledge, few studies have been addressed the microbiological contamination of groundwater and the poor sanitation practices that still determine health issues in coastal precarious neighbourhood[10].

The objectives of this research are: (i) To evaluate the habitat conditions and risky sanitation practices of the populations of the "Bois des Singes" neighbourhoods, (ii) To determine the physicochemical and bacteriological quality of the "Bois des Singes" groundwater's and its suitability for drinking and (iii) To determine the impact of the presence of electric pumps in certain wells on the physicochemical and bacteriological quality of "Bois des Singes" groundwater.

MATERIALS AND METHODS

Study area: The present study was conducted in "Bois des Singes", precarious neighbourhoods of the city of Douala in Cameroon. Douala is watered by an equatorial climate of Guinean type and a Cameroonian coastal sub-type, characterized by two seasons: A long rainy season from March to November and a short dry season from December-February. Temperatures vary between 23-33.5°C with a monthly average of about 28°C and rainfall is abundant and regular (2596-5328 mm)[11]. In these precarious neighbourhoods, the problem of access to drinking water is exacerbated by three main determinants: (1) Absence of a drinking water supply network from CAMWATER, (2) Presence of wild dumping of sludge collected throughout the city of Douala and (3) Tidal movements that favour the dispersion of these sludge throughout the neighbourhood through a network of floods drains dug by the populations during the construction of houses in the mangrove. This research project was conducted from March-June, 2018.

Collection of the characteristics of the sanitary environment: The collection of data on the environmental conditions of the "Bois des Singes" neighbourhoods was carried out between March, 1st and April, 30th, 2018. The assessment of the health environment of the populations of the "Bois des Singes" was made through seven key variables: (i) Drinking water supply sites, (ii) Habitat type, (iii) Typology of sanitation facilities, (iv) Domestic wastewater disposal method, (v) Mode of solid waste disposal, (vi) Frequency of floods and (vii) Frequency and risk factors of diarrheal diseases among the population consulting in the "Ismael Koweit" health centre, located in "Bois des Singes" neighbourhoods.

Two types of surveys were conducted to determine the characteristics of the health environment in the precarious neighbourhoods. Firstly, a field survey which consisted of *in situ* investigations in the “Bois des Singes” and allowed for the observation and characterization of the various sanitation devices. And secondly, a household survey, involving 100 households randomly selected and during which a questionnaire was administered to the heads of households. Besides, data on the frequency and risk factors of diarrheal diseases were obtained at the "Ismael Koweit" health centre, located in the “Bois des Singes” neighbourhood.

Description of sampling points: The sampling points were chosen based on the results of the field survey and the household survey. The criteria used to select the sampling points chosen for this study included, the structure of the groundwater abstraction point (wells without electric pumps and wells equipped with electric pumps), the assessment of good protection against pollution, health risks, frequency of diarrhoea in households near groundwater points, mode of supply and various uses of water. A total of 12 wells were selected for this study, 3 wells with an electric pump and 9 without an electric pump. Of the 9 wells without electric pumps, 4 had a lid and 5 had curbstone. Distances between wells and sanitary structures ranged from 3-19 m. Only 3 of the 12 wells surveyed are at least 15 m away from the sanitary structures. The data in Table 1 presents the characteristics of studied wells.

Collection of water samples: The collection of water samples for physicochemical analyses was conducted on May, 5th, 2018, between 6 and 11 am in the 12 selected wells. For wells without an electric pump, the water was collected using a 5-litre, one-rope-weighted bucket and was introduced into 500 mL polyethylene double-capped bottles. For wells equipped with an electric pump, the groundwater sample was taken from the tap in 500 mL polyethylene double-capped bottles. Subsequently, all samples were preserved and transported to the laboratory in refrigerated conditions at 4°C.

The collection of water samples for bacteriological analyses was made following the recommendations of Kianpoor Kalkhajeh *et al.*[12], at the same time and date as the collection of water samples for physicochemical analyses. For the wells without an electric pump, samples were manually collected at 50 cm below the surface in 500 mL sterile Pyrex bottles. For the wells with an electric pump, samples were collected in 500 mL sterile Pyrex bottles at the tap. The samples were then transported to the laboratory and kept in dark refrigerated conditions for laboratory analyses.

Table 1: Characteristics of sampling points

Sampling point	Latitude N	Longitude E	Presence of curbstone	Presence of lid	Internal retaining	Distance well-sanitary structure (m)	Presence of electric pump	Drinking water/domestic use
P_1	04°0'13.21"	09°43'5.49"	No	No	No nozzles	12	No	Yes/Yes
P_2	04°0'18.22"	09°42'57.70"	No	No	Nozzles	8	No	Yes/Yes
P_3	04°0'17.63"	09°42'55.97"	Yes	No	No nozzles	10	No	No/Yes
P_4	04°0'16.29"	09°42'45.55"	Yes	Yes	Nozzles	3	No	Yes/Yes
P_5	04°0'16.15"	09°42'52.35"	Yes	Yes	Nozzles	18	No	Yes/Yes
P_6	04°0'18.25"	09°42'40.24"	Yes	Yes	No nozzles	7	No	Yes/Yes
P_7	04°0'21.59"	09°42'40.80"	No	No	No nozzles	7	No	No/Yes
P_8	04°0'21.57"	09°42'41.62"	Yes	Yes	Nozzles	15	No	No/Yes
P_9	04°0'20.59"	09°42'48.19"	No	No	Nozzles	19	No	Yes/Yes
P_{10}	04°0'12.35"	09°42'58.29"	/	Yes	Nozzles	7	Yes	Yes/Yes
P_{11}	04°0'16.23"	09°42'59.13"	/	Yes	Nozzles	5	Yes	Yes/Yes
P_{12}	04°0'21.06"	09°42'50.67"	/	Yes	Nozzles	10	Yes	Yes/Yes

Measurement of physicochemical parameters: pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Salinity (Sal) and Turbidity (Turb) were measured *in situ*, using a HORIBA U-53 multi-parameter. In the laboratory, Total Hardness (TH) and Nitrate (NO_3) were measured using a Wagtech CP 7500 spectrophotometer according to Wu *et al.*[13] methods.

Identification and enumeration of bacteria: Bacteriological analysis focused on the search and isolation of Fecal Coliforms (FC), Total Coliforms (TC) and Fecal Streptococci (FS), *Salmonella* spp. and *Vibrio* spp. All these bacteria were enumerated by the membrane filtration technique, using cellulose filters membrane of 0.45 μm nominal pore size (47 mm diameter). The membranes were then placed on selective media and incubated for 24-48 hrs at 44°C for FC and meanwhile, TC and FS were incubated at 37°C for the same duration. FC and TC were inoculated into Endo agar culture while FS was seeded in Bile Esculin Azide (BEA) Agar. *Salmonella* and *Vibrio* bacterial genera were isolated onto plates of SS agar and Thiosulfate Citrate Bile Salts (TCBS, BioMerieux), respectively and then incubated at 37°C for 24 hrs. The number of Colony-Forming Units (CFU) was expressed in 100 mL of sample (CFU/100 mL).

Data analysis: The data collected during the surveys were subdivided into themes according to the 7 variables chosen for the characterization of the environmental conditions of the "Bois des Singes". Theme by theme automatic analysis was done using Excel software and graphs generated. The physicochemical and bacteriological data were subjected to two types of analysis: A first non-statistical analysis made it possible to determine whether the water of the studied wells was fit for consumption. Thus a comparison between the values of the physicochemical and bacteriological parameters of the waters studied and the guide values of the World Health Organization[14] for drinking water was done.

Statistical analysis: The second test carried out was statistical. The Student's t-test was performed to search for significant differences between the physicochemical and bacteriological variables measured at wells without electric pump and wells equipped with electric pump. Pearson correlations were searched between physicochemical and bacteriological parameters. The p-values were used to assess the significance of the correlation between physicochemical and bacteriological parameters. The statistical analyses were carried out using the XLSTAT 2014 software. The safety threshold was 5% (p 0.05).

RESULTS

Housing conditions, sanitation practices and people's perception of the causes of health problems: The field survey revealed that 38, 31, 15, 9 and 7% of the houses are built in wood, cinder blocks+concrete, sheet metal, bricks+concrete and plywood respectively (Fig. 1a). Total 34% of households surveyed said they have been subjected to at least one flood event during the rainy season, while 66% of households did not suffer from flooding (Fig. 1b). As far as drinking water is concerned, 28% of households in "Bois des Singes" consume CAMWATER water from the surrounding neighbourhoods, 51% of households get their drinking water from wells with electric pump present in "Bois des Singes", while 21% of households consume water from wells without an electric pump and sometimes without a cover (Fig. 1c). In terms of sanitary facilities, only 16% of households have a modern latrine with siphon and manual flush. 58 and 5% of households have non-ventilated pit latrine and ventilated improved pit latrine respectively. Total 19% of households have a traditional toilet with outlet pipe and 2% do not have a toilet, thus using the environment as a toilet (Fig. 1d). Total 36% of households discharge their wastewater into their latrines. The remaining households discharge their wastewater either into the watercourses (24%), into the canals crossing the district (22%) or directly onto the road (18%) (Fig. 1e). Total 44 and 31% of households dump their solid waste in wild dumps and watercourses respectively (Fig. 1f). A small proportion of households use individual solid waste management systems either by burial in a hole in the ground (21%) or by incineration (4%) (Fig. 1f). Total 70% of the populations surveyed associate their health problems with the insalubrity of the neighbourhood. Also, the records of the "Ismael Koweit" health centre located in the "Bois des Singes" revealed that 28% of consultations in this health centre are associated with diarrhoea. The risk factors associated with the occurrence of diarrhoea are food poisoning (40%), quality of drinking water (38%) and poor household hygiene (22%).

Physicochemical characteristics: The analyzed values of different water quality parameters are presented in Table 2. The groundwater turbidity values ranged from 2-15.5 NTU. Wells P_1 (15.5 NTU), P_3 (14.30 NTU), P_4 (11.77), P_5 (8.61 NTU) and P_8 (6 NTU) had turbidity values above the WHO recommended guideline value for drinking water (5 NTU) (Table 2). In this study, the TDS values vary between a minimum of 8.90 mg L^{-1} and a maximum of 315.67 mg L^{-1}, indicating that all of the groundwater samples lie within the

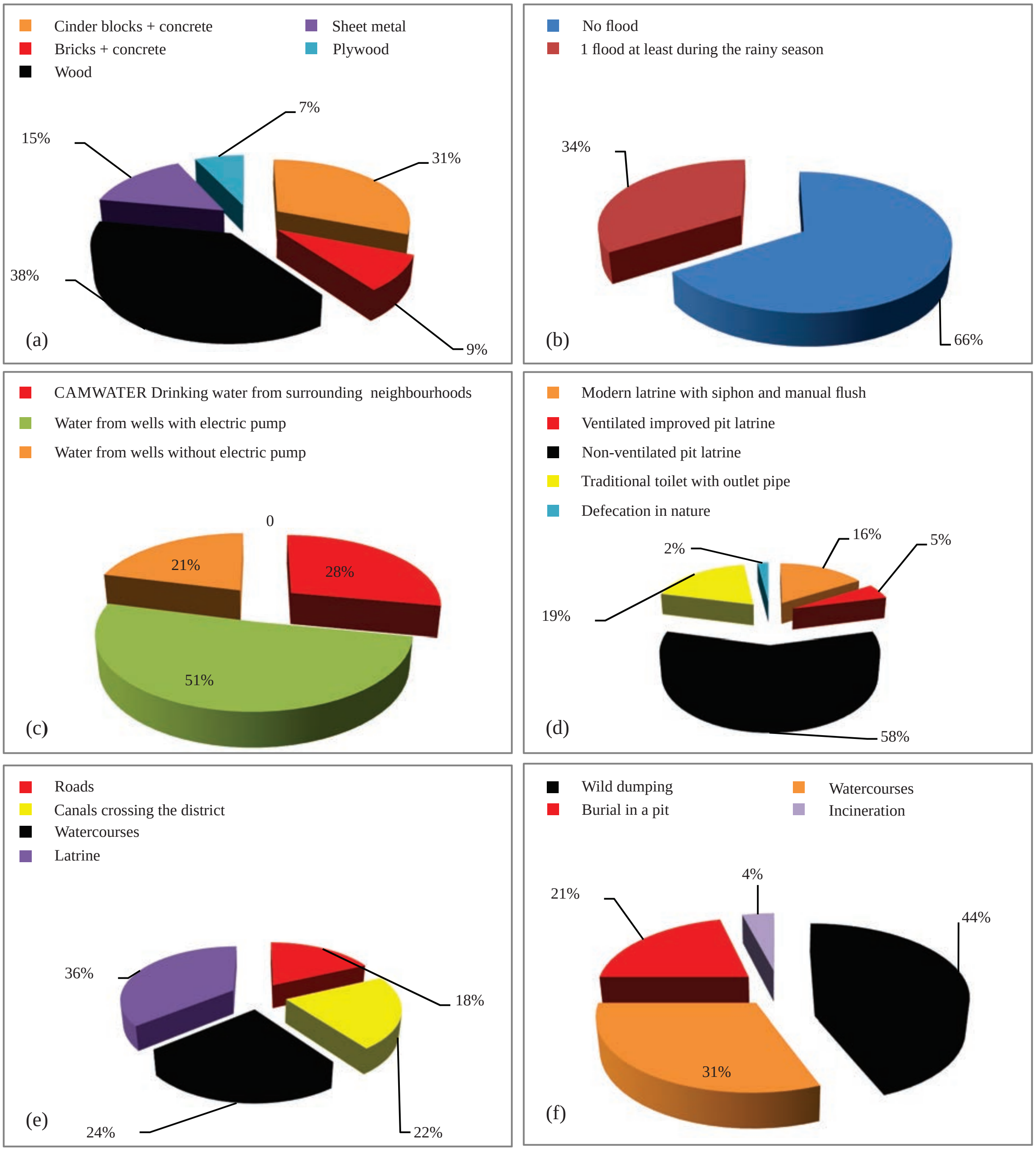

Fig. 1(a-f): Sanitation and hygiene conditions in the "Bois des Singes" neighbourhood.
(a) Building materials, (b) Frequency of flooding, (c) Place of supply of drinking water, (d) Type of toilet facilities, (e) Wastewater disposal and (f) Solid waste disposal

maximum permissible limit (1000 mg L^{-1}). The pH values of samples P_1, P_2, P_4, P_7 and P_9 were found to be within standard values of WHO. All other wells had acidic pH values below 6.5 and varying between 4.96 and 6.16. As regards the EC, all wells have EC below the WHO guideline value for drinking water (750 µS cm^{-1}). Wells P_4 and P_3 have EC of 605.33 and 485.33 µS cm^{-1} respectively, while all the other 10 wells have EC below 150 µS cm^{-1}. Nine out of the 12 wells studied had salinities higher than 0 ppm, which is the WHO guide value for drinking water. Also, the wells whose salinity values comply with the WHO standard are P_5, P_{11} and P_{12}. Nitrate concentrations in the groundwater studied ranged from vary 1.9-35.2 mg L^{-1}. No nitrate concentrations have been above the WHO guideline value (50 mg L^{-1}) for drinking water.

Table 2: Values of groundwater physicochemical parameters

Sampling sites	Parameters						
	pH	EC (µS cm^{-1})	Sal (ppm)	Turb (NTU)	TDS (mg L^{-1})	NO_3 (mg L^{-1})	TH (mg L^{-1} $CaCO_3$)
P_1	8.24	108	0.067	15.50	70.00	3.70	0
P_2	7.52	126.67	0.10	4.36	82.33	3.70	5.00
P_3	6.16	485.33	0.20	14.30	315.67	8.60	25.00
P_4	6.69	605.33	0.267	11.77	383.00	1.90	100.00
P_5	5.37	61.33	0	8.61	38.67	4.30	5.00
P_6	6.04	55.50	0.01	4.00	25.90	33.60	60.00
P_7	7.35	91.10	0.10	4.00	49.20	35.20	0
P_8	6.15	39.50	0.01	6.00	20.40	8.24	15.00
P_9	6.94	18.40	0.09	2.00	8.90	1.02	40.00
P_{10}	6.00	141.33	0.07	2.34	89.67	8.64	0
P_{11}	5.45	39.33	0	2.07	18.33	1.63	0
P_{12}	4.96	38.00	0	2.06	24.33	3.30	0
WHO limit (2006)	6.5-8.5	750	0	5	1000	50	500

EC: Electrical conductivity, TDS: Total dissolved solids, Sal: Salinity, Turb: Turbidity, TH: Total hardness and NO_3: Nitrate

Table 3: Overview of the descriptive statistical of data set of the physicochemical and bacteriological parameters of groundwater in study area

	Wells without electric pumps			Wells equipped with electric pumps		
Parameters	Min	Max	Mean	Min	Max	Mean
pH	5.37	8.24	6.72[a]	4.96	6.00	5.47[a]
EC (µS cm^{-1})	18.40	605.33	176.80	38.00	141.33	72.89
Sal (ppm)	0.00	0.27	0.09	0.00	0.07	0.02
Turb (NTU)	2.00	15.50	7.84	2.06	2.34	2.16
TDS (mg L^{-1})	8.90	383.00	110.45	18.33	89.67	44.11
NO_3 (mg L^{-1})	1.02	35.20	11.14	1.63	8.64	4.52
TH (mg L^{-1} $CaCO_3$)	0.00	100.00	27.78	0.00	0.00	0.00
TC (CFU/100 mL)	3.00	550.00	201.67	0.00	5.00	1.67
FC (CFU/100 mL)	0.00	124.00	29.33	0.00	0.00	0.00
FS (CFU/100 mL)	0.00	390.00	127.67	0.00	280.00	93.33
Salmonella spp. (CFU/100 mL)	0.00	70.00	8.56	0.00	0.00	0.00
Vibrio spp. (CFU/100 mL)	0.00	115.00	14.56	0.00	8.00	2.67

Values with same superscripts alphabets indicate significant differences. $p<0.05$. EC: Electrical conductivity, TDS: Total dissolved solids, Sal: Salinity, Turb: Turbidity, TH: Total hardness NO_3: Nitrate, FC: Fecal coliforms, TC: Total coliforms and FS: Fecal streptococci

Among all the physicochemical parameters measured, only the pH was varied significantly between wells without electric pump and wells with electric pump (Table 3).

Bacteriological characteristics: The results showed that, except for the P_{11} well, the water from all the other wells is contaminated by at least one of the microbial indicators searched (Table 4). With regards to TC, well P_{10}, like well P_{11}, is distinguished from the others by the absence of these microbes. Thus, only wells P_{10} and P_{11} comply with the WHO recommended guideline value. The groundwater from the other 10 wells are contaminated by TC, with concentrations ranging from 3-550 CFU/100 mL (Table 4). TC counts were higher in wells without electric pumps (mean = 201.67 CFU mL^{-1}) than in wells with electric pumps (mean = 1.67 CFU mL^{-1}) but the difference was not significant (Table 3). In terms of FC, wells P_1, P_3, P_4, P_5, P_6, P_7 and P_8 recorded 18, 108, 5, 1, 2, 124 and 6 CFU/100 mL, respectively (Table 4). The water from these wells does not meet the WHO guideline value for drinking water (0 CFU/100 mL). No FC was detected in the groundwater of the 5 others wells. Higher counts occurred in wells without electric pumps (mean = 29.33 CFU/100 mL) than in wells equipped with electric pumps where no colony of FC has been counted (0.0 CFU/100 mL) but the difference was not significant (Table 3). FS was found in 6 of the 12 wells studied, these include wells P_3, P_4, P_5, P_7, P_9 and P_{12} with FS concentrations of 92, 139, 390, 336, 192 and 280 CFU/100 mL, respectively (Table 4). These wells do not comply with the WHO standard giving the guide value for these bacteria. Conversely, FS was not found in the 6 other wells (P_1, P_2, P_6, P_8, P_{10}, P_{11}). Higher counts were obtained in wells without pumps (mean = 127.67 CFU/100 mL) while the lowest concentrations were observed in wells equipped with electric pumps (mean = 93.33 CFU/100 mL) (Table 3) but the difference was not significant. *Salmonella* species were only found in wells

Table 4: Concentrations of groundwater bacteriological parameters

	Parameters				
Sampling sites	TC (CFU/100 mL)	FC (CFU/100 mL)	FS (CFU/100 mL)	*Salmonella* spp. (CFU/100 mL)	*Vibrio* spp. (CFU/100 mL)
P_1	46	18	0	5	1
P_2	21	0	0	0	0
P_3	215	108	92	70	13
P_4	550	5	139	0	0
P_5	3	1	390	0	0
P_6	86	2	0	0	1
P_7	440	124	336	0	115
P_8	58	6	0	0	1
P_9	396	0	192	2	0
P_{10}	0	0	0	0	8
P_{11}	0	0	0	0	0
P_{12}	5	0	280	0	0
WHO limit (2006)	0	0	0	0	0

FC: Fecal coliforms, TC: Total coliforms and FS: Fecal streptococci

P_1, P_3 and P_9 at concentrations of 5, 70 and 2 CFU/100 mL, respectively. *Salmonella* spp. concentrations were higher in wells without electric pumps (mean = 8.56 CFU mL^{-1}) than in wells equipped with electric pumps (mean = 0.00 CFU mL^{-1}) (Table 3). Bacteria of the genus *Vibrio* were identified in wells P_1, P_3, P_6, P_7, P_8 and P_{10} where 1, 13, 1, 115, 1 and 8 CFU/100 mL were counted respectively. *Vibrio* species were not detected in the other 6 wells. The average *Vibrio* concentration in wells without an electric pump is 14.56 CFU/100 mL whereas in wells with an electric pump the concentration is 2.67 $FUmL^{-1}$ (Table 3). The difference was not significant.

Correlation between physicochemical and biological variables: All correlations between the different physicochemical and bacteriological parameters are summarized in Table 5. The safety threshold was 5% (p 0.05). Significant correlations have been revealed between certain physicochemical parameters and others. Thus, EC was positively and significantly correlated with Sal (r = 0.915), TDS (r = 0.999), Turb (r = 0.635) and TH (r= 0.617). Sal was positively and significantly linked with TDS (r = 0.914) and Turb was positively and significantly correlated with TDS (r = 0.645). Significant correlations were also observed between physicochemical parameters and bacteriological parameters. We noted a positive and significant correlation between the TH and TC (r = 0.645). Similarly, NO_3 was positively and significantly correlated to *Vibrio* spp. (r = 0.686). Sal showed positive and significant correlations with TC (r = 0.741). Regarding the correlations between different bacterial indicators, FC was positively and significantly correlated to *Salmonella* spp. (r = 0.608) and *Vibrio* spp. (r = 0.789).

DISCUSSION

In this study, 72% of the households surveyed consume groundwater, while 84 and 100% of these households use traditional latrines and inadequately disposes of their solid and liquid wastes respectively. Physicochemical analyses of the groundwater in this precarious neighbourhood revealed its poor organoleptic quality. As regards bacteriological analyses, 91.67% of the wells studied do not meet WHO standards for drinking water.

The precarious neighbourhood studied is located in a prohibited construction zone and is characterized by dwellings built mostly (60%) with temporary materials (wood, sheet metal, plywood), the absence of a public drinking water supply service and the discharge of solid and liquid waste into nature (wild dumps), watercourses and roads. Indeed, precarious neighbourhoods are most often built by poor populations, on the outskirts of urban centres, in areas without urban planning[2]. These living spaces without infrastructure and socio-economic facilities put their inhabitants at the margin of any safe quality of life[15]. Also, the absence of a wastewater collection network and a solid waste collection system is the cause of the stagnation of wastewater in these neighbourhoods, which favours the proliferation of disease vectors and the multiplication of pathogenic microorganisms[16].

Nine out of the 12 wells studied had salinities higher than 0 ppm, which is the WHO guide value for drinking water. The study area is located in the mangrove area and is subjected to the action of the tide. Thus, the groundwater studied is globally influenced by saline intrusions of brackish water into the sandy aquifers of the city of Douala. The effect of saline

Table 5: Pearson's correlation coefficient between different variables

Variables	pH	EC	Sal	Turb	TDS	TH	NO_3	TC	FC	FS	*Vibrio* spp.	*Salmonella* spp.
pH	1	0.121	0.409	0.382	0.122	0.056	0.113	0.369	0.257	-0.236	0.295	-0.032
EC	0.121	1	0.915	0.635	0.999	0.617	-0.156	0.541	0.316	-0.059	-0.041	0.547
Sal	0.409	0.915	1	0.534	0.914	0.597	-0.106	0.741	0.401	-0.015	0.136	0.463
Turb	0.382	0.635	0.534	1	0.645	0.237	-0.181	0.180	0.306	-0.070	-0.113	0.539
TDS	0.122	0.999	0.914	0.645	1	0.600	-0.176	0.525	0.313	-0.059	-0.055	0.561
TH	0.056	0.617	0.597	0.237	0.600	1	0.061	0.645	-0.136	-0.077	-0.220	0.032
NO_3	0.113	-0.156	-0.106	-0.181	-0.176	0.061	1	0.197	0.513	0.110	0.686	-0.041
TC	0.369	0.541	0.741	0.180	0.525	0.645	0.197	1	0.431	0.329	0.452	0.100
FC	0.257	0.316	0.401	0.306	0.313	-0.136	0.513	0.431	1	0.296	0.789	0.608
FS	-0.236	-0.059	-0.015	-0.070	-0.059	-0.077	0.110	0.329	0.296	1	0.439	-0.072
Vibrio spp.	0.295	-0.041	0.136	-0.113	-0.055	-0.220	0.686	0.452	0.789	0.439	1	0.003
Salmonella spp.	-0.032	0.547	0.463	0.539	0.561	0.032	-0.041	0.100	0.608	-0.072	0.003	1

Significant correlations ($p<0.05$) are indicated in bold. EC: Electrical conductivity, TDS: Total dissolved solids, Sal: Salinity, Turb: Turbidity, TH: Total hardness NO_3: Nitrate, FC: Fecal coliforms, TC: Total coliforms and FS: Fecal streptococci

intrusion may be the reason for the observed increase in EC and TDS, hence positive and significant correlations between EC and Sal and between TDS and Sal. Sarah Prasanth *et al.*[17], in a study conducted in a coastal zone in India, indicate that salt intrusions are responsible for the increase in EC in groundwater. Besides, Olusegun Oguntoke *et al.*[18] showed that well water with high salt content (EC), particles (TDS) and turbidity in appearance indicates the intrusion of run-off into the well. Four and five of the wells sampled during this study are devoid of curbstone and lids respectively, this facilitates the introduction of run-off water into these wells. The groundwater in "Bois des Singes" is globally acidic with an average pH of 6.40. This may be attributed to the wild dumping in "Bois des Singes" of sewage sludge collected throughout the city of Douala, which does not have any wastewater treatment unit. Furthermore, the silicate nature of the soil in Douala and the oxidation of organic matter also contributes to the acidity of the groundwater in the study area[6]. The total hardness is 0 mg L^{-1} in wells P_1, P_7, P_{10}, P_{11} and P_{12}. In the others wells, this parameter varied between 5 and 100 mg L^{-1} of $CaCO_3$. Maskooni *et al.*[19] classified groundwater, based on total hardness as groundwater with TH<75, 75-150, 150-300 and >300 mg L^{-1}, corresponding to soft, moderately hard, hard and very hard, respectively. According to the above categorization, 91.67% (11 samples out of 12) of the total groundwater samples are soft, while 8.33% belongs to moderately hard. Ca and Mg ions are largely responsible for water hardness[20], however, Ketchemen-Tandia *et al.*[7] showed that the groundwater in Douala generally has low concentrations of Mg ions. Thus, these low concentrations of Mg ions would be at the origin of the water softness recorded in this study. In this study, apart from wells P_6 (33.60 mg L^{-1}) and P_7 (35.20 mg L^{-1}) with high nitrate concentrations, all the other wells recorded low nitrate concentrations ranging from 1.02-8.64 mg L^{-1}. The low level of nitrate contamination in the wells could be due to the selective removal of nitrates during infiltration through their adsorption in organic colloids[21]. Another possible reason to explain the relatively low levels of nitrate is a decrease in pH leads to the formation of ammonia[7]. However, the potential source of nitrate in groundwater may be latrines dug into the ground and sewage sludge dumped anarchically in the study area.

Although only the pH values varied statistically between wells with electric pump and wells without electric pump, the values of all other physicochemical parameters were the highest in wells without an electric pump. This is explained by the fact that the majority of wells without electric pump are exposed to the environment, either because they lack a cover and curbstone or because their walls are not protected by a lining (nozzles) and therefore receive more pollutants.

Globally, the Bacteriological quality of water was very poor in wells without electric pumps as indicated by TC, FC and FS count, which is an indication of water polluted with faecal matter. The presence of TC, FC and FS in most well without electric pumps can be explained by the movement of pollutants from closely wild dumping of faecal matter, pit toilets and leaking septic tanks as well as indiscriminate defecation around wells. Besides, wells without electric pump, even when covered, are usually in contact with the outside environment, when people use buckets for water supply, which is also a source of microbial contamination. Another reason to explain the poor quality of these well waters could be attributed to the non-respect of the protective perimeter. Indeed, the commonly used guideline is that the distance should be at least 15 m between wells and sanitary facilities[22] but in our study, only 3 of the 12 wells surveyed complied with this recommendation. Akoachere *et al.*[10], Rochelle-Newall *et al.*[23] and Djaouda *et al.*[24] working in groundwater found similar results.

In wells with an electric pump, *Salmonella* spp. and FC were not counted, whereas TC (5 CFU/100 mL) and FS (280 CFU/100 mL) were counted only in well P_{12}. *Vibrio* spp. (8 CFU/100 mL) was present only in well P10. This low concentration of bacteria in wells with electric pumps is because these wells are isolated from the outside environment by a cover and by lining their walls with nozzles. Similar results have been found by Akoachere *et al.*[10] in the groundwater of Douala, notably in the New Bell and Bepanda neighbourhoods. FC may indicate the presence of pathogens mainly bacteria, which are responsible for waterborne diseases such as cholera and typhoid[25]. Thus, significant and positive correlations have been found between FC and *Vibrio* on one hand and between FC and *Salmonella* on the other hand.

Access to safe drinking water is essential for the health and well-being of individuals and therefore an internationally accepted human right[1]. In this study, 53.33% of the wells have acidic pH values out of the WHO standard (6.5-8.5) for drinking water quality. West *et al.*[26] and Buzalaf *et al.*[27] have shown that acidic pH levels can be the cause of dental problems. Besides, the acidity of groundwater can be the cause of gastric problems as bacteria adapted to the acidic conditions of groundwater can easily overcome the acid barrier of our stomach and cause illness[28]. The turbidity shows that 58.33% of the wells met WHO standards, while the remaining 41.67% have turbidity values above the threshold of 5 NTU. Although turbidity has no direct effect on health, many consumers associate turbidity with health safety and consider turbid water unfit for consumption. However, high turbidity affects effective disinfection of water by adsorptive characteristics of some colloids and because solids partly shield microorganisms from disinfectants[29]. The other parameters, mainly NO_3, TH and EC, were below the threshold values for drinking water recommended by WHO.

Except well P_{11} which does not contain any of the bacteria searched in this study, the groundwater concentrations of bacterial indicator exceeded WHO[14] quality regulations in all other wells. The presence of these bacteria in the groundwater indicates the origin of the water-borne diseases suffered by the population of the “Bois des Singes” neighbourhood. Surveys carried out by the health centre in this neighbourhood revealed that 28% of consultations are associated with diarrhoea, the risk factors associated with the occurrence of diarrhoea are quality of drinking water and poor household hygiene. Several authors[24,7] have shown that TC, FC and FS indicate the potential presence of pathogenic microorganisms and opportunistic pathogenic bacteria such as *Salmonella* sp., *Shigella* sp., *Vibrio cholerae*, *Pseudomonas* sp., responsible for numerous waterborne diseases. Besides, *Salmonella* and *Vibrio* infections usually result in gastroenteritis ranging from moderate to severe diarrhoea. Indeed, between 2000 and 2012, a total of 43474 cases of cholera were reported in Cameroon with 1748 deaths, the most affected urban districts are located in Douala in the Littoral region[30].

The groundwater in the precarious "Bois des Singes" neighbourhood in the coastal city of Douala is affected by various anthropic pollutions linked to poor individual and collective sanitation practices. Furthermore, saline intrusions linked to the proximity of the ocean strongly influence the organoleptic properties of water in coastal areas. These poor quality waters cause waterborne diseases in the populations that consume them. It is recommended that, water must be treated before consumption, that particular attention is paid to the proper management of solid and liquid waste and that the 15-metre safety distance between the well and the sanitary facilities should be respected. To complete the present study, it would have been necessary to identify the bacteria to the taxonomic level of species and to study the susceptibility of these bacteria to antibiotics.

CONCLUSION

This study revealed many inadequacies in the sanitation management system of the precarious “Bois des Singes” neighbourhood, including the discharge of solid and liquid waste into the environment and the majority use of traditional sanitary facilities. Chemical analysis reveals that the groundwater in the study area is globally acidic, soft and affected by saline intrusions, which modifies their organoleptic characteristics. As far as bacteria are concerned, 11 of the 12 wells studied are contaminated. The presence of electric pumps in some wells does not significantly improve their water quality. Besides, the values for bacterial counts exceeded the values recommended by the WHO for drinking water, which may be at the origin of the waterborne diseases of the populations.

SIGNIFICANCE STATEMENT

This study has shown that poor waste management, particularly liquid waste, is the cause of groundwater pollution in precarious neighbourhoods of Africa. Also, despite measures aimed at isolating the wells from their external environment, pollutants, particularly bacteriological ones, continue to contaminate the groundwater through infiltration processes. Furthermore, saline intrusions linked to the proximity of the ocean strongly influence the organoleptic properties of water in coastal areas. This bacteriological contamination of water is the cause of the waterborne diseases that kill people in precarious neighbourhoods of Africa.

ACKNOWLEDGMENT

For their contribution in the measurement of environmental variables, we thank Aquafrik, Yaoundé, Cameroon.

REFERENCES

1. Fenwick, A., 2006. Waterborne infectious diseases-could they be consigned to history? Science, 313: 1077-1081.
2. Ooi, G.L. and K.H. Phua, 2007. Urbanization and slum formation. J. Urban Health, 84: 27-34.
3. Kuitcha, K., K.B.V. Sigha, N.I. Sigha, G. Lienou and G.E. Ekodeck, 2008. Water supply, sanitation and health risks in Yaounde, Cameroon. Afr. J. Environ. Sci. Technol., 2: 379-386.
4. Attard, G., Y. Rossier and L. Eisenlohr, 2016. Urban groundwater age modeling under unconfined condition-impact of underground structures on groundwater age: Evidence of a piston effect. J. Hydrol., 535: 652-661.
5. Boum-Nkot, S.N., B. Ketchemen-Tandia, Y. Ndje, H. Emvouttou, C.R. Ebonji and F. Huneau, 2015. Origin of mineralization of groundwater in the tongo bassa watershed (Douala-Cameroon). Res. J. Environ. Earth Sci., 2: 29-41.
6. Takem, G.E., D. Kuitcha, A.A. Ako, G.T. Mafany and A. Takounjou-Fouepe *et al*., 2015. Acidification of shallow groundwater in the unconfined sandy aquifer of the city of Douala, Cameroon, Western Africa: Implications for groundwater quality and use. Environ. Earth Sci., 74: 6831-6846.
7. Ketchemen-Tandia, B., S.N. Boum-Nkot, S.R. Ebondji, B.Y. Nlend, H. Emvoutou and O. Nzegue, 2017. Factors influencing the shallow groundwater quality in four districts with different characteristics in urban area (Douala, Cameroon). J. Geosci. Environ. Prot., 5: 99-120.
8. Fantong, W.Y., B.T. Kamtchueng, B. Ketchemen-Tandia, D. Kuitcha and J. Ndjama *et al*., 2016. Variation of hydrogeochemical characteristics of water in surface flows, shallow wells and boreholes in the coastal city of Douala (Cameroon). Hydrol. Sci. J., 61: 2916-2929.
9. Emvoutou, H.C., B.K. Tandia, S.N.B. Nkot, R.C.S. Ebonji and Y.B. Nlend *et al*., 2018. Geologic factors controlling groundwater chemistry in the coastal aquifer system of Douala/Cameroon: Implication for groundwater system functioning. Environ. Earth Sci., Vol. 77. 10.1007/s12665-018-7400-z.
10. Akoachere, J.F.T.K., L.A. Omam and T.N. Massalla, 2013. Assessment of the relationship between bacteriological quality of dug-wells, hygiene behaviour and well characteristics in two cholera endemic localities in Douala, Cameroon. BMC Public Health, Vol. 13. 10.1186/1471-2458-13-692.
11. Takem, G.E., D. Chandrasekharam, S.N. Ayonghe and P. Thambidurai, 2010. Pollution characteristics of alluvial groundwater from springs and bore wells in semi-urban informal settlements of Douala, Cameroon, Western Africa. Environ. Earth Sci., 61: 287-298.
12. Kalkhajeh, Y.K., B.J. Amiri, B. Huang, A.H. Khalyani, W. Hu, H. Gao and M.L. Thompson, 2019. Methods for sample collection, storage and analysis of freshwater phosphorus. Water, Vol. 11. 10.3390/w11091889.
13. Wu, Z., X. Wang, Y. Chen, Y. Cai and J. Deng, 2018. Assessing river water quality using water quality index in Lake Taihu Basin, China. Sci. Total Environ., 612: 914-922.
14. WHO, 2008. Guidelines for Drinking Water Quality. 3rd Edn., WHO, Geneva, Switzerland.
15. Jimmy, E.N., J. Martinez and J. Verplanke, 2020. Spatial patterns of residential fragmentation and quality of life in Nairobi city, Kenya. Appl. Res. Qual. Life, 15: 1493-1517.
16. Pacione, M., 2003. Urban environment quality and human wellbeing a social geographical perspective. Landscape Urban Plann., 65: 19-30.
17. Prasanth, S.V.S., N.S. Magesh, K.V. Jitheshlal, N. Chandrasekar and K. Gangadhar, 2012. Evaluation of groundwater quality and its suitability for drinking and agricultural use in the coastal stretch of Alappuzha District, Kerala, India. Appl. Water Sci., 2: 165-175.

18. Oguntoke, O., O.A. Komolafe and H.J. Annegarn, 2013. Statistical analysis of shallow well characteristics as indicators of water quality in parts of Ibadan city, Nigeria. J. Water Sanitation Hyg. Dev., 3: 602-611.
19. Maskooni, E.K., M. Naseri-Rad, R. Berndtsson and K. Nakagawa, 2020. Use of heavy metal content and modified water quality index to assess groundwater quality in a semiarid area. Water, Vol. 12.
20. Ako, A.A., J. Shimada, T. Hosono, K. Ichiyanagi and G.E. Nkeng *et al*., 2011. Evaluation of groundwater quality and its suitability for drinking, domestic and agricultural uses in the banana plain (Mbanga, Njombe, Penja) of the Cameroon volcanic line. Environ. Geochem. Health, 33: 559-575.
21. Wotchoko, P., M.A. Tita, N.G.D. Kouankap, M. Alice, J.Z. Nkemnji, C.S. Guedjeo and K.V. Kamgang, 2016. Physico-chemical analysis of water quality of springs in Bafia-Muyuka, North-Eastern flank of mount Cameroon (South West Region, Cameroon volcanic line). Am. J. Water Resour., 4: 111-120.
22. Kimani-Murage, E.W. and A.M. Ngindu, 2007. Quality of water the slum dwellers use: The case of a Kenyan slum. J. Urban Health, 84: 829-838.
23. Rochelle-Newall, E., T.M.H. Nguyen, T.P.Q. Le, O. Sengtaheuanghoung and O. Ribolzi, 2015. A short review of fecal indicator bacteria in tropical aquatic ecosystems: Knowledge gaps and future directions. Front. Microbiol., Vol. 6. 10.3389/fmicb.2015.00308.
24. Djaouda, M., A. Lecke, M.K. Maine, Z. Wadoube, S. Liang, M. Nola and T. Njine, 2018. Assessment of bacteriological quality of groundwater from boreholes in Maroua (Far North Cameroon). Int. J. Biol. Chem. Sci., 12: 958-974.
25. Mkandawire, T., 2008. Quality of groundwater from shallow wells of selected villages in Blantyre District, Malawi. Phys. Chem. Earth Parts A/B/C, 33: 807-811.
26. West, N.X., J.A. Hughes and M. Addy, 2008. The effect of pH on the erosion of dentine and enamel by dietary acids *in vitro*. J. Oral Rehabil., 28: 860-864.
27. Buzalaf, M.A.R., A.R. Hannas and M.T. Kato, 2012. Saliva and dental erosion. J. Appl. Oral Sci., 20: 493-502.
28. Bancessi, A., L. Catarino, M.J. Silva, A. Ferreira, E. Duarte and T. Nazareth, 2020. Quality assessment of three types of drinking water sources in Guinea-Bissau. Int. J. Environ. Res. Public Health, Vol. 17.10.3390/ijerph17197254.
29. Ericsson, C.D., R. Steffen and H. Backer, 2002. Water disinfection for international and wilderness travelers. Clin. Infect. Dis., 34: 355-364.
30. Ngwa, M.C., S. Liang, I.T. Kracalik, L. Morris and J.K. Blackburn *et al*., 2016. Cholera in Cameroon, 2000-2012: Spatial and temporal analysis at the operational (health district) and sub climate levels. PLOS Negl. Trop. Dis., Vol. 10. 10.1371/journal.pntd.0005105.