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Scarcity of Potable Water and Sanitation Facilities in the Endemic Cholera Region of North Cameroon

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Abstract In North Cameroon, cholera outbreaks regularly occur during the rainy season. Nevertheless, how the outbreak takes place and how the disease is spread in the region remain largely unknown. This study aimed to characterize quality of water sources and explore potential environmental reservoirs of the causative agent, *Vibrio cholerae*, and factors maintaining its persistence. Of the 33 water sources investigated, 5 (4 wells and 1 stream point) were positive for *V. cholerae*. The water provided from wells and stream points is unsafe for consumption with regard to microbial indicators. High-risk zones of cholera were identified which could be used to inform local risk. The household size was shown to be a significant risk factor for reported cholera cases ($P<0.05$). Use of uncontrolled quality water (from well and stream) was also found as a risk factor for cholera ($P<0.001$). This study showed that individuals who do not wash their hands with soap are most vulnerable to cholera risk ($P<0.001$). The use of chlorine treated water, improvement in sanitation structures and hygiene are possible solutions to reduce cholera outbreaks.

Keywords: *Vibrio cholerae, reservoirs, sanitation, hygiene, north Cameroon*

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1. Introduction

Cholera remains a major public health problem in many parts of the world and is often a relatively neglected disease [1]. In 2014, a total of 190 549 cholera cases with 2231 deaths were reported to WHO by 42 countries, resulting in an overall case fatality rate (CFR) of 1.17%. Fifty five percent (55%) of all reported cases originated from Africa. CFRs >5% were reported in 4 African countries: Cameroon, Ivory Coast, Guinea Bissau and Kenya. In Cameroon, the Regions of North and Far North reported 47.3% of cholera cases reported in the country between 2004 and 2013 [2].

Cholera outbreaks regularly occur every year at the rainy season in north Cameroon. The number of victims is even increasing with year [2]. The recurrent cholera outbreaks point to the existence of hotspot cholera potential reservoirs including on-site sanitation systems, heavily polluted surface aquatic and groundwater systems [3,4]. According to Kaas *et al.* [5], *V. cholerae* is endemic to the Lake Chad basin and they further suggest that it is clonal and different from other African *V. cholerae*. Literature elsewhere shows that cholera outbreaks are controlled by its complex interactions with environmental drivers and reservoirs [6]. However, a paucity of information exists on the environmental reservoirs of *V. cholerae* and factors maintaining its persistence in the region. Such information is key for the development of effective methods for the prevention and control of cholera [7]. The environmental reservoirs respond to hydroclimatic and anthropogenic factors such as poor sanitation and hygiene, human migration, and cross-border movements that may promote the dissemination of cholera [8,9]. In north Cameroon, concerns remain about the high proportion of people living in unsanitary conditions and at risk of cholera and other waterborne diseases.

Over the years, the local people of the north Cameroon have adapted their water consumption behaviour because of varying levels of water availability. Well water is the primary source of drinking water for the majority of poor people. Wells have been installed at various depths, depending on availability and the level of groundwater. There are few areas where people are so poor that they cannot afford installing a well. In such areas, streams are the only source of drinking water. Digging for water in a dried up stream bed and street vending of water are sources of drinking water commonly used in dry season. The absence of proper water facilities and services leads to health problems with the major one being the creation of a network of increased illhealth through diseases such as cholera and typhoid fever [10]. According to Obeng-Odoom [11], water from boreholes, wells and rivers is more often than not contaminated with bacteria, hence should rather be considered as unimproved sources.

To ensure safe sources of water is one of the most important issues for human health [10]. Planning for effective water supply in the north Cameroon requires understanding of the existing water consumption patterns. The lack of waste water treatment and traditional latrines practices constitute a major factor of contamination of wells and streams, largely used as drinking water sources by poor communities. Efforts of government and NGOs are not sufficient to prevent or eliminate cholera because factors of persistence and transmission of this disease are not well known. Given massive cholera cases in north Cameroon, it has been imperative to investigate the factors responsible for the spread of the disease in order to prevent or eliminate outbreaks. Information are needed to understand the transmission patterns and the causes of the persistence of cholera in north Cameroon.

The main objective of this study was to investigate water quality, human consumption behaviour, and sanitation facilities of the endemic cholera region of north Cameroon. The findings of the present study may help in planning and implementation of improved water supply and sanitation facilities; and to make suggestions for future safe water supply and sanitation.

2. Material and Methods

2.1. Study Site

The north Cameroon region is located between latitude 9° and 13° north and longitude 13° and 15° east (Figure 1). This is the Sudano-sahelian zone of Cameroon.

The Sudano-Sahelian zone is made up of the Mandara Mountains, the Far North plains and the Benue valley. Rainfall ranges from 800 to 900 mm annually, arriving within the months of July to October, while the remaining eight months are dry [12]. There is a dense hydrographical network made up of ‘mayos’ or seasonal rivers and permanent rivers which crisscross the zone [12]. The temperature shows wide fluctuations (minimum value around 18°C in January and maximum value about 42°C in March).

The Far North Plains are major collectors of water basins for ‘mayos’ which come mainly from the Mandara Mountains [13]. As such, they are subject to irregular variations of these flows that significantly affect human activities downstream (such as irrigation, fishing, only to mention but these).

In comparison with other areas of the Far North Region, the Mandara Mountains have a higher altitude (600 to 1400 m), a slightly milder climate, and a much higher rainfall around 900 to 1000 mm/year [14].

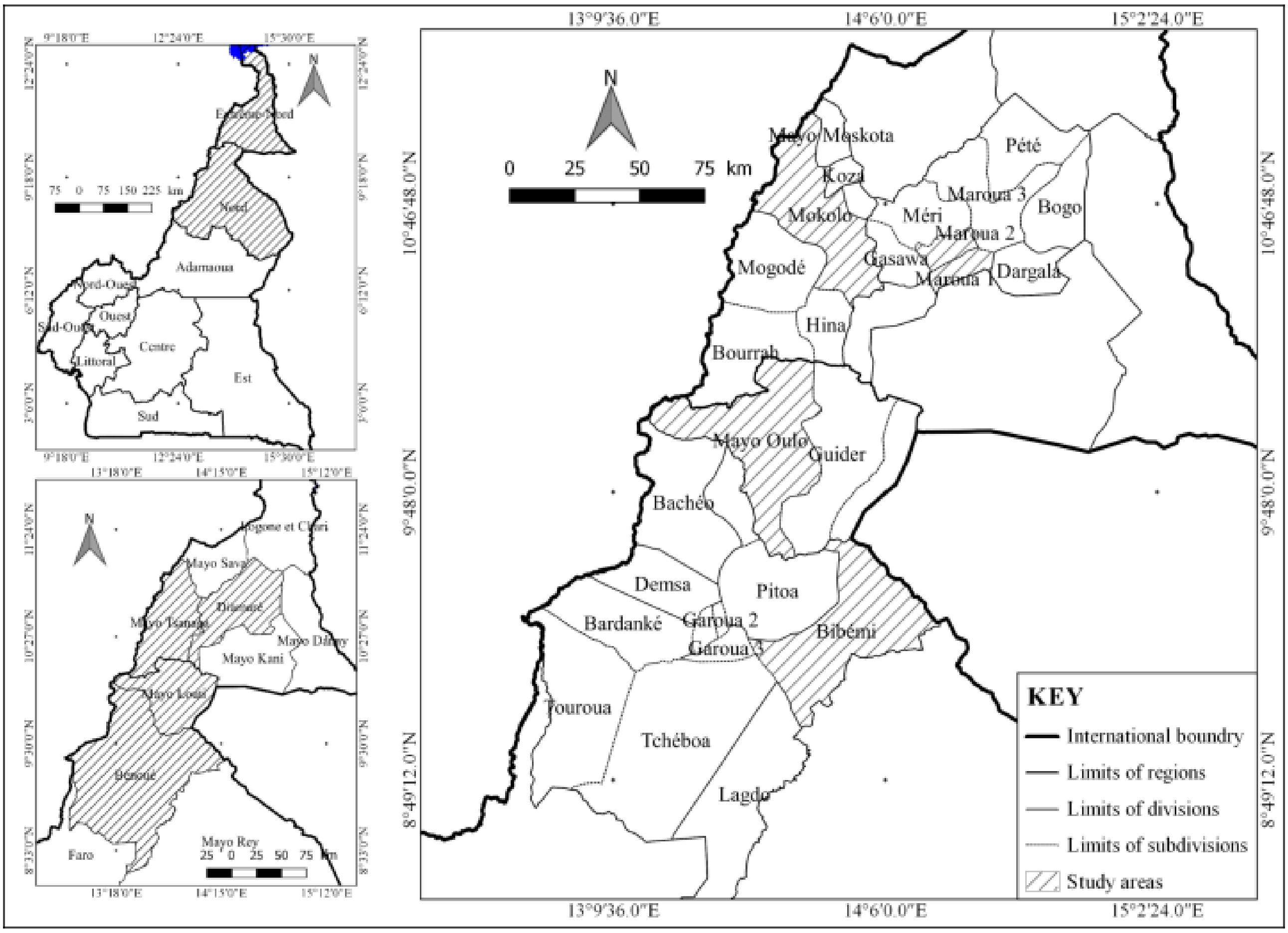

Figure 1. Map showing the location of the study site

The Benue basin fed by tributaries from three catchment areas: the western highlands, the Adamaoua highlands and the Mandara Mountains [12]. It rises from the central northern slopes of the Adamaoua. The tributaries which originate from the eastern sector are the Mayo Rey and Mayo Godi. From the central region is the Mayo Farda from the Poli Mountains. The Faro, Mayo Njal and Mayo Deo, which form the western arm of the tributaries of the Benue, all converge to join the Benue at the exit point into Nigeria. The main tributary from the Mandara Mountains is the Mayo Louti. To the south of the Diamare plain is the Mayo Kebi and its tributaries flow through the Republic of Chad before meeting with Mayo Kebbi.

Due to the presence of the Boko Haram terrorist group in the Far North region, security and safety issues led to significant modification of the delimitation of the study sites. The study was conducted in 5 localities (Figure 1): Mayo oulo and Bibemi (North Region), and Maroua I, Maroua II and Mokolo (Far North Region), according to their geographical location, cholera endemicity and security issues.

Mokolo, located in the Mandara mountains zone and hosting a lake, is one of the 8 health districts (including Kolofata, Mada, Maga, Maroua, Kousseri, Yagoua, Guere, and Mokolo) in the Far North that have a cumulative incidence rate of cholera greater than 1 per 10 000 persons from 1996 to 2011. Maroua I and II (located in Far North plains) do not host permanent water body but had the highest incidence rate of cholera during the 1996-2014 years [13]. Bibemi is one of the areas where floods occur every year during the peak period of rainfall between August and September. Flood episodes are often followed by cholera outbreaks. Mayo oulo, located at the border with Nigeria, hosts a small river which flow is modified by the presence of series of small dams made to provide potable water in the Mayo louti division. This area is regularly affected by cholera outbreaks, with small number of victims that often originate from Nigeria linked to people movement.

2.2. Identification and Cartography of Cholera's Foci

A preliminary survey was undertaken in public health hospitals of the region. Data on cholera incidence for the last 2010-2011 major outbreaks were collected from public hospitals of the study areas. The foci and number of cholera cases of each area were then documented and geo-referenced. All identified foci for cholera were later mapped based on their GPS coordinates collected during the field survey.

2.3. Identification of Drinking Water Sources

A survey was carried out in the different foci to determine the source of drinking water at each focus. A structured questionnaire was administered to residents of the different foci. The distribution, characteristics and uses of water sources were described. Water sources coordinates were registered using a GPS receiver, for mapping.

2.4. Population Behaviours Associated with Cholera Outbreaks and Spread in the North Cameroon

A comprehensive questionnaire was used in this study to obtain baseline characteristics of the study households in the identified cholera foci. In addition to ethical clearance obtained from the Regional delegation of Public Health and University of Maroua, the head of each study household gave verbal consent to participate after being informed about the purpose of the study. The original questionnaire was formulated in English and French and the interview was conducted in local language, Fulfulde/French, with the female head of each household. Four graduate students from University of Maroua were trained as field-workers to conduct the survey. Both students are fluent in English/French and Fulfulde. The draft questionnaire was pre-tested. The questionnaire was revised after two rounds of pre-testing. The household was considered as a unit of analysis because water supply issues were concerns of the entire household. From each selected household, one representative was selected as the sample. Only the female participants were selected because they are mainly responsible for collecting drinking water in the household. Data were obtained on household demographics, water collection practices, water transportation practices, water utilization, water handling and storage, sanitation, prevalence of diarrhoea during the past six months prior to the interview and general observations made by the interviewer during the interview. Allocation of questionnaire was based on the population of each area; 75 residents were sampled from each area. The questionnaire was administered face-to-face by the principal investigator (grantee) and the trained surveyors (graduate students).

2.5. Water Sample Collection

The samples were collected from surface and ground water sources (27 wells, 6 stream sampling points) that were used directly for drinking purpose in the community. Water sources coordinates were recorded using a GPS receiver for mapping. Samples from wells and streams were collected to fill the sampling bottle using the same technique that household members typically used when handling their drinking water. Water samples for both physical and chemical analysis were collected in pre-cleaned plastic bottles while the water samples for bacteriological analysis were collected in sterile glass bottles according to Standard Methods [15]. Replicates of water samples were collected bimonthly between May 2015 and April 2016. Samples were transported on ice, in coolers, to the laboratory for analysis within 24 hours.

2.6. Isolation and Identification of *Vibrio Cholerae* from Water Samples

The identification and isolation of *V. cholerae* used multi-stage approach. For each sampling site, 100 ml raw/diluted water sample was filtered through a sterile 47 mm, 0.22 µm-pore-diameter, gridded membrane filter, under partial vacuum. Funnel was rinsed with three 30 ml portion of sterile dilution water. Filter was removed with a sterile forceps and transferred to Alkaline Peptone water for enrichment. A loop full of enrichment culture was picked just beneath the surface of broth and streaked onto thiosulfate citrate bile salt sucrose (TCBS) agar (Liofilchem s.r.I. Bacteriology Products, Italy) plates and incubated at 37°C for 18-24 hours. Presumptive colonies (yellow, measuring 2-4 mm) were sub cultured on brain heart infusion agar to obtain pure cultures. Gram negative, curved and motile rods that were oxidase positive were subjected to further biochemical characterization using the API 20E kit (Bio Merieux SA, France). Biochemically confirmed *V. cholerae* was serotyped by slide agglutination as described by CDC [16] using *V. cholerae* O1 polyvalent antiserum (Remel Europe Ltd, UK). Isolates that did not show agglutination with polyvalent O1 antiserum were tested with O139 antiserum (Remel Europe Ltd, UK).

2.7. Bacteriological Water Quality Analysis

The water quality parameters include total and faecal coliform counts. These parameters were determined using standard methods for water analysis [15]. The presence of coliforms, in higher counts in water indicates contamination by potentially pathogens that compromises the safety of such water sources [15]. Coliforms presence in the water is therefore useful for monitoring the microbial quality of drinking water from time to time. The isolation of coliforms was carried out by the membrane filtration technique using the Eosine Methylene Blue (EMB)/Endo media. Results were expressed as the number of colony forming units (CFU) per volume of water.

2.8. Physico-Chemical Water Quality Analysis

The main physico-chemical parameters of water quality were: temperature, total dissolved solids, pH, electrical conductivity and salinity. These parameters were chosen in accordance with their general importance on bacterial metabolism. They are helpful to explain the survival and growth of *V. cholerae* in water and identify environmental factors of occurrence and persitence of cholera outbreaks. All these parameters were measured using the pH/ Conductivity/TDS/Salinity/Temperature Meter Extech EC 500.

2.9. Data Analysis

Statistical analyses were performed in R freeware version 3.4.1. Data were analyzed descriptively and analytically. The Kruskal Wallis-test was used to see the difference in average of coliforms counts, temperature, pH levels, electrical conductivity, TDS, and salinity between water sources. The chi-square test of independence was performed to explore the relationship between presence/ absence of cholera cases in a household prior to the study and categorical explanatory variables. The logistic regression was used to assess the link between cholera risk (presence/absence of cholera cases in the household within six months prior to the study) and the other binary variables. Graphical analysis of data was based on SigmaPlot 10.1 and Excel.

3. Results and Discussion

3.1. Cartography of Cholera's Foci

Maps were produced to show the spatial pattern of cholera incidence during the 2010 and 2011 outbreaks (Figure 2).

The results show that the occurrence of cholera outbreak during these years followed a spatial distribution indicating the most seriously affected areas. Cholera cases were more concentrated in the border region with Nigeria and Chad (Kolofata, Mora, Mokolo, Mogode, Tokombere, Maroua, Kousseri, Maga, Bibemi, Golombe, Tcholire, Rey Bouba, etc.) during 2010 and 2011. Overall, very few health districts have been relatively free from cholera outbreak. By identifying high-risk zones of cholera, this study made it possible to stratify local risk.

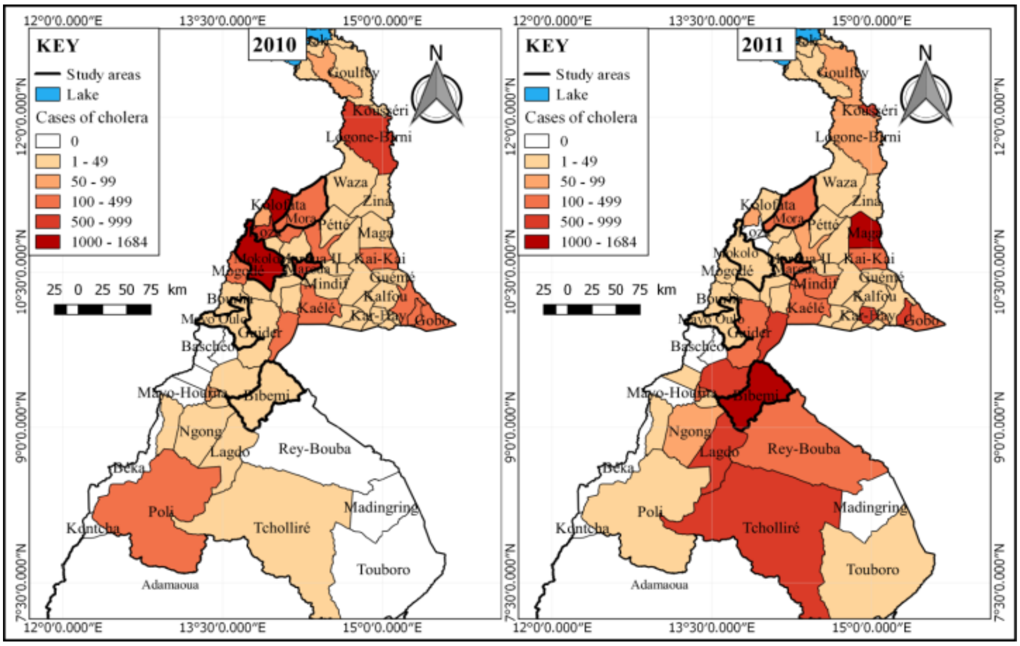

Figure 2. Map showing distribution of the cases of cholera per Health District of North Cameroon in 2010 (left) and 2011 (right)

Table 1. Summary of the household demographics indicating the number of people in households and gender (M=male, F=female) for different ages and the level of education of the female head of the household

Demographics	Localities					Total
	Bibémi	Mayo-oulo	Maroua I	Maroua II	Mokolo	
Household size mean (sd)	7.67 (4.09)	7.23 (4.79)	7.41 (4.88)	7.84 (4.80)	6.02 (2.74)	7.23 (4.36)
People in household Gender						
Male	271 (47%)	255 (47%)	256 (46%)	267 (45%)	200 (44%)	1249 (46%)
Female	304 (53%)	289 (53%)	301 (54%)	323 (55%)	252 (56%)	1469 (54%)
Age group						
Children<5 years	105 (18%)	116 (21%)	105 (19%)	119 (20%)	116 (26%)	561 (21%)
Children (6-10 years)	118 (21%)	132 (24%)	91 (16%)	137 (23%)	93 (20%)	571 (21%)
Children (11-18 years)	127 (22%)	96 (18%)	120 (22%)	128 (22%)	82 (18%)	553 (20%)
Adult (>18 years)	225 (39%)	200 (37%)	241 (43%)	206 (35%)	161 (36%)	1033 (38%)
Education level of female head of household						
University	0 (0%)	0 (0%)	2 (3%)	0 (0%)	0 (0%)	2 (0%)
Secondary school	11 (15%)	9 (12%)	11 (15%)	6 (8%)	9 (12%)	46 (12%)
Primary school	31 (41%)	16 (21%)	26 (35%)	20 (27%)	22 (29%)	115 (31%)
None	33 (44%)	50 (67%)	36 (48%)	49 (65%)	44 (59%)	212 (57%)

3.2. Socio-Demographic Characteristics of the Study Population

The mean family size was 7.23±4.36 persons in a household. This average value was similar to that found by Healy-Profitos *et al*. [17] in villages and camps of Maroua and Mpakam *et al*. [18] in the Bafoussam quarters, where 7 people on average live in the households. In the study region, the lowest average of number of people living in a household was noticed in Mokolo and the highest in Maroua II. The average obtained was close to the average number of children per African family which is one of the highest in the world [18]. This result highlights the popular character of the surveyed areas and the non-respect of the standards of family planning. The socio-demographic characteristics of the households are shown in Table 1.

The 0 to 18-years-olds were the most represented in all the studied communities (57 to 65%). Children under 5 represented 18 to 25 % (Table 1). In this study significant association between number of people in households and cholera cases was seen ($P< 0.05$). Significant statistical difference was also found between cholera risks among localities ($P<0.001$, χ^2: 52.15, df: 4). The population density was shown to be a significant risk factor for reported outbreaks of all categories of water-associated infectious diseases and the probability of outbreak occurrence increased with the population density [19].

Nearly 44-67% of the respondents had no formal education. 8-15% achieved secondary education, and 21-41% reached the primary education level, and 0-3% the higher education level. These results fit the national values, in Cameroon it is the primary education level which shows the highest rates of literacy [20].

3.3. Drinking Water Sources and Pattern of Water Use

The survey results reveal a complex water sourcing pattern. The types of water sources available varied considerably among localities (Figure 3). Drinking water sources available in the study areas are presented in Table 2.

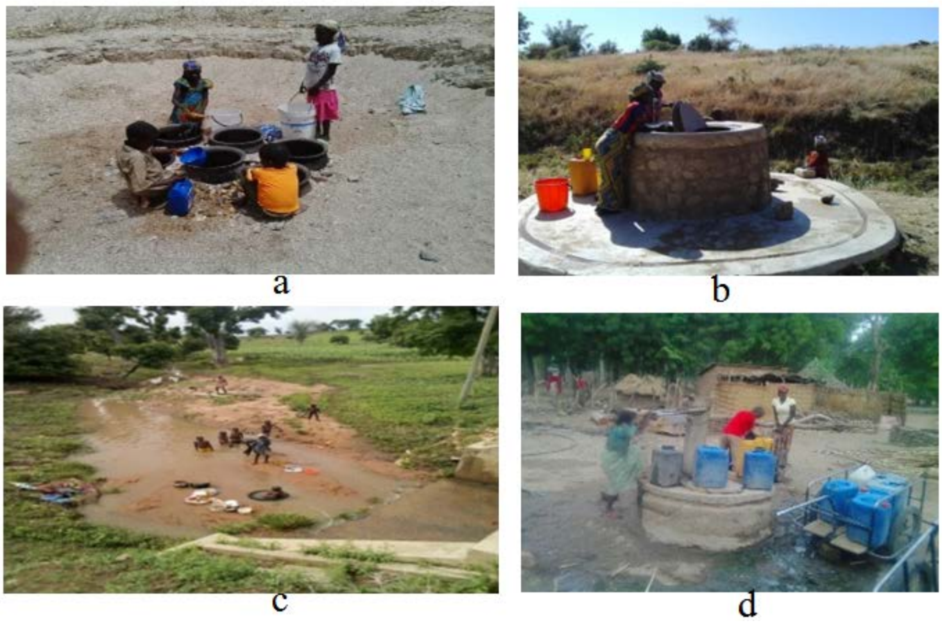

Figure 3. Pictures of typical water sources used in the study site. [a: Stream water in a dried up mayo during the dry season, b: Dug well with concrete walls, c: Stream water source in a mayo during the rainy season, d: Borehole with a hand pump]

Table 2. Summary of the water sources used by the study households in the study sites

Water use characteristics	Bibémi	Mayo-oulo	Maroua I	Maroua II	Mokolo
Water source					
Rain	0 (0%)	0 (0%)	0 (0%)	1 (1%)	0 (0%)
Stream	46 (61%)	25 (27%)	0 (0%)	3 (2%)	1 (1%)
Well	26 (35%)	23 (25%)	37 (38%)	41 (34%)	38 (41%)
Private borehole	3 (4%)	0 (0%)	3 (3%)	4 (3%)	0 (0%)
Communal borehole	0 (0%)	0 (0%)	2 (2%)	19 (16%)	0 (0%)
Indoor tap	0 (0%)	7 (7%)	3 (3%)	4 (3%)	2 (2%)
Communal tap	0 (0%)	38 (41%)	52 (54%)	49 (41%)	52 (56%)
Source distance from household					
0	1 (1%)	12 (16%)	5 (7%)	6 (8%)	0 (0%)
50-100	22 (29%)	54 (72%)	28 (37%)	20 (27%)	25 (33%)
100-500	47 (63%)	8 (11%)	15 (20%)	39 (52%)	32 (43%)
500-1000	5 (7%)	1 (1%)	2 (3%)	9 (12%)	14 (19%)
>1000	0 (0%)	0 (0%)	0 (0%)	1 (1%)	4 (5%)
Method used to fetch water from the source					
Deeping into it with a container	74 (99%)	45 (50%)	27 (31%)	29 (29%)	38 (44%)
tap	0 (0%)	45 (50%)	58 (67%)	48 (48%)	49 (56%)
hand pump	1 (1%)	0 (0%)	2 (3%)	22 (22%)	0 (0%)
Do you pay water					
yes	3 (4%)	45 (60%)	60 (81%)	50 (68%)	54 (73%)
No	72 (96%)	30 (40%)	14 (19%)	23 (32%)	20 (27%)
If yes how much do you pay					
<750	0 (0%)	0 (0%)	2 (3%)	0 (0%)	4 (7%)
750-1500F	3 (100%)	5 (11%)	3 (5%)	5 (10%)	13 (24%)
1500-3000F	0 (0%)	19 (42%)	17 (28%)	19 (38%)	19 (35%)
3000-6000F	0 (0%)	15 (33%)	21 (35%)	18 (36%)	12 (22%)
>6000F	0 (0%)	6 (13%)	17 (28%)	8 (16%)	6 (11%)
who fetches the water for the household					
Female adults	69 (53%)	48 (49%)	34 (27%)	44 (44%)	72 (60%)
Children	58 (46%)	41 (42%)	51 (40%)	45 (44%)	45 (38%)
Male adults	2 (1%)	9 (9%)	36 (28%)	8 (8%)	2 (2%)
Both	0 (0%)	0 (0%)	6 (5%)	4 (4%)	0 (0%)

Almost all households reported that they rely on two or more sources to obtain drinking water. However, in Bibemi all households rely on one source (61% stream, 35% well and 4% borehole) to obtain drinking water. According to Sorlini *et al.* [21], people living in the same village in the northern Cameroon can use both improved and unimproved water sources, which may have different health effects. Households' choice of water sources is income dependent. Wells were found to be the most common source of drinking water, followed by stream, with the use of other sources being limited. In Mayo-oulo, Maroua and Mokolo, 48-58% of the households reported using taps as their main drinking water sources. In all the localities, wells are widely used (25-41%) as drinking water sources. Stream is the main drinking water source for 21 and 61% of households in Mayo-oulo and Bibémi, respectively. Tap water is based on the local groundwater that is chlorinated and distributed to households by Cameroon Water Company which control its quality. More than 50 % of the households were found to use tap water for drinking purposes in urban areas of Maroua and Mokolo. According to Healy-Profitos *et al.* [17], the greatest bacterial contamination of drinking water from taps occurs within the household and that improvements of the originating source water quality deteriorate once the drinking water moves through the distribution system and is stored in the household.

A large percentage of the households pay for water (60- 81%); others use free untreated wells/streams water (19-40%) in urban areas where tap water is available (Maroua I, Maroua II, Mokolo, Mayo Oulo). Only 4% of the study population reported paying for water in Bibemi where tap water is unavailable. Approximately 72-89% of the participants who pay for water reported monthly cost of water of less than FCFA 6000 (approximately 12 USD) in Maroua, Mokolo and Mayo-oulo. Some women felt that tap water was too expensive and many households were unable to afford the cost. Statistical relationship was found between paying water and cholera risk (odds ratio: 1.15, 95% IC: 0.99-1.34). Similarly, using drinking water from uncontrolled sources (wells and streams) was associated to cholera risk (P<0.001, χ^2: 28.77, df: 5). Not paying for water is a sign that the household uses uncontrolled water and is exposed to cholera risk. The other authors had found that the consumption of treated water constituted a protective factor [22,23,24].

Fifty-six (56)-70% of households were found to obtain their drinking water from water sources located more than

100 meters in the study localities, except Mayo-oulo where 88% of the households reported have their drinking water sources near their houses. The morning and the afternoon were found to be the periods where the water sources are most visited in Bibemi, Mayo Oulo, Maroua I, Maroua II, and Mokolo, respectively. Female adults (27-60%) and children (38-46%) are mainly responsible for collection of water for their households. All the women stated that they did not treat tap water at home because it had been treated at the water treatment plant. When the tap water was not provided, the women reported that they had to walk much further to fetch water, either from dug wells or the river, even though they recognized that the water from these sources was not good to drink. A majority reported that they use plastic container to fetch water from the source. Manual abstraction of water from the source was common amongst the households; only standpipe and boreholes had a tap for water collection. The containers used to draw water from wells are partly responsible for the water contamination in the catchments used for drinking purposes [25]. It is obvious that the basic requirements of safe drinking water are not met in all of the five studied localities. The majority of the respondents said that there is no community-based management for operation and maintenance. In the 5 studied localities, 3% of the households reported the presence of a water committee in their locality. This should be a good indicator when one seeks to know if a population can potentially carry on successful collective actions [18]. Such associations are usually voluntary group of individuals brought together to ensure the maintenance of the collective accesses to water. The duration of water storage at home is presented in Figure 4.

Ninety nine (99)% of households reported storing water for more than one day before consumption. 56% of households wash their storage containers every day. According to the survey, 98% of households stored their water containers outdoors with a closed lid, while 2 % of households stored their water outdoors in open containers (Figure 5). This is a traditional practice to which the majority of inhabitants of north Cameroon are attached to. Clay pots (74-99%) were the most represented storage containers compared with plastic containers (1-7%), barrels and metallic containers (0-1%). Most of the households (99%) use a mug to collect water from the storage container. The method used to obtain water from the storage container could contribute to contamination and the spreading of pathogens between members of the same households [26]. Households reported that they mostly use only water to wash the water storage containers (Figure 6).

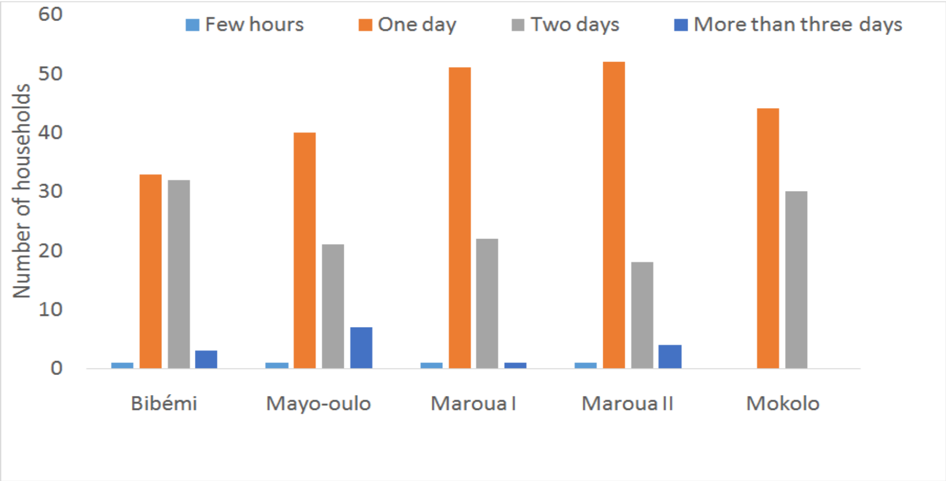

Figure 4. Duration of water storage at home

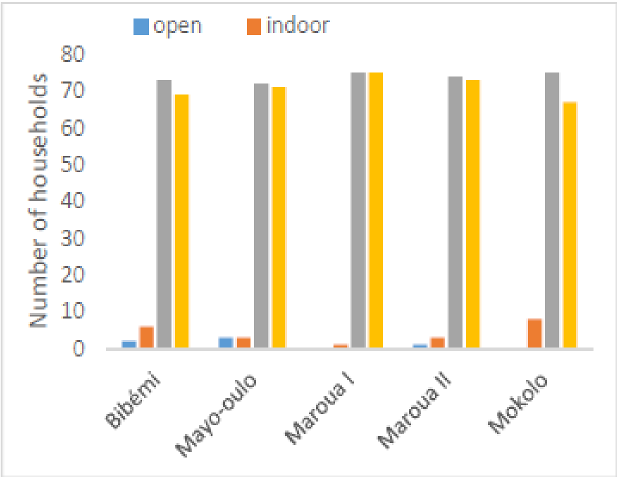

Figure 5. Conditions of keeping the water storage container

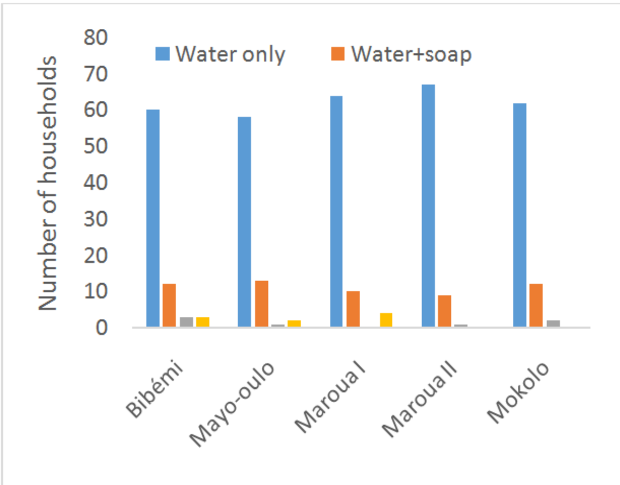

Figure 6. Method used to clean the water storage container

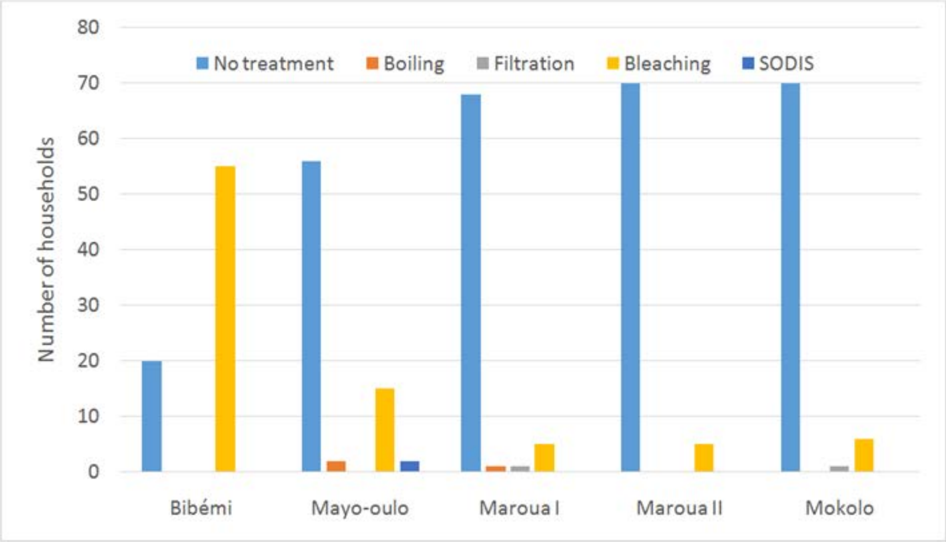

Figure 7. Treatment of stored water

Observations made by interviewers showed that the used mug was not washed every time and was left next to the storage container. According to Kabyla *et al.* [27], good hygiene, appropriate sanitation and safe water are of prime importance in the fight against cholera. Nearly 7-73% of households treat their water daily in some way, with majority of these households relying on chlorination by bleach as their primary treatment method in Bibémi (Figure 7). Among the reasons for non-treatment of drinking water, some authors mentioned the bad taste and odors caused by the water treatment product [28]. Contrary, the large use of water treatment seen in Bibémi could be related to the fact that during the epidemic the chlorine is distributed to households by NGOs and government and could only be used in a context of fear of epidemic. Subsequent studies should be conducted outside any outbreak to assess the determinants of water treatment in this locality.

3.4. Sanitation Options and Personal Hygiene

Table 3 summarizes waste management and sanitation situations in the study sites. The investigation of latrines types (Figure 8) and their uses by respondents show three situations: traditional latrines ("salka") are widely used (79-96%); modern latrines (21%) only in Mayo-oulo usually provide the most privacy; the worst situation (4-16%) was that of residents who defecated in open fields. For these households, having a toilet facility at home does not seem to be a priority. Human feces are found in open spaces with the resultant stench and flies nuisance.

Table 3. Summary of waste management and sanitation in the study site

Variables	Bibémi	Mayo-Oulo	Maroua I	Maroua II	Mokolo
Type of toilet used					
Traditional	69 (92%)	68 (79%)	69 (92%)	73 (96%)	63 (84%)
Use bush	6 (8%)	0 (0%)	6 (8%)	3 (4%)	12 (16%)
Modern	0 (0%)	18 (21%)	0 (0%)	0 (0%)	0 (0%)
Number of people using the toilet					
1 to 5	21 (30%)	30 (42%)	30 (42%)	25 (33%)	30 (41%)
6 to 10	42 (59%)	26 (36%)	25 (35%)	31 (41%)	38 (51%)
>10	8 (11%)	16 (22%)	16 (23%)	19 (25%)	6 (8%)
Action when toilet is not available					
Relieve himself in the vicinity of the house	8 (11%)	27 (36%)	18 (24%)	18 (25%)	44 (62%)
use neighbour's toilet facilities	36 (48%)	33 (44%)	25 (33%)	31 (43%)	11 (16%)
wait for availability	19 (25%)	4 ((5%)	14 (19%)	1 (1%)	10 (14%)
use another toilet	12 (16%)	11 (15%)	17 (23%)	23 (32%)	6 (8%)
use river	0 (0%)	0 (0%)	1 (1%)	0 (0%)	0 (0%)
How is water including waste from flush toilets disposed of?					
Poured into a septic tank	4 (5%)	3 (4%)	10 (13%)	10 (13%)	3 (4%)
Poured outside of the yard	63 (81%)	71 (93%)	61 (81%)	62 (82%)	39 (49%)
Poured into the yard	11 (14%)	2 (3%)	4 (5%)	4 (5%)	38 (47%)
How do you dispose of your domestic rubbish?					
Rubbish is collected	4 (4%)	5 (6%)	4 (5%)	2 (2%)	0 (0%)
Pour in the yard	17 (17%)	5 (6%)	0 (0%)	5 (6%)	2 (3%)
Bury in the yard	3 (3%)	2 (2%)	2 (3%)	5 (6%)	3 (4%)
Pour ouside the yard	53 (55%)	59 (70%)	68 (88%)	64 (70%)	63 (84%)
Bury ouside yard	0 (0%)	2 (2%)	1 (1%)	5 (6%)	7 (9%)
Burn	20 (21%)	12 (14%)	2 (3%)	10 (10%)	0 (0%)

Variables	Bibémi	Mayo-Oulo	Maroua I	Maroua II	Mokolo
Waste storage in household					
Daily	62 (83%)	14 (20%)	48 (65%)	14 (20%)	66 (89%)
Weekly	9 (12%)	9 (13%)	9 (12%)	9 (13%)	0 (0%)
Monthly	3 (4%)	0 (0%)	1 (1%)	0 (0%)	0 (0%)
Rarely	1 (1%)	48 (67%)	16 (22%)	48 (67%)	8 (11%)
Animals kept at home					
Cats	13 (7%)	7 (8%)	12 (14%)	10 (11%)	13 (7%)
Dogs	38 (21%)	14 (16%)	12 (14%)	12 (13%)	36 (18%)
Goats	39 (21%)	38 (42%)	32 (38%)	34 (37%)	55 (28%)
Poultry	48 (26%)	25 (28%)	24 (29%)	30 (33%)	56 (29%)
Pigs	13 (7%)	0 (0%)	0 (0%)	0 (0%)	28 (14%)
Cattle	32 (18%)	6 (7%)	4 (5%)	6 (7%)	8 (4%)
What do you use to clean your baby's buttocks?					
Water and hands	75 (100%)	75 (99)	73 (99%)	67 (100%)	67 (86%)
Toilet paper	0 (0%)	1 (1%)	0 (0%)	0 (0%)	0 (0%)
Cotton tool/cloth	0 (0%)	0 (0%)	1 (1%)	0 (0%)	11 (14%)
Occasions of hand washing					
Before eating	75 (24%)	75 (27%)	74 (27%)	74 (27%)	75 (28%)
Before food preparation	24 (8%)	2 (1%)	9 (3%)	3 (1%)	4 (2%)
After being to toilet	74 (24%)	67 (24%)	73 (27%)	73 (27%)	62 (23%)
After waking up	73 (23%)	73 (27%)	64 (24%)	70 (26%)	71 (27%)
After cleaning baby's buttock	65 (21%)	58 (21%)	52 (19%)	52 (19%)	52 (20%)
Do you use soap to wash hands?					
Yes	23 (31%)	23 (29%)	27 (36%)	22 (30%)	23 (31%)
No	52 (69%)	54 (71%)	47 (64%)	52 (70%)	52 (69%)

Figure 8. Typical traditional latrines ("salka") used in the study site

The average number of persons using the same latrines in the study region was 6-10. The number of people using the same toilet varied across localities. Only 30-42% households have one toilet for less than 6 users. When the toilet is unavailable, 11-62% of households reported that they relieve themselves in the vicinity of the house, 16-48% use neighbors' toilet. The frequent shared use of toilets by neighboring households indicates the situation how conditions of hygiene are shared among the neighborhood. Poorly cleaned and maintained toilets can be a source of contamination and subsequent disease [27]. It has been found that improving drinking water quality would have no effect on reduction of diarrheal diseases in the neighborhoods with very poor environmental sanitation [29]. Improvement of sanitation is urgently needed in study area for a better preparedness and control of cholera.

Domestic waste water is primarily discharged around the houses (49-93% of households), in the yards (3-47% of households), into a septic tank (4-13%). According to Ako et *al.* *[20]*, local and disorganized waste water discharge could be the consequence of the absence of a centralized sewage system.

Observations made by the interviewers showed that 70% of the households had a dirty yard of which 99% of households had flies present in the yard. 72% of households had dirty kitchens and 92% of the households had flies present in the kitchen. Ninety nine (99)% of the households had flies present in the toilet. The presence of wastes in the environment usually leads to nuisances manifested by bad odors, proliferation of mosquitoes and the dispersion of numerous bacteria, including *V. cholerae* [30]. Recent studies have shown that *V. cholerae* can remain for more than 5 days in the digestive tract of houseflies and multiply there; which gives evidence in the role played by the latter in the transmission of the disease [31].

23-27% of the respondents wash hands after going to the toilet. In addition, only 19-21% of the mothers in households reported to wash their hands after cleaning their baby's buttocks. Furthermore, it was observed that not more than 1% of households had toilet paper available in the toilet. 1-8% of households reported to wash hands before they prepared food. Not using soap to clean hands may increase the risk of cholera (odds ratio: 1.26, 95% CI: 0.79-2.00). Households who do not wash their hands with soap are most exposed to cholera risk. According to Fewtrell *et al.*[32], hygiene-based interventions, such as hygiene education campaigns and handwashing promotion, may reduce the risk of diarrheal illness by 45%, with a pooled estimated relative risk of 0.55 (95% CI 0.40-0.75). There were no significant relationships between cholera cases and most assessed socio-economic parameters ($P>0.05$). This result can probably be explained by the positive impact of control strategies that limit the number of victims during cholera epidemics in the study site. In addition, it is likely that some other factors might be associated with the outbreaks.

3.5. Knowledge and Prevalence of Waterborne Diseases

During the survey, it was found that 19% of the households had a child under the age of 5 years who had suffered from diarrhoea in the last 6 months prior to the survey. Few households complained about cases of cholera (0-33% of the households), diarrhoea (11-43% of the households), and typhoid (5-9% of the households) (Table 4). These water-borne diseases are common to the majority of developing countries. The prevalence of these diseases is the result of biological pollution of water which poses serious problems of public health [33]. However, 48% of respondents had no idea what the causes of the child's diarrhoea were; 12% of the households gave contaminated water as the cause and 36% mentioned food as possible reason. Similarly, 61% of households had no idea how to prevent the child from getting diarrhoea.

3.6. Water Quality

3.6.1. Physicochemical Water Quality

The maximum and minimum values of the physicochemical parameters analysed are summarized in Table 5.

During the dry season, the water temperature values recorded for wells and streams ranged from 21.9 to 31.8° C and 22.4 to 29.7°C, respectively. The variation of water temperature with season was not significant (p>0.05). Water temperature between 25 and 28° C would be good for microbial growth [34]. The water temperature is an important factor for metabolism of aquatic organisms. This is because it affects the physical and chemical properties of water, in particular its density, viscosity, solubility of its gas and the rate of chemical and biochemical reactions [35].

For all of the wells, the water pH ranged from 6.46 to 7.96CU (conventional unit) for both seasons (Table 5). The pH values of well water can be explained by the geological nature of the watershed rocks [36]. The pH of stream water remained >7 in both seasons. The increase in pH is related to the dissolution minerals that increase the levels of some ions [36]. Domestic wastewater discharged into nature without treatment would be the main source of some of these chemicals in the groundwater [37].

The electrical conductivity (EC) values of well water samples fluctuated between 111 and 2321µS/cm in the dry season. Some variations were observed under the influence of the rainy season. The relatively high values of electrical conductivity could be related to localized pollution of the aquifer [38]. It varies also according to the spatial heterogeneity of the soil of the region. Similarly, EC of stream water varied from 185.5 to 1363µS/cm in both seasons. The analysis of all acquired data confirms that there is a relationship between the geographical location of the sites and the level of mineralization of water.

TDSs and salinity showed the same variations as EC. Although the high values of TDS do not represent a direct threat to consumer health [39], by their probable composition, high levels of TDS would indicate the significant pollution of water [40,41]. Substantial spatial variations in concentrations of dissolved salts could be due to the diversity of contamination sources of the water sources in the study region.

The Kruskal-Wallis test revealed that pH of water samples differed significantly (P<0.05) between wells and streams. The difference observed for EC, TDS, salinity and temperature was linked to the locality of water sources (p<0.05).

Table 4. Causes and preventions of common waterborne diseases according to local populations

Localities	Disease/symptom incidence (%)			Causes	Preventions
	Cholera	Typhoid fever	Diarrhea		
Bibemi	9	8	40	water, food, fungi, teething	Avoid source of contamination, compliance with hygiene rules
Mayo-oulo	12	9	29	contaminated water and food	Avoid source of contamination, boiling drinking water
Maroua I	0	5	33	contminated food, teething, malaria, heat, traditional beer, fruits and stream water	Avoid source of contamination
Maroua II	33	5	11	Dirt, teething, contaminated water and food	Avoid source of contamination, food hygiene
Mokolo	11	5	43	Rainy season, food, water, vegetables, fungi, well water, teething, fruits	Avoid source of contamination

Table 5. Seasonal variations of the physicochemical parameters minimum (and maximum) values according to sampled water sources in the localities of the study sites

		Dry season									
Water sources	Localities	Temperature (°C)		pH		EC (mS/cm)		TDS (mg/L)		Salinity (*ppm*)	
		min	Max	min	max	min	Max	min	Max	min	Max
Wells	Bibémi	25.3	27.0	7.23	7.79	242	595	166	420	112	290
	Maroua	28.4	31.8	6.76	7.64	254	1673.6	113.8	1402.7	132	1498
	Mayo-oulo	25.2	30.7	7.26	7.52	593	2321	164	791	106	553
	Mokolo	21.9	29.8	6.7	6.9	111	306	113.2	345	122	202
Streams	Bibémi	25.1	29.5	7.35	7.67	326	448	216	312	215	300
	Maroua	22.4	29.7	7.21	7.98	195.6	784	97.8	399	89.8	564
		Rainy season									
Wells	Bibémi	25.3	28.0	6.99	7.79	313	605	217	461	204	305
	Maroua	27.3	30.5	6.46	7.96	226	1539	226	1206	236	1103
	Mayo-oulo	25.0	28.6	6.87	7.69	541	1056	405	766	283	544
	Mokolo	20.5	28.7	6.6	7.01	122	365	164.7	346	105	341
Streams	Bibémi	23.6	27.05	7.03	7.67	365	603	238	506	225	286
	Maroua	23	30.1	7.39	7.93	185.5	1363	93.2	683	96.4	705

3.6.2. Bacteriological Water Quality

Bacteriological analysis was carried out on 33 (27 wells, 6 streams) water sources that had been identified in the 5 localities (Table 3).

All the 27 dug wells (6 in Bibémi, 6 in Maroua I, 5 in Maroua II, 5 in Mayo-oulo and 5 in Mokolo) were Faecal coliforms positive (100%), with 100% having more than 10 cells of *E. coli* in the 100 mL sample. Due to distance between the localities, we were unable to map all the wells together. The average bacterial content in almost all the water points obtained in dry season was increased with the occurrence of the rains (Figure 9).

Abundances of all bacterial indicators of faecal contamination in well water exceeded the standards set by the WHO [42] for drinking water. Such bacterial abundances were obtained by [43] in well water in Garoua. The spatial distribution of these organisms has been associated with human activities over the watershed. According to [43], the seasonal fluctuations of abundances of these organisms depend on water points, which is due to the diversity of sources and intensity of pollution of groundwater in the study site. Poor sanitary practices observed around wells in the study were at the origin of the contamination of these water points. Almost all households use containers that are sometimes placed on the ground, to draw water from wells, which causes continual bacterial contamination of these wells. Most of the wells were dug by local diggers without technicality. Such wells are not in the scope of protection, they are sometimes close to sources of pollution such as latrines. According to [43], the infiltration of faecal bacteria from latrines constitutes a significant source of pollution of such wells.

Streams constitute a major water source for some households in Bibémi and Maroua. Three (3) sampling points were chosen in each of the streams of the two localities (Mayo Lawa and Mayo Kaliao, respectively) for bacteriological analysis. Abundances of the faecal coliforms in the stream water of Bibémi varied between 60 and 670 CFU/ mL, and between 610 and 7590 CFU/mL in dry season and rainy season, respectively. In the stream water of Maroua, abundances of faecal coliforms varied between 61 and 560 CFU/ mL, and between 560 and 1210 CFU/mL in dry season and rainy season, respectively (Figure 10).

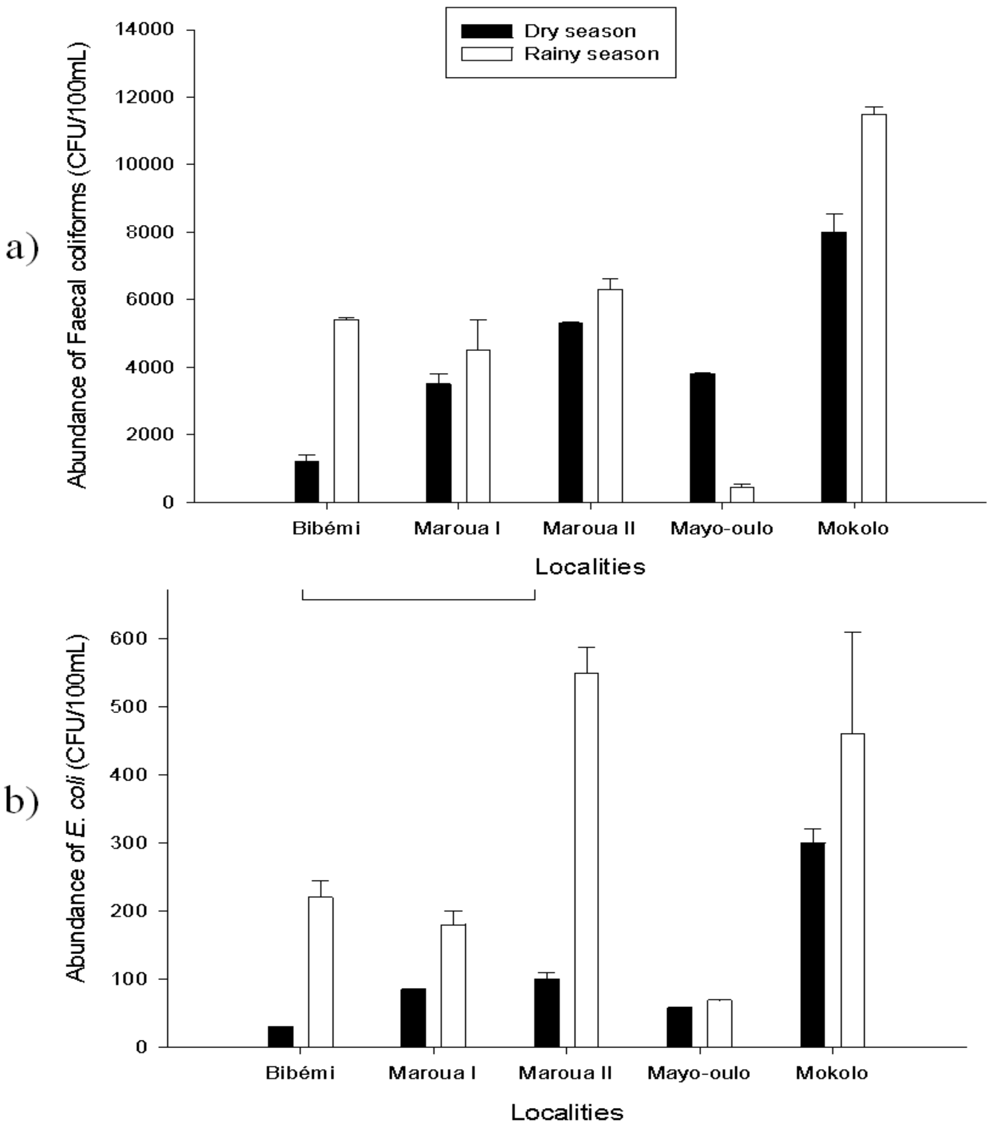

Figure 9. Seasonal variations in average abundances of Faecal coliforms (a) and *E. coli* (b) in sampled wells water from the study localities. The error bars represent the standard error of measurements

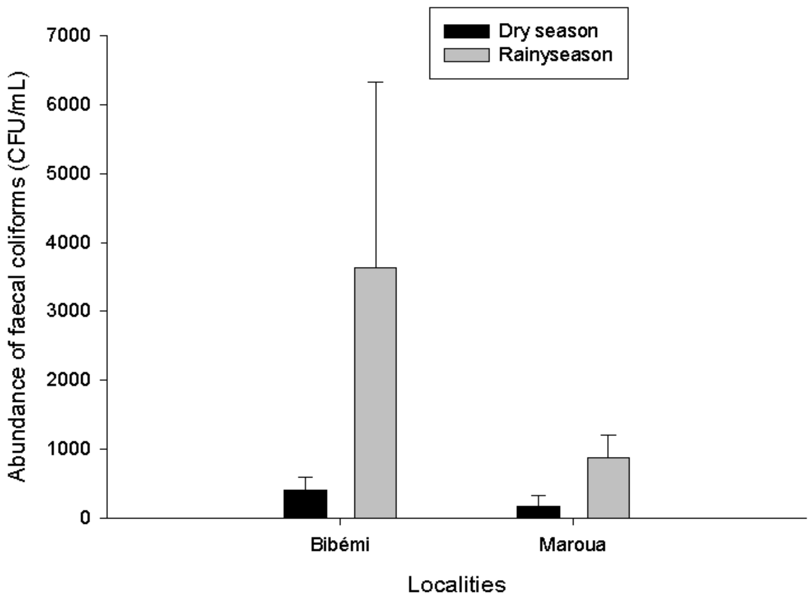

Figure 10. Seasonal variation of the abundance of faecal coliforms (average±standard deviation) in the stream water of Bibémi and Maroua

Stream water proves to be more polluted than well waters in the same localities. The presence in this water of high concentrations of indicator bacteria suggests that these streams should be the potential sources of the waterborne diseases experienced by the households' members in this study. Increase in bacterial abundance of stream water in rainy season highlights the contamination of the water sources by runoff water.

3.7. Detection of *Vibrio Cholerae* in the Sampled Water Sources

Of the 33 water sources investigated, 5 (4 wells and 1 stream) were positive for *V. cholerae* and 21 isolates were collected. The positive water samples were from Doualaré (Maroua 2), Hardé (Maroua 1), Bibémi and Mokolo. All the strains were *V. cholerae* non-O1. *V. cholerae* appears predominately as viable but non-culturable (VBNC) cells within the bacterioplankton and as culturable cells in biofilm consortia, either as aggregates or attached to biotic and abiotic surfaces. [44] The majority of environmental *V. cholerae* strains isolated are non-toxigenic [45,46], which suggests that associations with the human host is only one small aspect of the *V. cholerae* life cycle and is not necessary for environmental persistence. Although it is not certain that O1 and non-O1 strains grow under comparable conditions, the presence of non-O1 *V. cholerae* strains in water sources suggests that conditions are appropriate for growth of *V. cholerae* O1 strains. The presence of such strains could represent a hidden public health threat to users of the contaminated water sources. Due to the small number of positive samples, correlation between occurrence of *V. cholerae* and abiotic and biotic factors could not be assessed using statistical analysis. The vast majority of surveys for *V. cholerae* based on collecting isolates after cultivation also identified some *V. cholerae* isolates from cholera endemic and non-endemic areas sporadically and in very small numbers, preventing any meaningful ecological analysis [47,48]. Culture-independent investigation of bacterial communities through sequencing of various regions of the 16S rRNA is necessary to optimize the detection of *V. cholerae* O1.

There are some limitations to the study. Safety issues led to loss of data in some study areas frequently affected by cholera outbreaks such as Kolofata, Mogode, Mora, Kousseri and Darak. As *V. cholerae* is known to enter a VBNC state in aquatic environments, cultivation-based studies cannot accurately describe their diversity and abundance [49].

4. Conclusion

This study aimed at characterizing water quality of major drinking water sources in 2 regions (North and Far North) of Cameroon and exploring potential environmental reservoirs of the causative agent, *Vibrio cholerae* O1, and factors maintaining its persistence. The water provided from wells and stream points is unsafe for consumption with regard to microbial indicators. Of the 33 water sources investigated, 5 (4 wells and 1 stream point) were positive for *V. cholerae*. All the strains were *V. cholerae* non-O1. The positive water samples were from Doualaré (Maroua II), Hardé (Maroua I), Bibémi and Mokolo. The discharge to the environment of sewage drains by 87-96 % of households, the use of traditional latrines ("salka") by 79-96% households, the absence of latrines in 4-6 % of households and the use of materials placed on the soil to collect water by 29-99 % of households render these water resources vulnerable. These factors, coupled with rainfall, might play critical roles in the distribution of faecal matters and water contamination. Use of uncontrolled quality water was found as a risk factor for cholera. This study showed that households who do not wash their hands with soap are most exposed to cholera risk. However, it is likely that some other factors either social, cultural or economic might be associated with the cholera outbreaks. Our research contributed to highlight the main concerns regarding the quality of drinking water, the sanitation and hygiene issues in order to suggest appropriate solutions to control cholera outbreaks in north Cameroon.

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Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

References

[1] Mengel, M. A.; Delrieu, I.; Heyerah, L.; Gessner, B. D. "Cholera outbreaks in Africa", *Current Topics in Microbiology*, vol. 379, pp. 117-144, 2014.

[2] UNICEF, "Choléra, épidémiologie et réponse factsheet Cameroun", https://www.unicef.org/cholera/files/UNICEF-Cholera_Factsheet-Cameroun-VF.pdf, 2013, Accessed 21 April 2018.

[3] Osei F.B. and Duker A.A. "Spatial dependency of *V. cholerae* prevalence on open space refuse dumps in Kumasi, Ghana: a spatial statistical modelling", *Int. J. Health Geogr*., Vol. 7, pp. 1-17, 2008.

[4] Bwire G., Ali M., Sack D.A., Nakinsige A., Naigaga M., Debes A.K., Ngwa M.C., Brooks W.A., Garimoi Orach C. "Identifying cholera "hotspots" in Uganda: an analysis of cholera surveillance data from 2011 to 2016", *PLoS Negl. Trop. Dis*., vol. 11, e0006118, 2017.

[5] Kaas R. S., Ngandjio A., Nzouankeu A., Siriphap A., Fonkoua M. C., Aarestrup F. M., Hendriksen R. S. "The Lake Chad basin, an isolated and persistent reservoir of *Vibrio cholerae* O1: a genomic insight into the outbreak in Cameroon, 2010", *PloS One*, vol. 10, pp. 1-12, 2016.

[6] Gwenzi W. and Sanganyado E. "Recurrent cholera outbreaks in Sub-Saharan Africa: moving beyond epidemiology to understand the environmental reservoirs and drivers", *Challenges*, vol. 10, no. 1, 2019.

[7] Almagro-moreno S. and Taylor R.K. "Cholera: environmental reservoirs and impact on disease transmission", *Microbiol. Spectr.*, vol. 1, 1-12, 2013.

[8] Vezzulli L., Pruzzo C., Huq A., Colwell R.R. "Environmental reservoirs of *Vibrio cholerae* and their role in cholera", *Environ. Microbiol. Rep.*, vol. 2, pp. 27-33, 2010.

[9] Akoachere J.F.T.K., Omam L.A. and Massalla T.N. "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, p. 692, 2013.

[10] Matuamo Mahama A., Asomanin Anaman K. and Osei-Akoto I. "Factors influencing householders' access to improved water in low-income urban areas of Accra, Ghana", *J. Water Health*, vol. 12, no 2, 2014.

[11] Obeng-Odoom F. "Beyond access to water", *Dev Pract*., 22, 1135-1146, 2012.

[12] Molua E. L. and Lambi C. M. "Climate Hydrology and Water Resources in Cameroon", 2015.

[13] Arabi M., Xiao N., Kolyang D. T., Liang S. "Cholera incidence in the far north region of Cameroon: a geographic perspective", *African Journal of Social Sciences*, vol. 5, no. 3, pp. 141-156, 2014.

[14] MacEachern A.S. "*Processes of montagnard ethnogenesis in the northern Mandara mountains of Cameroon*", Mandaras Publishing, 433p, 2003.

[15] A.P.H.A. "*Standard Methods for the Examination of Water and Wastewater*", American Public Health Association, American Water Works Association, Water Environment Federation, Washington, DC, USA, 22nd edition, 2012.

[16] Cheryl A. B, Allen A. R. and Joy G. W. "*Isolation and identification of Vibrio cholerae serogroups O1 and O139*", In Laboratory methods for the diagnosis of epidemic dysentery and cholera, Center for Disease Control and Prevention, Atlanta, Georgia, pp 37-54, 1999.

[17] Healy-Profitos J. M., Arabi M., Lee S., Garabed R., Moritz M., Piperata B., Tien J., Bisesi M. and Lee J. "Muddying the waters: a new area of concern for drinking water contamination in Cameroon", *Int. J. Environ. Res. Public Health*, vol. 11, no. 12, pp 12454-12472, 2014.

[18] Mpakam H. G., Kamgang Kabeyene B.V., Kouam Kenmogne G. R., Bemmo N., Ekodeck G.E. "L'accès à l'eau potable et à l'assainissement dans les villes des pays en développement (cas de Bafoussam au Cameroun)", *Vertigo, La Revue électronique en Sciences de l'Environnement*, vol. 7, no. 2, 10p, 2006.

[19] Yang K., LeJeune J., Alsdorf D., Lu B., Shum C. K. and Liang S. "Global Distribution of Outbreaks of Water-Associated Infectious Diseases", *PLoS Negl. Trop. Dis*., vol. 6, no. 2, e1483, 2012.

[20] Ako A. A., Shimada J., Takem Eyong G. E. and Fantong W. Y. "Access to potable water and sanitation in Cameroon within the context of Millennium Development Goals (MDGS)", *Water Sci. Technol*., vol. 61.5., 2010.

[21] Sorlini S., Palazzini D., Sieliechi J. and Ngassoum M. "Assessment of physical-chemical drinking water quality in the Logone Valley (Chad-Cameroon)", *Sustainability*, vol. 5, no. 7, pp. 3060-3076, 2013.

[22] Dempouo L. D., Bradford D. G., Ondobo G. A. and Etoundi G. A. M. "National surveillance data on the epidemiology of cholera in Cameroon", *J. Infect. Dis*., vol. 208, pp. 92-97, 2013.

[23] Swerdlow D. L., Malenga G., Begkoyian G., Nyangulu D., Toole M., Waldman R. J., Puhr D. N. and Tauxe R. V. "Epidemic cholera among refugees in Malawi, Africa: treatment and transmission", *Epidemiol. Infect.*, vol. 118, pp. 207-214, 1997.

[24] Borroto R. J. and Martinez-Piedra R. "Geographical patterns of cholera in Mexico, 1991-1996", *Int. J. Epidemiol*., vol. 29, no. 4, pp. 764-772, 2000.

[25] Maran N. H., Crispim B. D. A., Iahnn S. R., Araujo R. P. D., Grisolia A. B. and Oliveira K.M. "Depth and Well Type Related to Groundwater Microbiological Contamination", *Int. J. Env. Res. Pub. He.*, vol. 13, no. 10, p. 1036, 2016.

[26] Healy-Profitos J. M., Lee S., Arabi M., Garabed R., Moritz M., Piperata B. and Lee J. "Neighborhood diversity of potentially pathogenic bacteria in drinking water from the city of Maroua, Cameroon", *Journal of Water and Health*, vol. 14.3, 2016.

[27] Kabyla I. B., Ilunga K. S., Luvungu N., Basema M. F., Kavira L. G., Mulang Irung R., Mukonkole J., Kimba Mukanya P., Matungulu Matungulu C. and Mashini Ngongo G. "The recurrence of cholera in the city of Lubumbashi: investigation of risk factors for an effective response and health education perspective", *OALib. Journal*, vol. 5, e4554, https://doi.org/10.4236/oalib.1104554, 2018.

[28] Msyamboza K. P., Kagoli M., M'bang'ombe M., Chipeta S. and Masuku H. D. "Cholera outbreaks in Malawi in 1998-2012: social and cultural challenges in prevention and control", *J. Infect. Dev. Ctries*., vol. 8, pp. 720-726, 2014.

[29] Vanderslice J. and Briscoe J. "All coliforms are not created equal: a comparison of the effects of water source and in-house contamination on infantile diarrheal disease", *Water Resour. Res.*, vol. 29, p. 1983, 1993.

[30] Lowman A., Mcdonald M. A., Wing S. and Muhammad N. "Land application of treated sewage sludge: community health and environmental justice", *Environ. Health Persp.*, vol. 121, pp. 537-542, 2013.

[31] El-Bassiony G. M., Luizzi V., Nguyen D., Stoffolano J.G. and Purdy A. E. "*Vibrio cholerae* laboratory infection of the adult of house fly *Musca domestica*", *Med. Vet. Entomol*., vol. 30, pp. 392-402,, 2016.

[32] Fewtrell L., Kaufmann R.B., Kay D., Enanoria W., Haller L. and Colford J. M. "Water, sanitation, and hygiene interventions to reduce diarrhoea in less developed countries: A systematic review and meta-analysis", *Lancet Infect. Dis*., vol. 5, pp. 42-52, 2005.

[33] Kebiche M., Benabid C. and Adjal F. "Pollution des eaux superficielles dans un climat semi-aride: la région de Shétif (Algérie)", *Sécheresse*, vol. 2, no. 10, pp. 137-142, 1999.

[34] Chippaux J-P., Pernot C., Jouanneau D., Ciornei G., Moulin-Esnart P. and Couret D. "Évaluation de la potabilité de l'eau dans une zone peuplée du Sahel sénégalais: Niakhar", *Environ. Risque Santé*, vol. 6, no. 5, pp. 373-381, 2007.

[35] Belghiti M. L., Chahlaoui A., Bengoumi D. and El Moustaine R. "Etude de la qualité physico-chimique et bactériologique des eaux souterraines de la nappe plio-quaternaire dans la région de Meknes (Maroc)", *Larhyss Journal*, vol. 14, pp. 21-36, 2013.

[36] Njitchoua R., Dever L., Fontes J. C. and Naah E. "Geochemistry, origin and recharge mechanisms of groundwaters from the Garoua Sandstone aquifer, northern Cameroon", *J. Hydrol*., vol. 190, pp. 123-140, 1997.

[37] Surindra S., Jitender S., Mayuri C. and Arvind K.N. "Water quality assessment of river Hindon at Ghaziabad, India: impact of industrial and urban wastewater", *Environ. Monit. Assess*, vol. 165, pp. 103-112, 2010.

[38] R. Njitchoua. "*Hydrochimie et géochimie isotopiques des eaux souterraines de la nappe des «Grès de Garoua», (Nord-Cameroun)*", Thèse nouveau Doctorat, Université de Paris, 11, Orsay, France, 1991.

[39] W.H.O. "*Total dissolved solids in drinking-water: background documents for development of WHO Guidelines for drinking-water quality*", 1996.

[40] Srinivasamoorthy K., Chidambaram S., Sarma V.S., Vasanthavigar M., Vijayaraghavan K., Rajivgandhi R., Anandhan P. and Manivannan R. "Hydrogeochemical characterisation of Groundwater in Salem District of Tamilnadu, India", *Res. J. Environ. Earth Sci*., vol. 1, no 2, pp. 22-33, 2009.

[41] Monjerezi M. and Ngongondo C. "Quality of groundwater resources in Chikhwawa, Lower Shire Valley, Malawi", *Water Qual. Expo. Health*, vol. 4, pp. 39-53, 2012.

[42] W.H.O. "*Guidelines for Drinking-Water Quality*", World Health Organization, Geneva, Switzerland, 3rd edition, 2004.

[43] Djaouda M., Njine T., Liang S., Ebang Menye D., Gaké B., Zebaze Togouet S. H. and Nola M. "Bacteriological quality of well waters in Garoua", *Wat. Qual. Expo. Health*., vol. 6, pp. 161-176, 2014.

[44] Alam M., Sultana M., Nair G. B., Sack R. B., Sack D. A., Siddique A. K., Ali A., Huq A. and Colwell R.R. "Toxigenic *Vibrio cholerae* in the aquatic environment of Mathbaria, Bangladesh", *Appl. Environ. Microbiol*., vol. 72, no 4, pp. 2849-2855, 2006.

[45] Faruque S.M., Chowdhury N., Kamruzzaman M., Dziejman M., Rahman M. H., Sack D. A., Nair G.B. and Mekalanos J.J. "Genetic diversity and virulence potential of environmental *Vibrio cholerae* population in a cholera-endemic area", *Proc. Natl. Acad. Sci. U.S.A*., vol. 101, no. 7, pp. 2123-2128, 2004.

[46] Haley B. J., Chen A., Grim C. J., Clark P., Diaz C. M., Taviani E., Hasan N.A., Sancomb E., Elnemr W.M., Islam M.A., Huq A., Colwell R.R. and Benediktsdóttir E. "*Vibrio cholerae* in a historically cholera-free country", *Environ. Microbiol. Rep*., vol. 4, no. 4, pp. 381-389, 2012.

[47] Haley B. J., Grim C. J., Hasan N., Taviani E., Chun J., Brettin T. S., Bruce D. C., Challacombe J. F., Detter J. C., Han C. S., Huq A., Nair G. B. and Colwell R. "The pre-seventh pandemic *Vibrio cholerae* BX 330286 El Tor genome: evidence for the environment as a genome reservoir", *Environ Microbiol Rep.*, vol. 2, no. 1, pp. 208-216, 2010.

[48] Choi S. Y., Rashed S. M., Hasan N. A., Alan M., Islam T., Sadique A., Johura F. T., Eppinger M., Ravel J., Huq A., Cravioto A. and Colwell R. R. "Phylogenetic Diversity of *Vibrio cholerae* associated with endemic cholera in Mexico from 1991 to 2008", *MBio*, vol. 7, no. 2, e02160, 2016.

[49] R. R. Colwell, "Viable but non culturable bacteria: a survival strategy", *J. Infect. Chemother*., vol. 6 no. 2, pp. 121-125, 2000.