Is drinking water from 'improved sources' really safe? A case study in the Logone valley (Chad-Cameroon)

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ABSTRACT

Within a cooperation project coordinated by the Association for Rural Cooperation in Africa and Latin America (ACRA) Foundation, water supplies were sampled across the villages of the Logone valley (Chad-Cameroon) mostly from boreholes, open wells, rivers and lakes as well as from some piped water. Microbiological analyses and sanitary inspections were carried out at each source. The microbiological quality was determined by analysis of indicators of faecal contamination, *Escherichia coli*, Enterococci and Salmonellae, using the membrane filtration method. Sanitary inspections were done using WHO query forms. The assessment confirmed that there are several parameters of health concern in the studied area; bacteria of faecal origins are the most significant. Furthermore, this study demonstrated that Joint Monitoring Programme (JMP) classification and *E. coli* measurement are not sufficient to state water safety. In fact, in the studied area, JMP defined 'improved sources' may provide unsafe water depending on their structure and sources without *E. coli* may have Enterococci and Salmonellae. Sanitary inspections also revealed high health risks for some boreholes. In other cases, sources with low sanitary risk and no *E. coli* were contaminated by Enterococci and Salmonellae. Better management and protection of the sources, hygiene improvement and domestic water treatment before consumption are possible solutions to reduce health risks in the Logone valley.

Key words | Chad-Cameroon, drinking water sources, quality monitoring, sanitary inspections

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INTRODUCTION

By 2015, Target 7c of the Millennium Development Goals (MDGs) aims to halve the proportion of people measured in 1990 without sustainable access to safe drinking water and basic sanitation. The World Health Organization (WHO) and the United Nations Children's Fund (UNICEF) report progress towards this target through their Joint Monitoring Programme (JMP) for Water Supply and Sanitation. The JMP has classified water sources into 'improved' and 'unimproved' categories (Table 1), as an interim measure of drinking water safety (WHO & UNICEF 2010a).

Thus, it considers the 'use of an improved drinking water source' as a simple proxy indicator of access to safe drinking water, assuming that water collected from 'improved sources' is more likely to be 'safe drinking water' than water collected from 'unimproved sources'. Consequently, this approach evaluates the access to specific types of water sources, but not the quality of water sources. The key concern is the inclusion of the word 'safe' in the target 7c of the MDGs and whether or not the available data on water quality are suitable both for monitoring access to safe drinking water until 2015, as well as for providing a retrospective estimate of access at baseline in 1990 (Bain *et al.* 2012). The term 'sustainable access' in target 7c is also imprecise, as it includes aspects such as time required for collection, temporal availability of water supplies over days or seasons, affordability and equity, which are not currently described in household surveys.

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Table 1 | JMP classification of improved and unimproved water sources (WHO & UNICEF 2010a)

Source class	Type of source
Unimproved drinking water sources	Unprotected dug well, unprotected spring, cart with small tank/drum, surface water (river, dam, lake, pond, stream, canal, irrigation channels) and bottled water
Improved drinking water sources: piped to dwelling, plot or yard	Piped household water connection located inside the user's dwelling, plot or yard
Improved drinking water sources: other sources	Public taps or standpipes, tube wells or boreholes, protected dug wells, protected springs or rainwater collection

'Safe drinking water' is defined by WHO as drinking water which 'does not represent any significant risk to health over a lifetime of consumption, including different sensitivities that may occur between life stages' (WHO 2011). The JMP reports that 783 million people in the world (11% of the total population) have no access to safe water; 84% of whom live in rural areas (WHO & UNICEF 2012). Nevertheless, a recent publication (Bain *et al.* 2012) shows that assessing the safety of drinking water according to whether or not it comes from an improved source is likely to overestimate the proportion of the population with access to safe drinking water. In fact, some improved sources may provide unsafe water, or be unsafe at the source or by the time it reaches home and is consumed, particularly in developing countries (Wright *et al*. 2004; Luby *et al*. 2008; Godfrey *et al*. 2011; Khadse *et al*. 2012). To determine how data on water source quality affect assessments of progress towards the MDG target 7c, data from five countries (Ethiopia, Jordan, Nicaragua, Nigeria and Tajikistan) on whether drinking water sources complied with WHO water quality guidelines were obtained from the Rapid Assessment of Drinking Water Quality (RADWQ) project (Aldana 2010; Aliev *et al.* 2010; Ince *et al*. 2010; Properzi 2010; Tadesse *et al.* 2010). Considering these data, the proportion of the population with access to safe drinking water resulted in lower values than the JMP estimate. The absolute reduction was 11% in Ethiopia, 16% in Nicaragua, 15% in Nigeria and 7% in Tajikistan. Microbial contamination was more common than the chemical one.

Another study (Onda *et al.* 2012) also accounted for sanitary risk together with water quality data from RADWQ to assess the safety of drinking waters and extrapolate the proportion of the population with access to safe drinking water at a global level. This study lowered the number of people estimated to use safe water from 5.8 billion (10^9) (WHO & UNICEF 2012) to 4.8 billion (10^9), only considering the faecal contamination of the 'improved sources', and to 3.6 billion (10^9), considering both faecal contamination and sanitary risk.

Thus, 'improved/unimproved' classification according to JMP and also water quality measurements should be seen as imperfect proxies of 'safe water' and will necessarily evolve over time. In particular, the JMP 'improved/unimproved' classification can be seen as a first step of a pyramid that should also include water quality monitoring and sanitary inspections to be carried out with a frequency and precision that increase with the local capacity of managing the water sector. Since capacities for water quality monitoring have been improved since 1990, 'second generation' indicators are needed. They should include direct water quality measurements and be able to ensure that the resulting information is nationally representative and comparable between countries, not only for the remaining MDG period, but also with a view to the post-2015 period. At this stage, it is agreed that it would be unrealistic to look for reliable indicators guaranteeing water quality on a permanent basis, in all situations (at home, at work, at school, etc.) and in compliance with all parameters affecting health. Therefore, in this second phase, it is suggested that water quality be assessed by using the three water quality parameters most strongly linked to health impacts: microbial contamination, arsenic and fluoride. Water Safety Plans, or some systematic approaches to risk assessment and management, could also be considered as an indicator of drinking-water quality. Finally, other indicators should be developed for other aspects of the Human Right to Water and Sanitation, including accessibility, availability, affordability and equity (WHO & UNICEF 2010b).

In 2009, in relation to the above mentioned target 7c, ACRA (Association for Rural Cooperation in Africa and Latin America), in collaboration with the universities of Brescia (Italy) and Ngaoundéré (Cameroon), started the cooperation project 'Applied research for the exploitation and processing of natural resources within a pathway of poverty reduction in Chad and Cameroon' in the Logone River valley on the border between Chad and Cameroon, in order to improve drinking-water quality. The first research activities, described in this paper, were aimed at assessing the safety of 'improved' and 'unimproved' water sources used by the population for drinking purposes. To achieve this goal, a preliminary investigation was carried out: microbiological analyses and sanitary inspections were carried out for different types of water sources in 14 villages with high health risks.

METHODS

Description of the sampling site

The study area is a valley crossed by the Logone River and located on the border between Chad and Cameroon (Figure 1(a)). In Cameroon, the zone is part of the Department of Mayo-Danay while in Chad it belongs to the Region of Mayo Kebby. It is mainly a rural area with difficult access to safe water (scarcity of drinking water sources and long distances between the source and the households). In 2010, an initial survey was carried out in order to investigate the practices of the local population regarding water management and to collect information on socio-economic, sanitary and environmental aspects. Thirty-seven villages in the valley (18 in Chad and 19 in Cameroon) were visited and 278 questionnaires were submitted to local families. In each village, families belonging to different socio-economic groups were interviewed; females were preferred when possible, as they are in general responsible for domestic water management. A statistical approach was not applied either for household selection or data analysis because the number of families in each village was too small. The questionnaires included six groups of questions: interviewee's identification; drinking water sources exploited in dry and wet seasons and water management at a household level; village people's opinions on drinking-water quality issues and applied treatments at a household level; economic status and purchasing power of the family; domestic hygiene and sanitation facilities; awareness on diarrhoeal diseases and the number of cases in the family. After this, 14 representative villages (seven in Chad and seven in Cameroon) were selected to continue the monitoring programme. The choice was made considering two criteria: the water source most used by the families investigated in the survey and the location of the village. These were chosen in order to consider all the source typologies throughout the entire territory of the Logone valley. People were using different

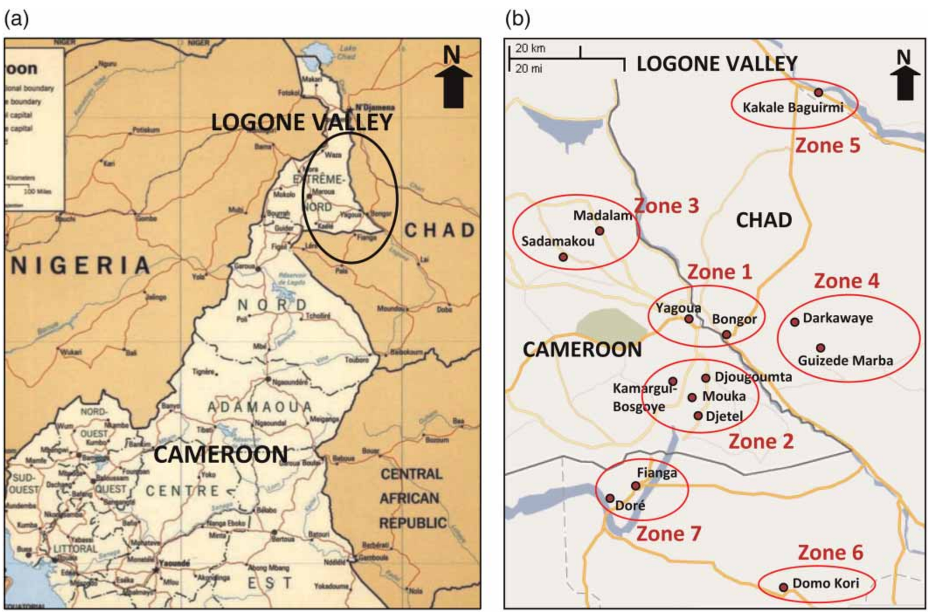

Figure 1 | Location of Logone valley in Chad-Cameroon (a) and target villages (b).

types of sources and the one most used is indicated in Table 2. This means that people living in the same village can use both improved and unimproved sources that may have different health effects. In the case of similarity between two or more villages, the percentage of unsafe domestic buckets used to store water, the percentage of people affected by a diarrhoeal disease and the willingness to pay for an improvement in the water sector in the village were considered. The domestic buckets were considered unsafe when not covered and/or with deposits and/or in contact with animals; the diarrhoeal diseases were estimated over the last month and self-reported by the interviewee; the willingness to pay was calculated as the amount/month that the family was able to pay for drinking-water quality improvement. The selected villages are represented in Figure 1(b) and the corresponding values of the criteria, based on the questionnaires, are indicated in Table 2.

In 2011–2012, different water sources used for drinking purposes were classified considering the JMP definitions, subjected to sanitary inspection, sampled and analysed. These sources belonged to five main categories (Figure 2):

- Category 1: piped water (Figure 2(a));
- Category 2: boreholes with hand pump (Figure 2(b)); average depth 30 m;
- Category 3: open hand dug wells with concrete walls (Figure 2(c)); average depth 16 m;
- Category 4: simple open hand dug wells, that do not have sealed walls (Figure 2(d)); average depth 5 m;
- Category 5: surface waters (Figure 2(e)).

Among these sources, only standpipe waters were chlorinated before distribution and no other treatment was applied at a domestic level. In total, 37 water sources were considered for the study: three (8%), nine (24%), nine (24%), seven (19%) and nine (24%) for the categories 1, 2, 3, 4 and 5 respectively. The distribution of these sources in the different villages is indicated in Table 3.

Sanitary inspections

Sanitary inspections are necessary to support microbiological water quality assessment by identifying potential pollution sources and contaminant pathways to provide an overview of the status of risk of the water source to contamination (WHO 1997; Howard 2002). Accordingly, sanitary inspections were executed at the same time of sampling in the studied area, using the forms indicated by WHO (1997) for boreholes with hand pump and open dug wells. In

Table 2 | Target villages of the study and criteria of selection

Village	Location	Source more used	Use of unsafe buckets (%)	People affected by a diarrhoeal disease (%)	Willingness to pay (US$/month)
Yagoua	Cameroon; Zone 1	Category 1	–	–	–
Djougoumta	Cameroon; Zone 2	Categories 2, 3, 4 and 5	30	43	0.8
Djetel	Cameroon; Zone 2	Category 2	60	40	0.3
Mouka	Cameroon; Zone 2	Category 4	53	40	2.4
Kamargui-Bosgoye	Cameroon; Zone 2	Category 3	0	43	0.6
Madalam	Cameroon; Zone 3	Category 5	57	100	1.4
Sadamakou	Cameroon; Zone 3	Category 3	100	100	5.0
Bongor	Chad, Zone 1	Category 1	–	–	–
Darkawaye	Chad, Zone 4	Category 4	53	40	6.2
GuizedeMarba	Chad, Zone 4	Category 3	65	40	8.4
KakaleBaguirmi	Chad, Zone 5	Category 5	63	80	1.6
Domo Kori	Chad, Zone 6	Category 4	56	78	3.0
Doré	Chad, Zone 7	Category 2	70	60	3.3
Fianga	Chad, Zone 7	All categories	54	70	1.0

Category 1: piped water; Category 2: boreholes with hand pump; Category 3: open dug wells with concrete walls; Category 4: simple open dug wells; Category 5: surface waters.

Figure 2 | Typical sources analysed in the target villages of the study. (a) Piped water; (b) boreholes with hand pump; (c) open dug wells with concrete walls; (d) simple open dug wells; (e) surface waters.

Table 3 | Location of the sampled water sources in the target villages

Total sources Number of samples N = 37	Category 1 N = 3	Yagoua N = 1; Bongor N = 1; Fianga N = 1
	Category 2 N = 9	Djougoumta N = 1; Djetel N = 1; Mouka N = 1; Kamargui-Bosgoye N = 1; Madalam N = 1; Guizede Marba N = 1; Domo Kori N = 1; Doré N = 1; Fianga N = 1
	Category 3 N = 9	Djougoumta N = 1; Djetel N = 1; Kamargui-Bosgoye N = 1; Madalam N = 1; Sadamakou N = 1; Darkawaye N = 1; Guizede Marba N = 1; Doré N = 1; Fianga N = 1
	Category 4 N = 7	Mouka N = 1; Kamargui-Bosgoye N = 1; Madalam N = 1; Darkawaye N = 1; Domo Kori N = 2; Fianga N = 1
	Category 5 N = 9	Yagoua N = 1; Djougoumta N = 1; Djetel N = 1; Mouka N = 1; Kamargui-Bosgoye N = 1; Madalam N = 1; Bongor N = 1; Kakale Baguirmi N = 1; Fianga N = 1

Category 1: piped water; Category 2: boreholes with hand pump; Category 3: open dug wells with concrete walls; Category 4: simple open dug wells; Category 5: surface waters.

these forms, the risk factor for faecal contamination for a water source was calculated considering a standardized list of common risks like breaks, poor drainage, proximity to latrines and animal waste. When the risk scores were calculated for each source, they were considered as a categorical variable and compared considering four risk levels: 0–2 = low; 3–5 = intermediate; 6–8 = high; ≥9 = very high.

Microbiological analyses

Water samples were collected from the different sources applying the procedures indicated by Bartram & Balance (1996) and WHO (1997). One-litre plastic bottles, that were previously sterilized by an autoclave, were used. The samples were immediately stored in ice boxes and analysed at the laboratory within 6 hours from the sampling. The membrane filtration method was applied. The procedure was derived from Bartram & Balance (1996) and WHO (1997), adapting it to the available testing equipment (TRAWAS portable laboratory, Sandberg & Schneidewind) and to the Sandberg & Schneidewind Nutrient Pad Set (NPS) Endo, Azide and Bismuth Sulphite used for the enumeration of *Escherichia coli*, Enterococci and Salmonellae respectively. *E. coli* and Enterococci were selected in the study according to WHO Guidelines (2011), that indicate *E. coli* as the primary indicator to detect faecal contamination and Enterococci as an indicator of faecal pathogens that survive longer than *E. coli.* Salmonellae in water was investigated because Typhoid fever and other typical diseases due to this contaminant were common in the Logone valley. When the number of colonies was uncertain, different volumes (chosen between 100, 50, 20, 10, 5 and/or 1 mL in function of the type of the source and the expected contamination) were filtered and cultured. When the sample was less than 20 mL, 10 mL of sterile dilution water was added to the filter funnel in order to distribute the bacteria evenly across the entire filter surface. After incubation, the number of colonies per 100 mL of a sample was evaluated from the plate count. For each day of analysis and for each parameter, the blank value was determined. Replicates were not executed.

RESULTS AND DISCUSSION

Table 4 shows the distribution of 'improved' and 'not improved' sources in the selected villages, according to JMP definitions. It is worth noticing that piped water was available in only three out of 14 villages, while the open dug wells with concrete walls and the surface waters were the most common water sources, followed by the boreholes with hand pump. Furthermore, in Chad, two villages (Darkawaye and Kakale Baguirmi) out of seven did not have an improved source while in Cameroon this was only one (Sadamakou) out of seven. Consequently, considering the JMP criteria, all the villages, except Sadamakou, Darkawaye and Kakale Baguirmi, are defined as having access to safe water thanks to the use of an improved source.

Nevertheless, the definition of 'improved' technologies is based on the assumption that certain technologies are better for health than others because, thanks to the nature of their construction, they are more likely to protect the source from outside contamination. However, this assumption may not be true in all cases. For instance, in some locations an unprotected well may provide a better supply of water, both in terms of quantity and quality of water, than a borehole. As a consequence, the issue is not only whether people have access to an improved source but if

Table 4 | Improved and not improved water sources in the target villages of the study

		Improved sources		Not improved sources		
Location	**Village**	**Category 1**	**Category 2**	**Category 3**	**Category 4**	**Category 5**
Cameroon, Zone 1	Yagoua	X				X
Cameroon, Zone 2	Djougoumta		X	X		X
	Mouka		X		X	X
	Djetel		X	X		X
	Kamargui-Bosgoye		X	X	X	X
Cameroon, Zone 3	Madalam		X	X	X	X
	Sadamakou			X		
Chad, Zone 1	Bongor	X				X
Chad, Zone 4	Darkawaye			X	X	
	GuizedeMarba		X	X		
Chad, Zone 5	KakaleBaguirmi					X
Chad, Zone 6	Domo Kori		X		X	
Chad, Zone 7	Fianga	X		X	X	X
	Doré		X	X		

Category 1: piped water; Category 2: boreholes with hand pump; Category 3: open dug wells with concrete walls; Category 4: simple open dug wells; Category 5: surface waters.

this source provides safe water. Therefore, during the survey in the Logone valley, the second step for evaluating drinking water safety consisted of verifying if water met microbiological standards set by WHO. Table 5 reports the mean, the minimum, the median and the maximum values, for each source category and for each faecal indicator measured in the water samples. Then, the data were re-elaborated calculating the percentages of samples belonging to five different levels of contamination for *E. coli* (Figure 3(a)), Enterococci (Figure 3(b)) and Salmonellae content (Figure 3(c)). For *E. coli*, the contamination levels correspond to different levels of health risk, as indicated in Table 6 (WHO 1997).

From Figure 3, it is possible to observe that, for *E. coli*, 100% of the boreholes and the piped waters complied with WHO guidelines as expected ('improved sources') and, at first glance, they could be considered safe sources. As regards the 'unimproved sources', 11, 0 and 0% of the samples coming respectively from the open dug wells with concrete walls, the simple open dug wells and the surface waters had no *E. coli*. Thus, a general decrease in water quality was observed passing from tap water to surface water, with the reduction of the source protection. Nevertheless, some water sources, with a low level of protection, provided samples with a relatively good quality. For example, waters from the simple open dug wells in Mouka and Darkawaye and the surface waters in Djetel, Kamargui-Bosgoye and Kakale Baguirmi had an *E. coli* content corresponding to a low health risk. On the contrary, some open dug wells with concrete walls, expected to be better than the simple dug wells mentioned above, were characterised by an high or very high level of risk (in Darkawaye, Djougoumta and Madalam). This confirms that water safety may not be completely predicted by using JMP classification, in agreement with other findings (Bain *et al.* 2012; Onda *et al.* 2012).

Furthermore, from Figure 3 it is possible to observe that the content of Enterococci was in general higher than *E. coli* and their presence was observed also in the *E. coli* free samples. The presence of Enterococci can be due to their longer persistence in the environment than thermotolerant coliforms or *E. coli* and their high resistance to drying (Bartram & Balance 1996). Moreover, the same authors observed that it is possible to isolate Enterococci from water that contains few or no thermotolerant coliforms as, for example, when the source of contamination is distant in either time or space from the sampling point. Also Salmonellae were found in the samples, spread by the faecal–oral route, and their presence, as well as the presence of *E. coli* and Enterococci, confirmed that water sources entered into contact

Table 5 | Results of the microbiological analyses

Parameter	Source category	N	Mean ± St. Dev	Min	Median	Max
E. coli (CFU/100 mL)	All	37	224 ± 534	0	2	2,450
	1	3	0 ± 0	0	0	0
	2	9	0 ± 0	0	0	0
	3	9	316 ± 756	0	40	2,450
	4	7	399 ± 603	2	60	1,800
	5	9	294 ± 461	1	35	1,300
Enterococci (CFU/100 mL)	All	37	1,518 ± 2,570	0	275	9,800
	1	3	2 ± 2	0	0	5
	2	9	9 ± 9	1	6	30
	3	9	2,349 ± 2,491	100	1,600	8,700
	4	7	3,302 ± 4,033	20	1,600	9,800
	5	9	1,312 ± 1,430	60	640	4,000
Salmonellae (CFU/100 mL)	All	37	242 ± 655	0	15	3,400
	1	3	16 ± 22	0	0	47
	2	9	3 ± 6	0	0	17
	3	9	668 ± 1,145	2	35	3,400
	4	7	99 ± 116	15	50	350
	5	9	244 ± 415	5	20	1,100

Category 1: piped water; Category 2: boreholes with hand pump; Category 3: open dug wells with concrete walls; Category 4: simple open dug wells; Category 5: surface waters.

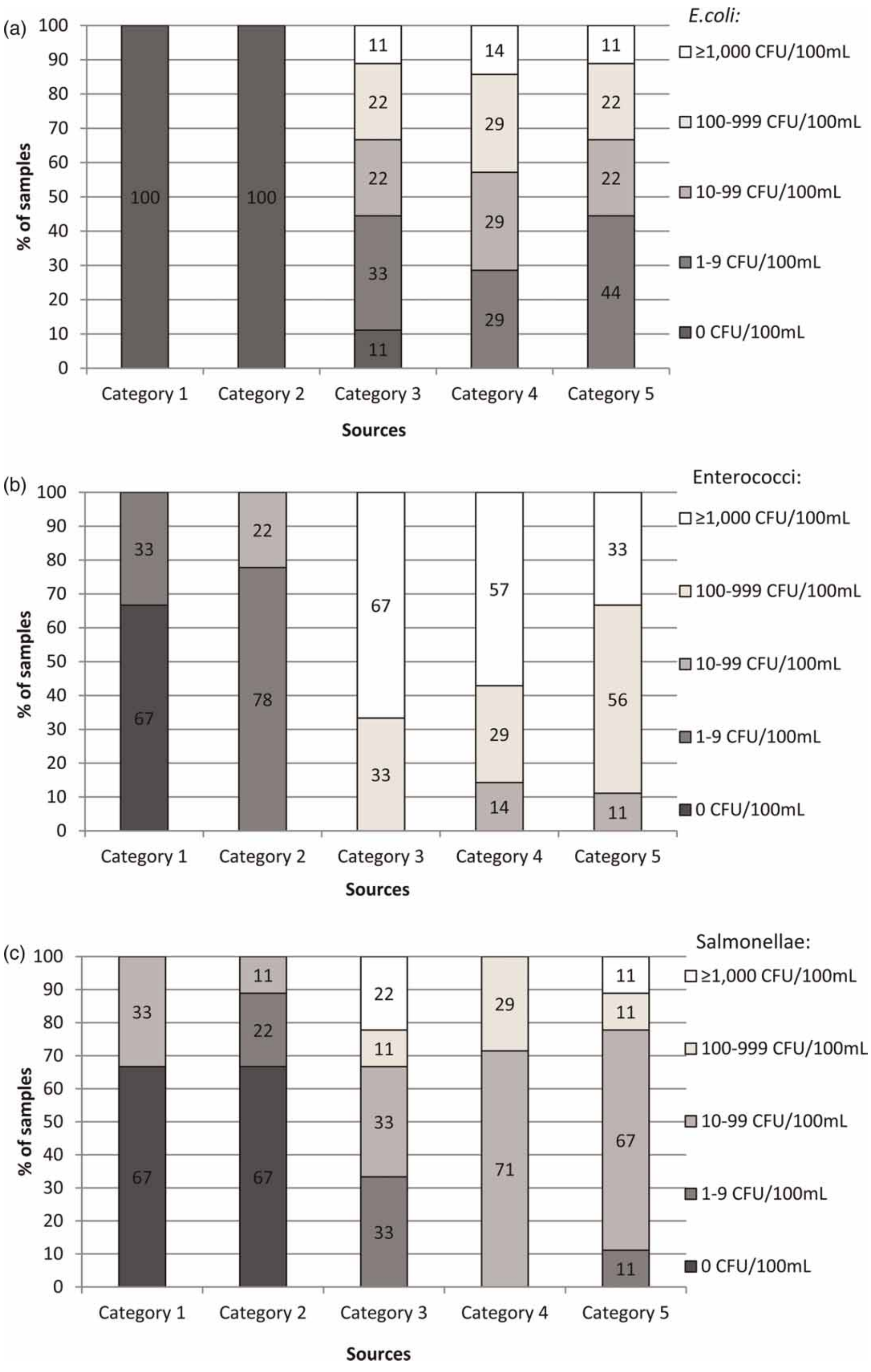

Figure 3 | Contamination levels of the different water source categories for *E. coli* (a), Enterococci (b) and Salmonellae (c) content. Category 1: piped water (Number of samples N = 3); Category 2: boreholes with hand pump (N = 9); Category 3: open dug wells with concrete walls (N = 9); Category 4: simple open dug wells (N = 7); Category 5: surface waters (N = 9).

Table 6 | Health risks associated with *E. coli* in water (WHO 1997)

E. coli (CFU/100 mL)	Remarks
0	In conformity with WHO guidelines
1–9	Low risk
10–99	Intermediate risk
100–999	High risk
≥1,000	Very high risk

with faecal contamination from sewage discharges, livestock and/or wild animals.

Finally, Enterococci were observed in all the boreholes with hand pump and Salmonellae in three (33%) of them, while both Enterococci and Salmonellae were found in tap water of Fianga. In all these sources *E. coli* were absent. As a consequence, these sources cannot be considered safe for drinking use, although they were considered 'improved sources' according to JMP classification and they were free from *E. coli*.

The structure and the level of protection of water supplies influence the risk of contamination. For this reason, during the survey in the Logone valley, the quality monitoring was combined with a sanitary inspection of the sources (WHO 1997) in order to identify the causes of contamination and to verify if there is a correspondence between the results of the quality monitoring (microorganisms in water) and those of the sanitary inspections (risk score). This correlation is presented in Table 7 that reports the cross-tabulation between sanitary risk and microbiological contamination (*E. coli*, Enterococci and Salmonellae content) for boreholes with hand pump (Table 7(a)), open dug wells with concrete walls (Table 7(b)) and simple open dug wells (Table 7(c)). In Table 7(a) it is worth noticing that, although 56% of boreholes had a high sanitary risk score, they were *E. coli* free like the other boreholes having low and intermediate sanitary risk. Otherwise, regarding the Enterococci, the boreholes with a high risk factor were more contaminated than those with low and intermediate sanitary risks, while all the samples with a low-intermediate sanitary risk belonged to the 1–9 CFU/100 mL class of contamination. Similarly, regarding Salmonellae, none of the boreholes with a low-intermediate sanitary risk were contaminated, while some samples with a high sanitary risk had a density up to10–99 CFU/100 mL.

Considering the open dug wells with concrete walls (Table 7(b)), for Enterococci the majority of the samples with a high sanitary risk belonged to the ≥1,000 CFU/100 mL class of contamination, while those with an intermediate sanitary risk were equally distributed between the 100–999 and the ≥ 1,000 CFU/100 mL classes. As regards Salmonellae, the high sanitary risk was associated with densities of 109–999 and ≥ 1,000 CFU/100 mL, while all the samples with intermediate sanitary risk belonged to the 1–9 and the 10–99 CFU/100 mL classes of contamination. Also for this water source category, regarding *E. coli*, an unexpected distribution of the samples was observed. In fact, some samples with an intermediate sanitary risk had 100–999 CFU/100 mL, while those with a high sanitary risk belonged to 1–9 and 10–99 CFU/100 mL classes of contamination. A similar behaviour was observed for the simple dug wells (Table 7(c)).

Consequently, it is possible to state that the percentages of water samples belonging to increasing contamination levels augmented passing from a low to a very high sanitary risk level, if Enterococci and Salmonellae were considered, in agreement with the study of Mushi *et al.* (2012) that showed a statistical correlation between *Thermotolerant Total Coliforms* and sanitary risk factors. Otherwise, other studies observed a low correlation with *E. coli* (Luby *et al.* 2008; Parker *et al.* 2010). These controversial results could be due to the different local conditions and assumptions used during the studies, as well as the different faecal indicators. Consequently, considering this study and literature data, it is not possible to state that sanitary inspections are a complete tool to predict faecal pollution. Therefore, sanitary inspections must not be the sole way of assessing water safety and they have to be accompanied by water quality monitoring, if it is feasible in the study area and if the government and/or the local non-governmental organizations (NGOs) have appropriate human and financial resources.

During the monitoring survey, it was also observed that the microbiological contamination increased particularly when the risk score was more than 6, passing from the intermediate level to the high one. This phenomenon is represented in Figure 4 that shows the count per 100 mL of *E. coli*, Enterococci and Salmonellae for the boreholes with hand pump (Figure 4(a)), the dug wells with concrete walls (Figure 4(b)) and the simple dug wells (Figure 4(c)) in the

Table 7 | Cross tabulation between sanitary risk and microbiological contamination; percentages of samples belonging to the different levels

(a) Boreholes with hand pump (number of samples N = 9)

	***E. coli* (CFU/100 mL)**					
Sanitary risk	**0**	**1–9**	**10–99**	**100–999**	**≥ 1,000**	**TOT**
0–2 (low)	33	0	0	0	0	33
3–5 (intermediate)	11	0	0	0	0	11
6–8 (high)	56	0	0	0	0	56
≥ 9 (very high)	0	0	0	0	0	0
Total	100	0	0	0	0	100

	Enterococci (CFU/100 mL)					
Sanitary risk	**0**	**1–9**	**10–99**	**100–999**	**≥ 1,000**	**TOT**
0–2 (low)	0	33	0	0	0	33
3–5 (intermediate)	0	11	0	0	0	11
6–8 (high)	0	33	22	0	0	56
≥ 9 (very high)	0	0	0	0	0	0
Total	0	78	22	0	0	100

	Salmonellae (CFU/100 mL)					
Sanitary risk	**0**	**1–9**	**10–99**	**100–999**	**≥ 1,000**	**TOT**
0–2 (low)	33	0	0	0	0	33
3–5 (intermediate)	11	0	0	0	0	11
6–8 (high)	22	22	11	0	0	56
≥ 9 (very high)	0	0	0	0	0	0
Total	67	22	11	0	0	100

(b) Open dug wells with concrete walls (N = 9)

	***E. coli* (CFU/100 mL)**					
Sanitary risk	**0**	**1–9**	**10–99**	**100–999**	**≥ 1,000**	**TOT**
0–2 (low)	0	0	0	0	0	0
3–5 (intermediate)	11	0	0	11	0	22
6–8 (high)	0	33	22	11	11	78
≥ 9 (very high)	0	0	0	0	0	0
Total	11	33	22	22	11	100

	Enterococci (CFU/100 mL)					
Sanitary risk	**0**	**1–9**	**10–99**	**100–999**	**≥ 1,000**	**TOT**
0–2 (low)	0	0	0	0	0	0
3–5 (intermediate)	0	0	0	11	11	22
6–8 (high)	0	0	0	22	56	78
≥ 9 (very high)	0	0	0	0	0	0
Total	0	0	0	33	67	100

(*continued*)

Table 7 | continued

	Salmonellae (CFU/100 mL)					
Sanitary risk	**0**	**1–9**	**10–99**	**100–999**	**≥ 1,000**	**TOT**
0–2 (low)	0	0	0	0	0	0
3–5 (intermediate)	0	11	11	0	0	22
6–8 (high)	0	22	22	11	22	78
≥ 9 (very high)	0	0	0	0	0	0
Total	0	33	33	11	22	100

(c) Simple open dug wells (N = 7)

	E. coli **(CFU/100 mL)**					
Sanitary risk	**0**	**1–9**	**10–99**	**100–999**	**≥ 1,000**	**TOT**
0–2 (low)	0	0	0	0	0	0
3–5 (intermediate)	0	0	0	0	0	0
6–8 (high)	0	14	29	29	14	86
≥ 9 (very high)	0	14	0	0	0	14
Total	0	28	29	29	14	100

	Enterococci (CFU/100 mL)					
Sanitary risk	**0**	**1–9**	**10–99**	**100–999**	**≥ 1,000**	**TOT**
0–2 (low)	0	0	0	0	0	0
3–5 (intermediate)	0	0	0	0	0	0
6–8 (high)	0	0	14	29	43	86
≥ 9 (very high)	0	0	0	0	14	14
Total	0	0	14	29	57	100

	Salmonellae (CFU/100 mL)					
Sanitary risk	**0**	**1–9**	**10–99**	**100–999**	**≥ 1,000**	**TOT**
0–2 (low)	0	0	0	0	0	0
3–5 (intermediate)	0	0	0	0	0	0
6–8 (high)	0	0	71	15	0	86
≥ 9 (very high)	0	0	0	14	0	14
Total	0	0	71	29	0	100

target villages, versus the risk score obtained from the sanitary inspections. Only the borehole of Mouka was characterized by a high risk although it provided water with the best quality. This could be due to its recent construction in 2012.

Finally, combining data from the JMP water source classification, microbiological analyses and sanitary inspections, it was possible to identify the villages at risk from a health perspective. The results are reported in Table 8 and categorize the target villages considering these parameters. First, it is worth noticing that 11 out of 14 villages had one improved source and that all these improved sources had 0 CFU/100 mL of *E. coli*. Secondly, among the 11 villages using an improved source free from *E. coli*, six villages had their source characterized by a sanitary risk score higher than 2 (upper limit for the low sanitary risk) and all these sources were also contaminated by

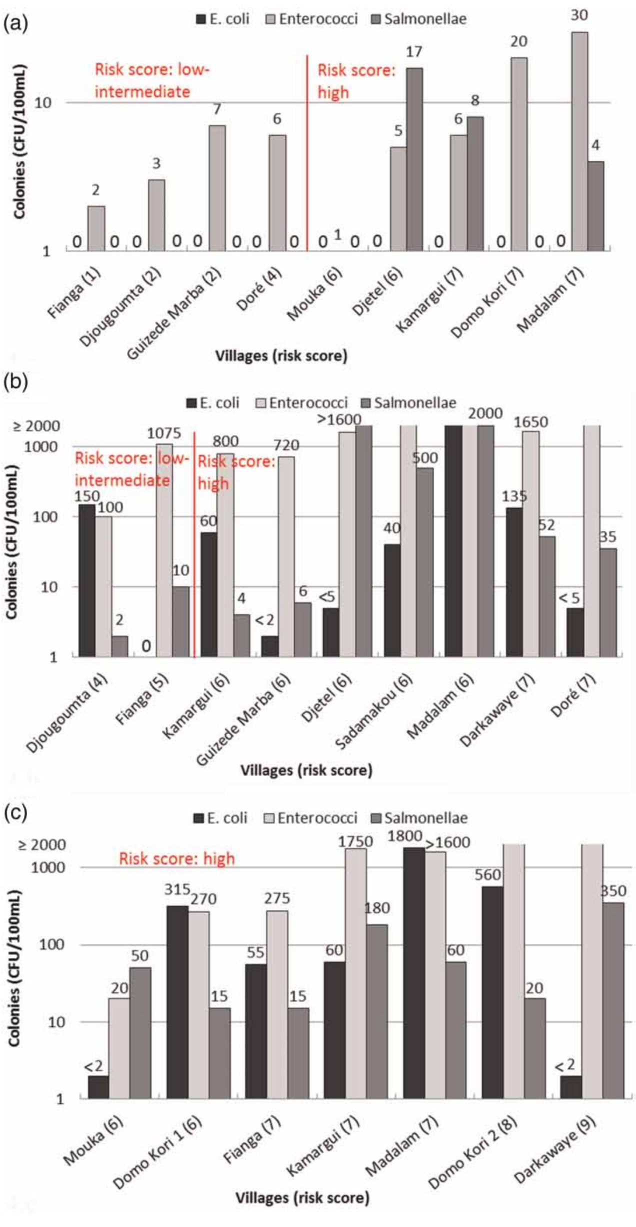

Figure 4 | Microbiological contamination as a function of the sanitary inspection risk score, for the boreholes with hand pump (a), the dug wells with concrete walls (b) and the simple dug wells (c) in the target villages.

Enterococci and Salmonellae. Then, among the five villages using an improved source free of *E. coli* and characterized by a low sanitary risk, three villages had their source containing Enterococci and Salmonellae. Consequently, it finally resulted that in only two villages (Yagoua and Bongor), the improved source used by the population (piped water) had no *E. coli*, Enterococci and Salmonellae and had a low sanitary risk score; these two conditions were used in this study to assess water safety. On the contrary, in the other 12 villages, it was not possible to state that people were using safe water; three and nine of them respectively were using unimproved sources and improved sources without *E. coli* but contaminated by Enterococci and Salmonellae.

These results represent the first set of data on the microbiological water quality in the Logone valley and they confirm the high level of sanitary risk already observed in other areas of Cameroon (Mbawala *et al.* 2010).

CONCLUSIONS

This study concludes that the JMP water source classification and *E. coli* measurements are not sufficient to state how safe the water is. In fact, some improved sources were microbiologically contaminated and some *E. coli* free sources presented Enterococci and/or Salmonellae.

A correspondence between microbiological contamination (Enterococci and Salmonellae content) and sanitary risk was observed; in particular, the increase in microbiological contamination was more evident when the sanitary risk score was higher than 6. Furthermore, in some cases, Enterococci and Salmonellae were found in sources with a low sanitary risk. Consequently, the results of this study suggest that both sanitary risk and microbial water quality should be assessed to determine water safety.

This assessment also demonstrated that in the Logone valley (Chad-Cameroon) bacteriological contamination was a primary water quality concern, that affected 12 out of 14 villages. In fact, three of these 12 villages were using unimproved sources and the other nine villages were using an improved source with 0 CFU/100 mL of *E. coli* that was contaminated by Enterococci and Salmonellae.

Consequently, the study finally concludes that integrated approaches that combine different levels of investigation are needed to comprehensively assess water safety. Ideally, these would include technology classification as used by the JMP, sanitary inspections and, where possible, direct monitoring of water quality. Microbiological parameters and monitoring frequency should be evaluated according to the type of water sources and the technical/human/economic resources available in the local context. As suggested by WHO (2011), *E. coli*

Table 8 | Target villages by water contamination status and sanitary risk

Target villages 14 (100%)	Using improved sources 11 (79%)	*E. coli* absent 11 (79%)	Low sanitary risk 5 (36%)	Enterococci and Salmonellae absent 2 (14%)
				Enterococci and Salmonellae present 3 (22%)
			Elevated risk score 6 (43%)	Enterococci and Salmonellae absent 0 (0%)
				Enterococci and Salmonellae present 6 (43%)
		E. coli present 0 (0%)		
	Using unimproved sources 3 (21%)			

is the primary indicator to represent faecal contamination and it can be detected with rapid and simple tests. Otherwise additional parameters (e.g. Enterococci) can be recommended to integrate the results of the *E. coli* analysis.

When the contaminated sources and the origin of contamination are identified, intervention programmes could be planned to prevent and/or solve water quality concerns. In the Logone valley, within the cooperation project of ACRA, better management and protection of the sources, hygiene improvement and domestic water treatment before consumption were studied and implemented as possible solutions to reduce health risks in the villages.

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