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Bacteriological Pollution of Artesian Ground Water Sources Used by Local Communities Living in and Around Bukavu Town (Democratic Republic of Congo) as Sources of Potable Drinking Water

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Abstract

Pollution of water for human consumption is a major environmental challenge in hundreds of towns across Sub-Sahara Africa. The objective of this work was to evaluate the degree of bacterial pollution of ground water sources as sources of safe drinking water consumed by local human communities living in urban and peri-urban zones of Bukavu town (eastern DR Congo). Populations living in these zones are generally disfavored in terms of safe water supply services by the national water corporation (REGIDESO). This study was conducted in 2011 during the dry and rainy seasons from 15 ground water sources used by the population from these peri-urban zones as sources of safe drinking water and as source of safe water for other domestic needs. In total, 150 samples were taken from these water sources. During both rainy and dry seasons, 5 water samples were taken for every source. These samples were analyzed for their physic-chemical and bacteriological properties in comparison to world health organization standards. Results indicated that the degree of bacterial pollution of water was high ($T=4.56$, $P<0.05$) during rainy season (20.6 ± 25.3 total coliforms/100 ml of water on average) than during the dry season (3.10 ± 6.023 total coliforms/100 ml of water on average) across all sources studied. Sources (sites) that were highly polluted included Mulehe I, Kaliba, Kahuranyi, Cemu, Bagira, Funu et Gihamba. Overall, bacterial pollution of drinking water sources was significantly ($P<0.05$) high during the rainy season than during the dry season. Similarly, cholera epidemic outbreak is high in these zones during the rainy season (September-December). In November-December 2011, more than 400 cases of death were registered in hospital and the victims were from these highly polluted areas where the study was conducted. In fact, the presence of *Vibrio cholerae* was detected in all rainy season water samples from these areas. The results of this study indicated that *Vibrio cholerae* is the principal dangerous pollutant agent of these drinking ground water sources used by more than half million people living in peri-urban areas and in over-populated areas in Bukavu town. There is a need to set a system of monitoring water quality for human consumption. Results (findings) of such a monitoring program may be used to inform policy makers and health agents on better strategies to control water pollution in Bukavu and in related Sub-Sahara African towns. There is a need for policy makers to develop new strategies to improve water sanitation and supply everyone safe drinking groundwater in Bukavu Town. The adoption of water sanitation, rainwater harvesting technologies may help in areas where the national water corporation can't be able to supply water in short to mid terms.

Keywords: Bacteriological pollution; Water sources; Bacteriological quality; Artesian water source; Peri-urban zones; Bukavu; Water sanitation strategies; Eastern of DR Congo

Introduction

Quality water is life. Access to potable water is major challenge in the tropical Sub-Sahara Africa, particularly from urban and peri-urban zones. Consumable water (with no health risk to humans) is more and rarer in various cities in African including DR Congo. Water contamination risks are currently minimized by application of new water treatment and management technologies. These technologies are well spread and well known by most water managers in the tropics. Despite the application of these technologies, public health concerns continue increasing across many areas in the tropics [1].

Access to safe water is no longer a problem in most developed countries as stands in developing countries. Access to safe water is fundamental social and economic right of every person living on the earth. Access to safe water should have been a collective right to all human communities [2]. However, this is not the case because one person out of five does not have access to safe water in the world; and if he has access to safe water, this is at high economic cost. Lack of access to safe water may be caused by various factors including malnutrition, rural migration, and high water bills. Lack of access to safe water exposes human being to various water born diseases. Ironically, the majority of populations do not have access to proper technologies/

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strategies to control of these water born diseases. They lack access to best/appropriate water and sanitation technologies [3].

Currently, there is a high prevalence of diarrheic diseases and repeated cholera epidemics (23 to 789 cases per annum per area for the period of 2001 to 2010) in some areas and avenues of the town, such as Nyamugo, Funu, Kasali, Nyakaliba, Nkafu, Panzi, Mushununu, Gihamba, Nyalukemba, Karhale, Burhiba, etc [4]. Overall the lack of access to safe water in Bukavu town is no longer a fact to demonstrate but a reality that require solution from various perspectives. It is currently obvious that REGIDESO does not supply sufficient water to the population of Bukavu. There is a rarity of safe water in many places of Bukavu. However, it is not clear if currently used as alternative sources of safe water (artesian water sources) by the population is safe or of good quality. This study was conducted to determine the quality of artesian water sources currently used by the population of Bukavu town as alternatives to REGIDESO water that is absent or rare in various places of the town. It was hypothesized that artesian water sources are of good quality since in most cases they are established by experts of locally operating NGOs with strong background in management of safe water supply techniques. This study aims at generating information on the degree of microbial pollution of artesian water currently consumed by certain citizens of Bukavu. It is believed that such information may be very critical in the management of public health concerns of the citizens. It is also expected that information to be generated may be used for corrective actions that may be taken by policy makers and any other public health managers to prevent water born diseases, as well as reducing consistent outbreaks of Cholera epidemics in Bukavu town and its surroundings.

Study Area, Materials and Methods

Water samples were collected from 15 artesian wells located in urban and in peri-urban zones of Bukavu town (Figure 1a and 1b, 2°30′S, 28°52′E). For the hydrogeological profile of artesian wells, most of them are of 1.1m to 3.12m deep (International Rescue Committee (IRC)-South-Kivu Province report 2011). They are constructed using local materials.

Figure 1a: Map of DRC showing where Bukavu town is located. (The details of Bukavu are found on the Google earth map of Bukavu town).

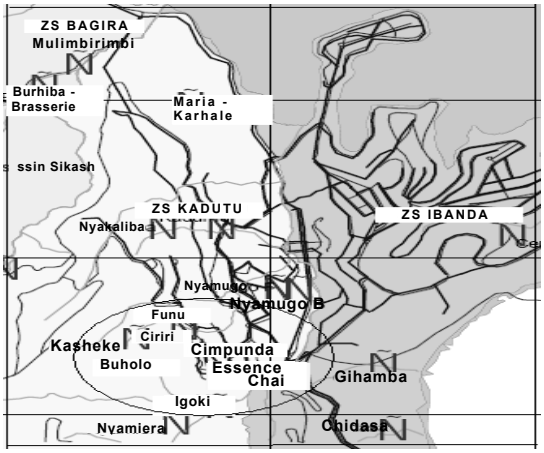

Figure 1b: Map of Bukavu showing where Bukavu town and the different zones where the different study sites (wells=souces) are located. These sources include Mulehe I, Mulehe II, Kahuranyi, Cemu Bagira and Kaliba localities belonging to Bagira zone; Kisima, Cemu Kadutu, Funu, Nyakaliba and Kadurhu are located in Kadutu zone; whereas Luziba, Gihamba, Ave-Maria, Kabangere and Mushununu are located in Ibanda zone. ZS Ibanda, ZS Kadutu and ZS Bagira zones are located on the above map.

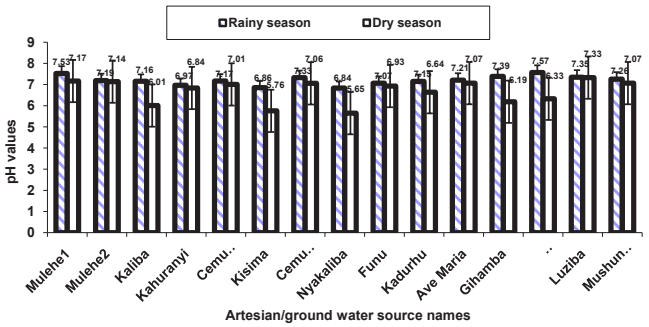

Figure 1c: Average pH values of water samples collected from the different artesian water sources during the rainy and dry seasons, Bukavu 2011, eastern DR Congo.

These samples were analyzed at the student laboratory of the Bukavu Institute of higher education in medical techniques (ISTM-Bukavu). In total, 150 samples were taken between February and March 2011(rainy season). Around 75 other samples were taken between July and August 2011(dry season). For each artesian source, five samples were taken during the rainy season and five other samples during the dry season.

Physico-chemical analyses were conducted by using (i) a Thermometer (type PRIMA long) for measurements of water temperature; (ii) a pH-meter (type Metrohm 827) for the measurement of water acidity; (iii) a turbidimeter (Type HANNA instrument) for turbidity measurements.

Bacteriological analyses were conducted following guidance and standards as proposed by international standardization organization (ISO): ISO9308-1: 200. The search and count of: (i) total coli-forms, fecal coli-forms (*Eschericia coli*) was conducted by membrane filtration method and by using ISO 7899-2: 2000 (Tables 1 and 2). The search and count of fecal streptococcus was done by applying the membrane filtration method. Suspected microbial colonies were identified using API20 gallery.

Parameters	Guide levels	Acceptable maximal values
Turbidity	0.05	0.10
Temperature (°C)	12	25
pH	6.5 to 8.5	9.5
Total coliforms (cfu / 100ml)	0	0
Fecal coliform (cfu / 100ml)	0	0
Escherchia coli (cfu / 100ml)	0	0
Vibrio cholerae	0	0
Other enteropathogens	0	0

Table 1: Indicative values (WHO 2006).

Coliforms/100 ml of water	Interpretation	Recommandations
0 to 10	Reasonable quality	Acceptable
10 to 100	Polluted water	Such water sources require better protection through simple treatment of water
100 to 1000	Very polluted water	Water from such sources may be treated, but it is recommended to seek for alternative sources
>1000	Excessively polluted water	Water sources that should be avoided

Table 2: Different levels of pollution (WHO, 2006).

Data Analysis

Data were sorted out using Excel spreadsheets. All analyses were conducted in Epi info 3.5.1 (2012) software. Descriptive statics (mean, standard deviation) were calculated for all quantitative variables. Results are presented in tables and figures. Absolute and relative frequencies were also calculated for qualitative variables. Criteria and levels of pollutions indicators from different are presented in tables 1 and 2

The effects of season, type of improvement of the artesian water sources, types of strategies of protection/maintenance of the water point, presence of pit latrines, and human buildings, presence of vagrant livestock moving around the sources on (i) bacteriological pollution levels and on (ii) physic-chemical parameters (turbidity, acidity, temperature) of the water points were tested using a chi-square tests. In this type of analysis, the effects was significant for $P<0.05$ at 95% interval confidence (IC).

Results

Mean (X ± SD) pH of different water sources was normal during rainy season (7.2 ± 0.21) and during dry season (7.01 ± 0.19). Similar results were observed for the temperature: during rainy season (23.19°C ± 0.64) and during dry season (25.04°C ± 0.48). Turbidity was high during both rainy (0.15 FTU ± 0.04) and dry (0.08 FTU ± 0.09) seasons (Table 3).

On average, colonies forming germ units per 100 ml of water were high during the rainy season than during dry season. During rainy season, the total coliforms were of 20.6 ± 25.29 against 3.10 ± 6.02 during dry season. There were 10.45 ± 14.67 fecal coliforms during rainy season against 1.64 ± 2.78 during the dry season. Around 3.96 ± 6.63 Escherichia coli were counted rainy season against 0.66 ± 1.57 during dry seasons. There were 0.37 ± 1.38 fecal streptococci during rainy season against 0.13 ± 0.82 dry season (Table 4).

All artesian water sources were significantly (χ^2=12.92, $P<0.001$, *df*=1; Table 5) polluted sincere the number counted of Vibrio cholera, was numerically high in all sources during rainy season than during the dry season (Table 6). These results suggests that the presence *Vibrio cholerae* in drinking water is the key pollutant factor of artesian water sources found within and around Bukavu town.

Paramters	Rainy season	Dry season
	Mean (X ± SD)	Mean (X ± SD)
pH	7.19 ± 0.22	
	7.022 ± 0.19	
Temperature (°C)	23.19 ± 0.64	
	25.04 ± 0.48	
Turbidity (FTU)	0.15 ± 0.04	
	0.081 ± 0.09	

Table 3: Average values for the physico-chemical parameters of water sources during rainy and dry seasons, Bukavu 2011, eastern DR Congo.

Parameters	Rainy season	Dry season
	Mean (X ± SD)	Mean (X ± SD)
Total coliforms (cfu /100ml)	20.06 ± 25.29	3.10 ± 6.02
Fecal coliforms (cfu/100 ml)	10.46 ± 14.67	1.64 ± 2.78
Escherichia coli (cfu/100ml)	3.96 ± 6.63	0.66 ± 1.57
Fecal Streptococci (cfu/100ml)	0.37 ± 138	0.13 ± 0.82

Table 4: Average number of colonies forming units (cfu) per 100 ml of water of sources across the different seasons, Bukavu 2011, eastern of Democratic Republic of Congo.

Variables	Factors	N=150	Average pollution	Low pollution	RP (χ^2-test)	Confidence interval limits	*P*
Seasons	Rainy season	77	24	51	34.32	4.75-713.19	<0.001
	Dry season	75	1	74			
Salmonella	Present	14	4	10	2.19	0.52-8.64	0.253
	Absent	136	21	115			
Vibrio cholerae	Present	125	13	112	12.92	4.37-39.28	<0.001
	Absent	25	15	10			

Table 5: Factors determining/influencing the degree of pollution of artesian water sources in urban and peri-urban areas of Bukavu town in 2011, eastern of Democratic Republic of Congo.

Variables	*Df*	*F-values*	Confidence interval limits	*P values*
Seasons	(1,147)	0.22	0.002-0.18	<0.001
Vibrio cholerae	(1,147)	18.60	5.19-66.70	<0.001

Table 6: ANOVA testing the effects of season and levels *Vibrio cholerae* on the levels of pollution of artesian water sources, Bukavu 2011, Eastern of Democratic Republic of Congo.

Summarized information on seasonal variability (rainy vs dry season) of different water sources is presented in figures 1c-10, respectively for temperature, turbidity, number of germs in water samples, number of total coliforms, number of fecal coliforms, number of *Escherical coli* colonies/100 ml of water, number of colonies of fecal *Streptocoques* par 100 ml water, number of *Vibrio cholera* infestations in water samples and percentage of *Salmonella* germs in water samples.

Discussion

The aim of this study was to determine the degree of pollution of artesian water sources consumed by urban inhabitants of Bukavu. Only bacteriological analyses were conducted. Other types of pollutants (metal, virus pollutants) were not analyzed due to financial constraints.

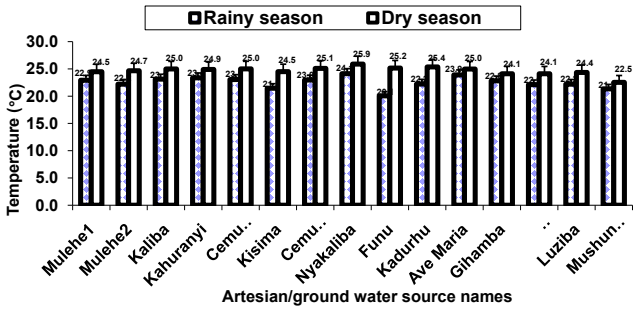

Figure 2: Average temperatures of water samples collected from the different artesian water sources during the rainy and dry seasons, Bukavu 2011, eastern DR Congo.

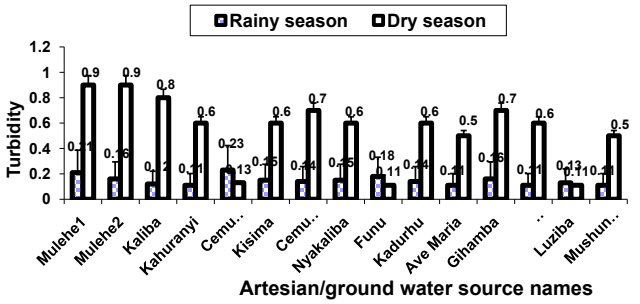

Figure 3: Average values of turbidity of water samples collected from the different artesian water sources during the rainy and dry seasons, Bukavu 2011, eastern DR Congo.

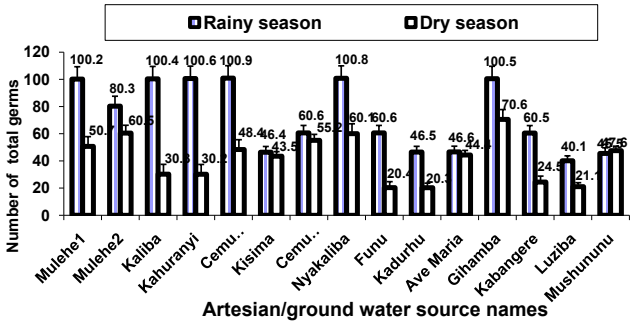

Figure 4: Percentage (%) of germs found from different samples of water collected from the different artesian water sources during the rainy and dry seasons, Bukavu 2011, eastern DR Congo.

However, bacteriological analysis can provide some indication on the degree of pollution of water. Since there has been no previous study of this kind in this town, the results of this study may constitute an entry point to establish monitoring programs of these water sources. The data may also be used by policy makers to protect these water sources and prevent or reduce the incidence of water born diseases among people consuming this water.

In this study, it was hypothesized that water sources are not polluted. Results rejected the hypothesis. In fact the results of this study indicated that turbidity levels were beyond WHO recommendations for drinking water qualities. Turbidity was high during rainy season than during dry season. WHO recommends that the turbidity is less or equal to 0.05 FTU. Values obtained either during rainy or during dry seasons were higher than those of WHO. Temperatures and pH values were under normal intervals for the 15 artesian water sources investigated, although there were tendencies for values to be high during rainy seasons than during dry seasons. Similar results were observed in Pakistan where Arshad and Aziz [4] found that turbidity was high during rainy season while the pH values were in the range of 6.5 and 8.0 (below the WHO norm) [5].

At Bukavu, due to un-planned (anarchic) settlement of human buildings (establishment of builds that do not respect urban regulations), lack of canalization of waste/rain water, there is a phenomenon of landslides and erosion. These two phenomena may have contributed to the currently observed high levels turbidity in artesian water sources. There is a need for policy makers to plan develop strategies that may reduce artesian water pollution (increase of turbidity due to landslides and soil water erosion and by waste ejection).

Results of this study indicated that total coliforms, fecal coliforms, number of *Eschericia coli/ Streptococcus* were the germs that were frequently isolated in water samples. These results are in accordance to findings off Boamah et al. [6] who worked in 2011 on the microbiological quality of artesian water sources in Ghana. Similar findings were reported by Chan [7] in Malasia where fecal coliformes, *Escherichia coli, Pseudomonas aeroginosa* and fecal Streptocoques were isolated in artesian waters used by urban people as source safe drinking water [7]. Studies conducted in various regions of the world yielded similar results [3,7,8-10].

In Zimbabwe, Nyati [11] studied physicochemical and microbiological quality of water in urban and peri-urban zones (Bindura

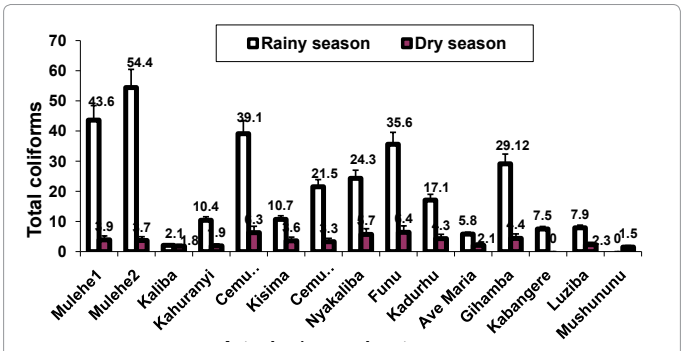

Figure 5: Average number of colonies forming total coliform units per 100 ml of water collected from the different artesian water sources during the rainy and dry seasons, Bukavu 2011, eastern DR Congo.

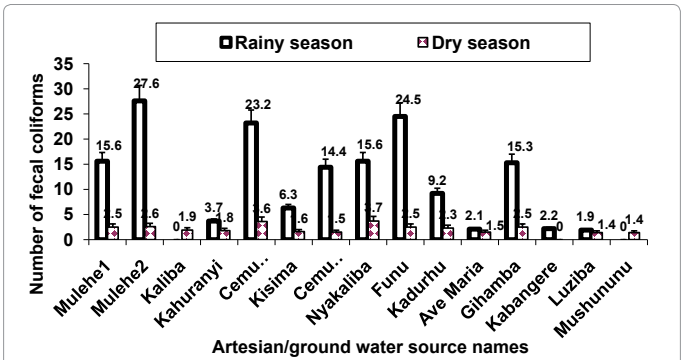

Figure 6: Mean number of colonies forming fecal coliforms/100ml of water collected from the different artesian water sources during the rainy and dry seasons, Bukavu 2011, eastern DR Congo.

region) during a period of 3 years. He found that fecal coliforms, total aerobial germs, and the physico-chemical parameters were not high (they were acceptable) although there was seasonal fluctuation with a high incidence of coliformes (1800 cfu/100 ml) during the rainy season.

Shakalisava et al. [12] conducted a study on microbial pollution of canal and river of Dublin urban zones I rivers while urban water canal had an acceptable level of microbial pollution. However, dangerous high quantities of fecal coliforms were sea water [12].

Salah et al. [13] worked on chemical and microbiological qualities of drinking water sources around Bande de Gaza (Palestine) and found that that water was mainly contaminated by total and fecal coliformes across the entire water distribution network including wells. However, in urban environment in Lithuania, Mindaugas Malakauskas et al. [14] found in 94.4% of samples of potable water examined that the quality of water (from official networks of water supply in urban region) was acceptable. However the authors found that well potable water was polluted and it was advised that such kind of water should not be sued by the communities although this water appeared to be clean. Well water in this city was polluted/contaminated by coliformes, anterococcus and *Eschericia coli* and the levels (8.96 ± 3.23 cfu/100 ml and 8.02 ± 2.56 cfu/100 ml, respective men for anterococcus and *Eschericia coli*) were high beyond WHO recomandations: 12.8-16.7% across all samples [14].

According to WHO, When bacterial levels of water sources with coliforms is in the range of 0 to 10 cfu coliforms/100 ml , the water is qualified to be reasonable quality. From 10 to 100 cfu coliforms/100 ml, the water source is qualified to be polluted. Under such situations, WHO recommends that the water sources are protected and that any water from such a sources should be treated first before consumption. From above 1000 cfu, the water source is qualified as excessively polluted and should avoid by humans as source of drinking water.

Results from this study indicated that water consumed by the population of Bukavu, is polluted, particularly during rainy than during dry season. On average, there were 20.06 ± 2529 total coliformes during the rainy season against 3.10 ± 6.02 during the dry season. The contamination of these groundwater sources may due to infiltration of surface that is already polluted. Transport of pathogenic/indicator micro-organisms such as coliforms may be largely influenced by texture, porosity and structure of the soil. The transport may also be influenced by local geology (size of pores and of mineralogical particles and by the types of rocks; example basaltic rock of Bukavu). The type of soil influences frequently the survival pathogenic batteries [15]. Soil play the role of natural filter that deep limit indicator micro-organisms such as coliforms [16], mainly under soils of fine texture [7] and soil

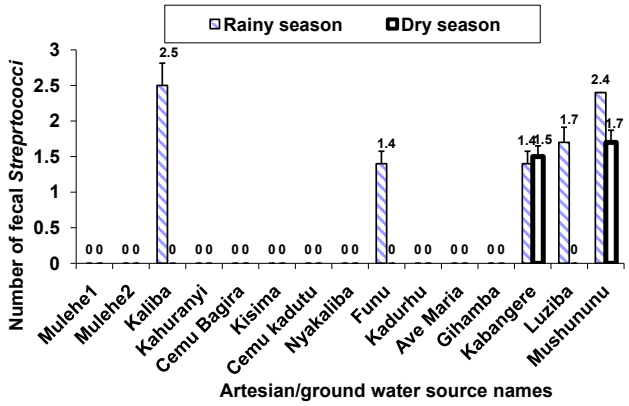

Figure 7: Average number of colonies forming total fecal units of *Escherichia coli*/100 ml of water collected from the different artesian water sources during the rainy and dry seasons, Bukavu 2011, eastern DR Congo.

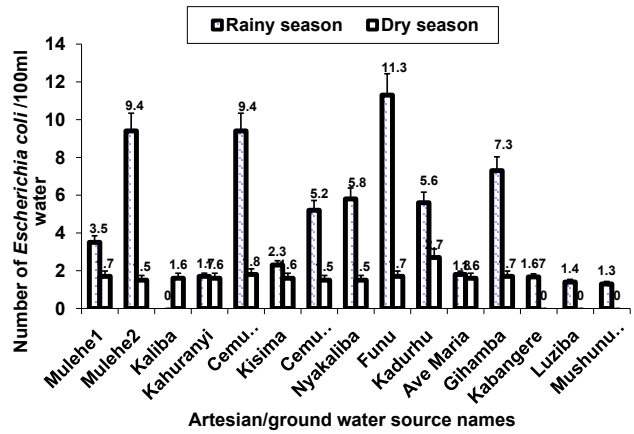

Figure 8: Average number of colonies forming total fecal number of units of *Streptococci* per 100 ml of water collected from the different artesian water sources during the rainy and dry seasons, Bukavu 2011, eastern DR Congo.

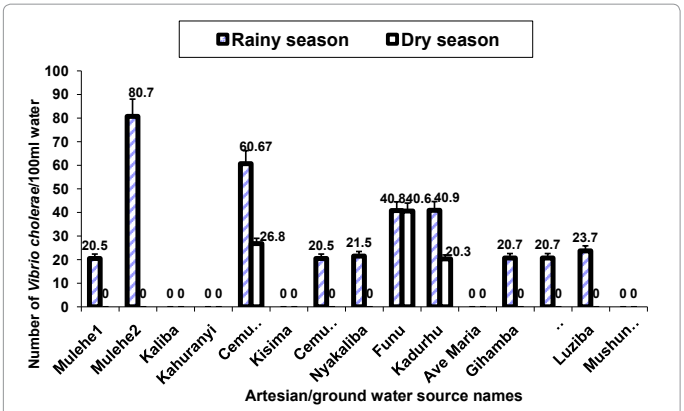

Figure 9: Proportion (%) of *Vibrio cholerae* in different samples of water collected from the different artesian water sources during the rainy and dry seasons, Bukavu 2011, eastern DR Congo.

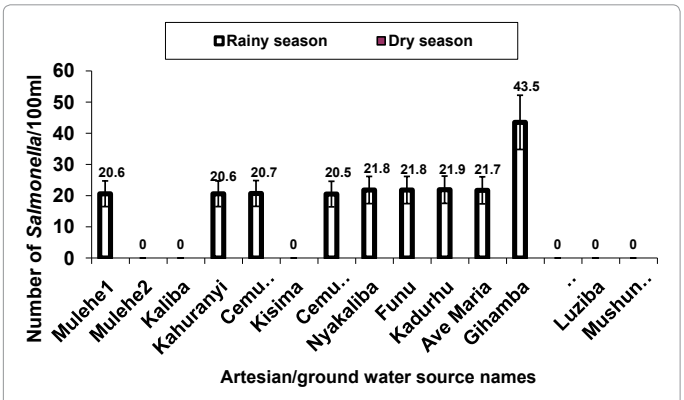

Figure 10: Proportion (%) of *Salmonella* found in different samples of water collected from the different artesian water sources during the rainy and dry seasons, Bukavu 2011, eastern DR Congo.

with degraded soil structures may be more vulnerable to contamination [17]. This is the case of most Bukavu soil types.

Factors that may explain high turbidity during rainy season may be the same factors explaining high turbidity levels during dry seasons.

Concerning the degree of pollution of each artesian water source, 100% germs were isolated from Mulehe 1, Kaliba, Kahuranyi, Cemu Bagira, Funu et Gihamba sources. At Mulehe 2, 80% of sanples collected contained germs. Results from figure 5 indicated that most water sources studied were polluted during the rainy season than during the dry season, except Kahuranyi, Kisima, Ave Maria, Kabangere and Luziba sources.

Pollution with fecal coliformes was high from Mulehe 1 and Mulehe 2, Cemu Bagira, Funu, Gihamba, Nyakaliba and Cemu Kadutu water sources. The isolation of fecal coliformes in water ground water sources is an indicator of pollution of human origin since the human digestive tube is full of coliformes. This situation may explained by the presence of fecal colifomes into water sources surveyed. This situation may not also be due to the fact that most artesian water sources are nor protected. Most artesian water sources are surrounded by pit latrines, waste water canals, human settlement buildings and by stagnant water points. The rainy season may facilitate the penetration of stagnant water. Once such contaminated water penetrates, it can easily reach the aquifer layer, hence contaminating the artesian water point.

Fecal coliforems and streptococcus were isolated in this study. Their presence in water sources indicated a contamination of animal origin. Among sources where fecal *streptococcus* was isolated include Kaliba, Funu, Kabangere, Luziba and Mushununu. Children and animal keepers like grazing their animals around artesian sources. This situation may explain why these artesian water sources had high levels of streptococcus. Several races of *Vibrio cholerae* and *Salmonella* were identified in this study.

Water born diseases are among the most important diseases in most developing countries. More than half of the world population experience theses water born diseases. The incidence of water born disease is high in developing countries because of consumption of polluted water [10]. Water born diseases are the main cause of child mortality in many developing countries. These sad realities led United Nations to declare the 1981-1990 decanal as period to supplies safe water to everybody and to water hygiene.

In DRC, one inhabitant out of five has access to safe water. Reason for such situation in DR Congo are diverse: households do not have salary and sufficient financial means, degradation of water supplies infrastructures, bad management of safe water networks, uncontrolled demographic growth of the population in urban and peri-urban zones across different provinces of the country.

The national water corporation (REGIDESO) a public institution has the mandate to supply and distribute safe drinking water to population at the national level. REGIDESO does not have the capacity to respond to the need on a growing urban population. There are many people to serve at the time that the agency does not have sufficient human and financial resources to cover the country and respond adequately to needs of everyone. Also, in rural areas, the national hydrological service (SNHR) has no means to supply safe water to rural communities.

In urban and peri-urban areas and in rural areas, water sources and safe water points are located very far from users. There are almost no individual safe water points in rural areas of DR Congo Thus; the population has to walk several Kilometers to access to safe water points. In some areas, women and children have to foot daily several kilometers to fetch needed household water. The cost of supplying safe water quality to people is high in peri-urban zones than in urban zones. This situation is due to the fact that there are many intermediate in the chain of distribution. This situation makes safe water to be a rare resource in these peri-urban zones with some times higher and human densities. High densities in these peri-urban zones increased because of the recent war and unrest situations that have been prevailing in eastern DR Congo: rural areas are currently less secure than urban areas; consequently people have are currently migrating from rural zones to urban zones where security is fair. This is the opposite of previous situation: in formers times, villages were more secure that urban environment. Most wars used to start from urban areas and people could get their refugia in rural zones.

The fact that women and children (from both urban and rural localities) have to move several kilometers in search of safe drinking water, has a negative impact on the health of the populations: increase in the incidence and prevalence of water born diseases, reduction in children (girls mainly) attendance to school because they are the manpower to fetch water morning and evening, yet school require children to be at school morning hours [8].

The majority of the population from main cities and towns of DRC (Kinshasa, Kisangani, Lubumbashi, Bukavu, Matadi) does not have sufficient access to safe water. Most households in these cities suffer to access safe water. Water stopped flowing several months/years ago in many areas of the Bukavu town and REGIDESO is doing nothing to solve the problem. Populations living in such areas have to send children to fetch water daily. In Bukavu town for example, during dry seasons (May-September), young girls have to move several streets to negotiate water in enclosures where REGIDESO may be still supplying water since a third of the town does not receive sufficient water. Water flow from tapes for only 2 to four hours, early morning. This situation exposes women and young girls to various dangers while searching for safe water in other enclosures during early morning hours (3h to 6h). People of Bukavu town have to move several distances searching points where to access potable water. People ends by evening fetching polluted (water flowing from various streets of the cities) water because they are desperate of accessing points with safe water. Some other children fear to be blamed by their parents: They are obliged to fetch any water (even polluter) they may find on their ways. Some other children end by being insulted and abused sexually (even raped) wherever they are looking for water in different enclosures. There are no settings (basic infrastructures) for water sanitations across most cities in DR Congo. This situation exposes children to various water born diseases (diarrheas, etc).

This situation is difficult to accept for a country has in endowed by a lot water resources: various rivers, it rains a lot. In addition there have been no initiatives to push for dissemination of water harvesting technologies, neither to water sanitation technologies.

It is hard to believe but the truth is that only a small portion of the population has access to safe water points (sources) in and around Bukavu town. These rare and few safe water sources are in most cases located very far from homestead [9].

This problem of access to safe water points in Bukavu Town is not new since there are many structures of REGIDESO that do not receive or make flowing water in many areas particular in Ibanda, Bagira and Kadutu administrative urban zones. Thus, populations from these zones are forced to look from water from private artesian water sources

points and wells. Some nongovernmental organizations (NGOs) and humanitarian agencies have also managed to create/improve some safe water points. During the process of artesian well construction by NGOs, water treatment technologies such as chlorination and filtration are not used in full to treat artesian wells. Wells constructed by the international Rescue Committee are treated but those constructed by others NGOs such as Care International are not treated.

In most cases, these water points are left to individuals or to communities' organizations for management, security, maintenance and improvements.

Pit latrines are found constructed/established at less than five meters from these artesian water source points. If there are not located at 5 m, pit latrines are found in the neighborhood or anywhere within the basin of the e artesian water. Pit latrines located in the watershed of artesian water sources are many in rural and in peri-urban areas, but often they are not seen by people. The indirect impact of these pit latrines is not easily perceived by local people.

In the neighborhood of artesian sources, there not only pit latrines, but also some of them are constructed at the base of landscapes subjected to regular landslides and to soil/water erosion. Sometimes, poorly planned buildings are erected in the neighborhood around these water sources points. Vagrants animals (pork, goats, sheep, etc) are commonly found feeding on communal grazing places located near these artesian water points. Pit latrines, vagrant livestock, homestead erection, soil erosion, landslides constitutes a danger for inhabitants of Bukavu town who are forced to consume artesian water since REGIDESO can supply safe water any more to them.

Conclusion and Recommendations

Seasonal variability in water quality is a common phenomenon. Water quality can degrade quickly particularly during rainy season.

Results of this study indicate that the turbidity was high although pH and temperature were normal across the 15 water sources studied. More than 80% of artesian water source studies has high levels of germs. These included Mulehe 1, Kaliba, Kahuranyi, Cemu Bagira, Funu and Gihamba.

Results indicated that most of water sources were polluted (except Kahuranyi, Kisima, Ave Maria, Kabangere and Luziba). Mulehe 1 and 2, Cemu Bagira, Funu, Gihamba, Nyakaliba and Cemu Kadutu were mainly polluted by fecal coliforms and fecal streptococcus (mainly from Kaliba, Funu, Kabangere, Luziba and Mushununu water sources). The results indicate that some *Vibrio cholerae* and *Salmonella* races were detected in some artesian water sources. *Vibrio cholerae* was found to be the principal pollutant biological agent.

Based on above described findings, it was recommended to: decision/policy makers and to public health actors and to the private sector operating in South-Kivu province to protect artesian water sources that are used a reliable source of safe drinking water by the population of Bukavu. It is also recommended to public health agents to make available water cleaning drugs such as (aquatas, PUR) to populations of Bukavu. It is recommended to the national water corporation company (REGIDESO) to supply reliable water quality and safe to all populations in urban and peri-urban zones. It is also recommended to the population of Bukavu to boil water before drinking it. It is also recommended to the population to adopt sanitation and hygienic measures in favor of all drinking water points: avoid anarchic construction of buildings) construct at beyond 100 m from the artesian water source). The population should be educated about bad manner of defecating everywhere in the surrounding of artesian water points. It is also recommended to leaders of communities to make fences and enclosures to protect these water sources. Parents are commended to teach their children not to graze animals around water sources in order to reduce the incidence of fecal matter into water sources. Finally, the population is recommended to adopt water harvesting technologies to reduce on the burden of fetching water every day.

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